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Wavelet Analysis of Business Cycle Synchronization in Europe

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Abstract

Business cycle synchronization is an essential criterion for creating and maintaining an optimal currency area. In this paper, it is investigated whether this required criterion holds for the Euro area at different time horizons (short run, medium run and long run), and if the financial crisis of 2007-2008 influenced the degree of synchronization in Europe. Wavelet analysis on the real GDP growth and unemployment rate is used to investigate business cycle synchronization between the EU-15 countries. The data is decomposed into time and frequency using both the continuous wavelet transform and the discrete wavelet transform, and varimax rotated principal component analysis is used to investigate business cycle synchronization at the different time horizons. It is found that there is a high degree of business cycle synchronization in Europe for the different time horizons considered, however the core is more synchronized while some peripheral countries tend to diverge. Furthermore, our results also suggest that there has been an increase in business cycle synchronization after the financial crisis for the core but not for some peripheral countries.

Keywords: wavelet analysis, business cycle synchronization, varimax rotation, principal component analysis, Euro area, optimal currency area

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1 Introduction

> *"Europe's common market exemplifies a situation that is unfavorable to a common currency. It is composed of separate nations, whose residents speak different languages, have different customs, and have far greater loyalty and attachment to their own country than to the common market or the idea of "Europe"."*
> Milton Friedman (1997)

On January 1st, 1999, the European Union introduced the euro as its new currency. From then on, a common monetary policy is being conducted under the authority of the European Central Bank (ECB). The introduction of the euro was not only meant solely as a currency, but also to encompass the political ideology on which the European Union was founded on. This political ideology is to create unity between European countries, prevent conflicts and to foster economic cooperation. Now, almost two decades after the European Economic and Monetary Union (EMU) was established, there is a divergence of economic trends in the Euro area. For a currency area to be optimal, there should be synchronization of business cycles between the member countries. If there were to be differing cyclical conditions in the Eurozone for example, it may create conflicts regarding the uniform monetary policy conducted, as countries in the downward phase of the business cycle will want to conduct expansionary monetary policy whereas countries in the upward phase would prefer a more restrictive policy (de Haan et al., 2008).

The discussion to whether the business cycles in the Euro area synchronize has been a long-standing empirical question, hence it has received a lot of attention by researchers in the literature and the debate remains open. There are contrasting results, for example, some find that there exist a synchronization of European business cycles (see e.g. Jiménez-Rodríguez et al, 2013; Aguiar-Conraria et al, 2013), while some find the opposite to be true (see e.g. Camacho et al., 2006; Granville & Hussain, 2015; Grigoraș & Stanciu, 2016), others find that there is synchronization between core members and divergence between core and peripheral countries (see e.g. Aguiar-Conraria & Soares, 2011; Aslanidis, 2010; Belke et al., 2017; Papageorgiou et al., 2010), lastly there is evidence of high business cycle synchronization in recessions but decoupling in high growth regimes (see e.g. Gomez et al. 2017; Di Giorgio, 2016; Jiménez-Rodríguez et al., 2013; Altavilla, 2004). For the interested reader, Appendix A presents a summary of previous research that have investigated business cycle synchronization in Europe. It summarizes data used, how the business cycle and its synchronization was measured, and their respective research conclusion.

In this paper, we intend to contribute with additional evidence to the notion of business cycle synchronization in Europe, by addressing the following research questions: (i) if there is business cycles synchronization in the short run, medium run and/or long run; and (ii) if the financial crisis of 2007-2008 influenced the degree of business cycle synchronization. We use quarterly data on real GDP growth and unemployment rate for the EU-15 countries[1] from 1995Q1 to 2017Q4 to analyse this matter.

Time-series data have two domains; the frequency and time domain. In this paper, we intend to study business cycle synchronization both in the time and frequency domain simultaneously, using wavelet analysis. This approach will let us decompose the real GDP growth and unemployment rate into different time horizons (such as the short run, medium run and long run) and let them vary in importance and cyclical characteristics over time. Firstly, the continuous wavelet transform will be used as preliminary evidence of business cycle synchronization over time and frequency. Thereafter, the business cycles of the EU-15 countries will be decomposed into the different time horizons using the discrete wavelet transform, and after which, varimax rotated principal component analysis on each respective time horizon will be used to investigate the sentiment of business cycle synchronization. The main contribution of this present study is that it is unique in the sense that never have wavelet analysis in conjunction with varimax rotated principal components been employed to study business cycle synchronization at different time horizons between the EU-15 countries.

Results show that there is a high degree of business cycle synchronization between the EU-15 countries. This hold for both the real GDP growth and unemployment rate cycles considering all time horizons being studied. In general, though, the countries are more synchronized for the real GDP growth cycles compared to the unemployment rate cycles. The results also reveal a distinction between a synchronized European core and a desynchronized peripheral, where Greece is especially desynchronized with the rest of the countries. Furthermore, there seem to be an increase in business cycle synchronization leading up to, and during, the financial crisis of 2007-2008, especially between core countries.

The remainder of this paper is structured as follows. Section 2 explains the theory behind business cycle synchronization. Section 3 describes the research method. Section 4 presents data and variables. Section 5 discusses the empirical results. Section 6 concludes the paper.

[1] The EU-15 countries are: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and United Kingdom.

2 Business Cycle Synchronization

2.1 Optimum Currency Area

For countries forming a monetary union there is a desire for economic convergence, so that monetary policy will have an even effect across the countries in which the policy is conducted. In fact, according to the theory of an optimum currency area developed by Mundell (1961), McKinnon (1963), and Kenen (1969) later extended by e.g. Alesina and Barro (2002), there is a set of criteria related to this economic convergence. The most commonly cited criteria are: 1) the extent of trade, 2) the degree of labour mobility, 3) the system of risk-sharing through fiscal transfers, and 4) business cycle synchronization (see e.g. Frankel & Rose, 1998).

Perhaps the most important criterion out of these, with regards to a country's suitability to enter a currency union, is business cycle synchronization (Gächter & Riedl, 2014). The rationale behind this is intuitive: if there is a high correlation between the business cycles of countries in a monetary union, then the area-wide mutually agreed upon monetary policy will most often respond in a way that is optimal for the macroeconomic stability in every member country (Kolasa, 2013; Furceri & Karras, 2008), and it will also increase the probability of having symmetric economic shocks (Farhi & Werning, 2017; Altavilla, 2004; Di Giorgio, 2016), thus lowering the sacrifice of monetary independence. If there were to be divergent economic conditions within the Euro area, for example about preferences of inflation and output stabilization, then this could lead to conflicts between the ECB and the members of EMU about the appropriate sought-after policies to be implemented, making the decision-making process difficult (Aksoy et al., 2002). Therefore, the monetary policy conducted by the ECB should be a very close and suitable substitute for the countries that lose the independence of a domestic monetary policy (Di Giorgio, 2016).

Business cycle synchronization being an important criterion when entering a monetary union means that we can evaluate potential future candidates of the EMU. The focus of this paper however comes from the theoretical viewpoint concerning the effects of economic and monetary integration in Europe, and through which channels business cycle synchronization is driven. As the cost of giving up the independence of monetary policy is especially high if business cycles between members of a currency area are only weakly correlated (Belke et al., 2017), essentially, we are interested in studying whether there recently has been an increase or decrease in the co-movement of macroeconomic variables in Europe. Conceptually, there is no consensus in the literature regarding whether there is synchronization or decoupling of business cycles in Europe. However, part of the reason as to why there is no consensual result about business cycle synchronization in Europe is because of different measurement of business cycles or different variables, methodologies used to investigate the matter and diverging ways of assessing synchronization (Aguiar-Conraria et al., 2013; de Haan et al., 2008). According to Aguiar-Conraria et al. (2013), there are two reasons as to why studying business cycle synchronization is important. Firstly, at a normative level, synchronization of business cycle is a necessary condition for an optimal currency area. Secondly, at a positive level, it is a case study of optimum currency areas which test the hypothesis of endogeneity.

2.2 Factors Affecting Business Cycle Synchronization

Frankel and Rose (1998) argued that economic and monetary integration will stimulate trade relations, thus leading to increased business cycle synchronization. Therefore, the co-movement of economic variables would start to converge between the members after joining the EMU. Since the creation of the currency area, both fiscal and monetary policy have become more similar and bilateral and intra-industry trade has increased in Europe. Some argue that this has led to a significant increase in the synchronization of business cycles between the EMU member states (Böwer & Guillemineau, 2006; Inklaar et al., 2008; Gächter & Riedl, 2014). Given the increased intra-industrial trade and coordination of economic and monetary policy making, it can also be argued that the probability of having asymmetric shocks in the EMU is reduced (Gouveia & Correia, 2008). According to Lee (2013) however, the result that business cycle synchronization increases because of greater economic integration through increased trade flows is not in line with the predictions of comparative advantage and specialization that traditional international economic theory claims. This view was raised by Krugman (1993) who hypothesised that the introduction of a common currency in Europe would lead to greater industry specialization among EMU countries, which therefore would mean that any industry-specific shock would become a country-specific shock. A common monetary policy in the Euro area when dealing with these types of shocks would, in such a case, be problematic at solving country specific needs, and these asymmetric shocks would naturally lead to decoupling between the countries' business cycles. (Gouveia & Correia, 2008; Montoya & de Haan, 2008). By studying the communality of an exchange rate arrangement between countries, Barro and Tenreyro (2007) found that currency areas such as the EMU increases bilateral trade but reduces the co-movement of business cycles, perhaps because of greater industry specialization.

Financial integration is another channel through which business cycle synchronization is affected, but the effect is ambiguous. Business cycle synchronization could be increased by the generation of large demand side effects, and contagion effects transmitted through financial integration could induce spill overs of macroeconomic fluctuations between countries (de Haan et al., 2008). However, financial linkages may increase the specialization of production by reallocating capital according to countries' comparative advantages, therefore increasing the asymmetry of industry- and country-specific shocks, leading to a decoupling of business cycles between countries (de Haan et al., 2008). Imbs (2004) studied the determinants of business cycle synchronization and found that economic regions with strong financial integration tend to be more synchronized, even though they are also more specialized.

2.3 Clustering Business Cycle Synchronization

Regional inequalities in the Euro area is evident from the pattern of "core-periphery". That is, the relatively most advanced and developed economies in Europe is found to the north of northern Italy, and away from this, one can find the peripheral countries where development is relatively low (Petrakos et al., 2005). Because of this, many business cycle synchronization studies of the EMU investigate and compares the intercountry heterogeneity between European countries. Since the ECB can only conduct a "one-size-fits-all" type of monetary policy, the core-periphery distinction essentially analyses the sustainable governance of the Euro area (Belke et al., 2017). The paradigm has shown that the set of core countries, such as Austria, Belgium, France, Germany and the Netherlands are often highly synchronized among themselves, while the peripheral countries of Greece and Portugal do not synchronize with other countries (Konstantakopoulou & Tsionas, 2011; Gouveia & Correira, 2008). Studies have also shown that disparities between core and peripheral European countries increased after the introduction of the euro (Lehwald, 2013).

Another evidence of this core-peripheral pattern was made clear after the latest global financial crisis, which brought deep economic imbalances within the EMU (Lane, 2012, Fernandez, 2014). The core countries, such as Germany, experienced only a temporary loss in output which was quickly abrogated, whereas peripheral countries like Greece and Portugal is still to this day haunted by weak economic activity and high unemployment. Since the crisis, although there has not been any sign of overall GDP growth differences among the Euro area countries, there has been a record high in cyclical divergence between the countries. The reason for this is the increasing divergence of heterogeneity between "vulnerable" countries and "privileged" countries (Fernandez, 2014). Various researchers have found that the financial crisis triggered a process of business cycle desynchronization in Europe, which was most prominent for the peripheral countries such as Greece, Ireland and Portugal, but that core countries are wellaligned with a common cycle (Degiannakis et al., 2014; Gächter et al., 2012; Grigoraș & Stanciu, 2016; Ferroni & Klaus, 2015). Others argue however that the time leading up to and during a global financial crisis will lead to an increase in business cycle synchronization. The reason for this is that such a global crisis will strike every country simultaneously, thus making each country slip into a recession at the same time. Then, some period after the crisis, will the desynchronization of business cycles occur as the recovery begins at different times for different countries (Gomez et al, 2013).

2.4 Business Cycle Synchronization at Different Time Horizons

The business cycle can be measured at various time horizons (or durations), a topic which has been the subject of many past studies (Kufenko & Geiger, 2017). Still, the average business cycle is usually thought of as being between 4 and 8 years (Andersson & Karpestam, 2014), but it is possible to theoretically identify different short run, medium run, and long run business cycles bearing the name of the person discovering them[2] (see e.g. Schumpeter, 1954; Korotayev & Tsirel, 2010). Many business cycle synchronization studies consider only one time horizon, which may leave out crucial insights. Instead, it is interesting to divide the economy into different time horizons, for example, to evaluate whether business cycle synchronization occurs in the short run, medium run and long run. Hughes Hallet and Richter (2006a, 2006b) decomposes the business cycle into different time horizons to study synchronization in Europe at different frequencies. They found that Germany have been more synchronized with the Euro area for the more long run business cycles, while United Kingdom correlates more with the Euro area for the short run cycles. Furthermore, Hughes Hallet and Richter (2008) conclude that the larger countries in the Euro area tend to converge more on the short run business cycles, but that there is less synchronization between the long run cycles.

2.5 Research Expectations

In summary, for the Eurozone to be viewed as optimal, the business cycles between the member countries should synchronize. The factors influencing the degree of synchronization has an ambiguous effect, therefore, there is a need to empirically investigate whether there actually is synchronization. We may expect there to be clustering of business cycle synchronization, where the core countries of Europe synchronize, and the peripheral countries diverge, and that the latest financial crisis may have had an impact on this division. Furthermore, there may exist

[2] Such as the Kitchin cycles (Kitchin, 1923) which comes about every 3 to 5 years because of time lags in businesses change of inventory, the Juglar cycles (Juglar, 1862) which occurs every 7 to 11 years from investment in fixed capital, the Kuznets swings (Kuznets, 1930) which is identified as cycles every 15 to 25 years arising from investment in infrastructure, and lastly the Kondratieff wave (see e.g. Kondratieff & Stolper, 1935) which is the longest business cycles that takes place every 45 to 60 years due to technological innovation.

business cycle synchronization at different time horizons. Approaching the sentiment of business cycle synchronization in Europe at different time horizons poses interesting research hypotheses. Following for example Artis et al. (2004) and Lee (2013) in this paper, we focus on assessing the effect of policy implications on the co-movement of business cycle dynamics at different cycle frequencies, by evaluating whether synchronization occurs in the short run, medium run and/or long run, and if idiosyncratic country synchronization differs at different frequencies.

3 Research Method

3.1 How to Measure the Business Cycle

A classical way of viewing the business cycle was defined by Burns and Mitchell (1946), who measured it in terms of absolute expansions and contractions of economic activity. This is however not how most contemporary macroeconomic studies measure the business cycle. Instead, they look at the deviation cycle, i.e. business cycles are measured as the deviation of economic activity from its trend (Lucas, 1977; de Haan et al., 2008; Baxter & King, 1999). The reason for this is twofold. Firstly, econometrical studies need stationary data to be able to correctly describe the cycle. Secondly, since most economies grow over time, there are far less frequent classical recessions compared to growth recessions (de Haan et al., 2008).

To measure the deviation cycle, there is thus a practical reason to filter the time-series of economic activity into its cyclical and trend components respectively. Perhaps the simplest way of filtering the data into a cyclical component is making it stationary by calculating first differences[3], this does remove the trend but might shift the troughs and peaks and increase fluctuations (de Haan et al., 2008). Other, more nonparametric methods have been proposed, such as the Hodrick-Prescott (HP) filter[4] (1981, 1997), the Baxter-King (BK) (1999) and Christiano-Fitzgerald (CF) (2003) band-pass filters, and the Boschan and Ebanks (1978) phase average trend (PAT). Out of these, the most commonly employed is the HP filter, which uses a smoothing parameter to filter the time series into a cyclical component by minimizing the deviations from its trend[5]. The BK and CF techniques are bandpass filters, which means that they de-trend the time series inside a range of frequency. Lastly, the PAT essentially calculates business cycle turning points, and then connects a trend via the mean values of each cycle

[3] Taking first differences of a series that is expressed in natural logarithm yields growth rates.
[4] Although, it was first proposed by Whittaker (1923).
[5] However, there are several drawbacks associated with the HP filter (see Hamilton (2017).

turning point. Even though these nonparametric filters have irrefutable differences, studies have shown that they are likely to yield similar conclusions (see e.g. Artis & Zhang, 1997, 1999; Calderon et al., 2003; Massman & Mitchell, 2004; Kožić & Sever, 2014).

These nonparametric filtering methods can however only separate between a short-term cyclical component and a long-term trend component, which might be unsuitable for studies where the economy is assumed to contain more time horizons. Because of this time domain limitation, an alternative to this is to instead study the frequency domain (Andersson, 2016). A common choice for this is to use the Fourier transform which is orthogonal and breaks down the time-series into sums of sines and cosines at various wavelengths to represent a given function (Andersson, 2008; Crowley, 2007; Aguiar-Conraria & Soares, 2011). The Fourier transform has a weakness however, because it assumes that the time series is stationary and repeats itself deterministically. For economic time series, this assumption may be unreasonable (Andersson, 2016) [6]. Since the economy changes regularly, business cycles are never stable, and therefore, the Fourier transform is unsuitable. A remedy to this problem is instead to use the wavelet transform, which combines both the time and frequency domain.

3.2 Wavelet Transform

Using wavelet analysis has several advantages at decomposing time series into trends and cycles compared to the previously mentioned methods because it combines time and frequency resolutions. When we plot a time series, we do it as a function with time as independent variable on the x-axis and its periodical amplitude as dependent variable on the y-axis. In many cases, especially considering the business cycle, much information of its time series is hidden in the frequency content. The frequency spectrum of a time series reveals the different rates of frequencies it has, where a high frequency means it oscillates rapidly and a low frequency means it changes smoothly. Wavelet transform, contrary to the nonparametric filtering techniques and the Fourier transform, provides us with a useful tool in extracting both the time series time and frequency domain (Andersson, 2016), an arguably valuable trait when investigating business cycle synchronization (Yogo, 2008). By combining the time and frequency domain, the wavelet transform can handle time series that changes over time, such as the business cycle, hence this is the reason to why it is employed in this paper.

[6] Fourier transformation allows us to study cycles in time-series in the frequency domain (Aguiar-Conraria & Soares, 2010), and spectral techniques can be used to identify some stylized facts about the business cycle (Nerlove, 1964; Aguiar-Conraria & Soares, 2008), however, the disadvantage is that we lose the time information of the time-series (Aguiar-Conraria & Soares, 2010) since the Fourier transform has finite power and infinite energy, thus it never dies out nor change over time (Crowley, 2007).

The general understanding of wavelet analysis (or wavelet transforms) is simple. Based on averages and differences between adjacent averages, wavelets are small wave-like oscillations with finite energy that begin at a particular point in time and ends at a particular point in time (Andersson, 2008). Wavelet analysis in science is the practice of decomposing wavelets in signals or time-series into a trend and a cyclical component by computing the inner products of a signal with a family of wavelets. The use of wavelet analysis has been common in the disciplines of e.g. signal processing, engineering, medical sciences, physics and astronomy. However, it is not up until recently that this has been overlooked in the field of economics. This is certainly peculiar considering the potential that wavelet analysis has to the economic science (Crowley, 2007).

Wavelet analysis is categorized into two types: i) the continuous wavelet transform (CWT) and ii) the discrete wavelet transform (DWT). Both have been used before in business cycle synchronization studies, however, not in conjunction with each other. In this paper, we employ both the CWT and the DWT to study business cycle synchronization in Europe. The CWT will be used as a preliminary evidence to see whether similar oscillations in cycles are occurring at the same time and frequency using wavelet coherence. However, it should be noted that the CWT may not always have high power in indicating synchronization, at least for the more persistent business cycles. Therefore, the DWT will also be used to study business cycle synchronization as it is more robust in decomposing the business cycle at different frequencies to study synchronization.

3.2.1 The Continuous Wavelet Transform

Using the CWT to study business cycle synchronization has been a common method in the past (see e.g. Berdiev & Chang, 2015; Aguiar-Conraria et al. 2013; Aloui et al. 2016; Rua, 2010). The purpose of using the CWT in this paper is to analyse how two time-series covaries at each time and frequency. According to Rua (2010, p. 687), the advantage of using a wavelet-based measure for analysing comovement is that it “allows one to quantify the comovement in the time–frequency space and assess over which periods of time and frequencies is the comovement higher”.

The CWT estimates the wavelet cohesion of the spectral characteristics of two time series. By comparing the wavelet spectra of the two time series, it will reveal areas where the time series have high common power. Wavelet coherence between two time-series is a localized correlation coefficient in the time-frequency space, which closely resembles that of a traditional correlation coefficient. Thus, applying the CWT to two time series of business cycles means that we can compare if both business cycles fluctuate at the same time or not, and if the peaks and troughs of the cycles occur simultaneously (Aguiar-Conraria & Soares, 2011). Wavelet cohesion is useful when investigating business cycle synchronization, both for the short- and long term dynamic features of many time series, and to identify dynamic clusters. It can therefore prove stylized facts about the business cycle, in terms of macroeconomic variables comovement, at the specific time horizons of interest (Croux et al., 2001). In this paper, the CWT will be calculated using the Morlet wavelet[7].

3.2.2 The Discrete Wavelet Transform

Using a DWT, the variables can be decomposed into separate frequency bands, where each frequency band represents the business cycle measured at a specific length. In this paper, the variables will be decomposed into five cycles (high frequency) and one trend (low frequency). The decomposition into these frequency bands represent cyclical variations at different time horizons, and is given by the following equation

$$y_{it} = D_{1\,it} + D_{2\,it} + D_{3\,it} + D_{4\,it} + D_{5\,it} + S_{5\,it} \tag{1}$$

where y_{it} is the variable(s) for country i at time t, D_1 to D_5 is the business cycles of varying time horizons (short run, medium run and long run) and S_5 it is the trend component for country i at time t (Ramsey & Lampart, 1998; Crowley, 2007; Ramsey, 2002). Since data on a quarterly frequency is used in this paper, these details should be interpreted as the following business cycle lengths[8]

Table 1. Frequency Interpretation

Detail	Length
D_1	2-4 quarters
D_2	4-8 quarters (1-2 years)
D_3	8-16 quarters (2-4 years)
D_4	16-32 quarters (4-8 years)
D_5	32-64 quarters (8-16 years)
S_5	Trend (>16 years)

This is an important consequence of using the DWT to decompose the data as it means that we can decompose the data into different time horizons. Thus, it enables us to capture the short run business cycles (1-2 years and 2-4 years), medium run business cycles (4-8 years) and long run

[7] The choice of using the Morlet wavelet is because of its advantages when studying wavelet coherence, since i) it yields optimal joint time-frequency concentration, ii) it is the best wavelet at compromising between time and frequency concentration compared to other wavelet functions, and iii) it results in comparatively richer frequency resolutions than other wavelet functions (Bilgili, 2015).

[8] See Crowley and Mayes (2008, p. 70) for a discussion.

business cycles (8-16 years and >16 years), which are almost identical to the ones revealed by the literature. It should be noted though that the relative importance of analysing the 2-4 quarter long business cycles is less, since any business cycle shorter than one year is mostly due to seasonal variations and not actual business cycles' (Burns & Mitchell, 1946). The wavelet filter that will be used in this paper to decompose the data is the Daubechies wavelet of length four, or in short, the db(4) wavelet (see Daubechies, 1988; 1992)[9] [10].

3.3 Principal Component Analysis and Varimax rotation

After having decomposed the business cycle into different cyclical and trend components using the DWT, business cycle synchronization between the EU-15 countries will be investigated using principal component analysis (PCA) on each respective time horizon. Previous researchers have in the past used PCA to study the sentiment of business cycle synchronization, or whether there exists a common business cycle[11]. PCA is a multivariate statistical technique based on decomposing the covariance or correlation matrix of a data set to identify and highlight patterns in the data, in terms of similarities and differences. The idea of PCA is to reduce the dimensionality of the dataset containing many correlated variables, by using an orthogonal transformation to transform them into a set of linearly uncorrelated variables called principal components (PCs). Specifically, let Y_{it} be the analysed variable, where $i = 1, \ldots, 15$ denotes each of the country investigated in this paper and $t = 1, \ldots, T$ is the point in time. The PCA is then expressed as a function of common PCs in the following way

$$Y_{it} = \alpha_{i0} + \alpha_{i1} f_{1t} + \alpha_{i2} f_{2t} + \ldots + \alpha_{iI} f_{It} \tag{2}$$

where f_k, $k = 1, \ldots, I$ are the common PCs that captures business cycle synchronization, and α_{ij} are the component loadings that shows the strength and direction of the business cycle synchronization. The transformation of these PCs is defined so that they are ordered according to variance, where the first PC has the largest variance, the second PC has the second largest

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9 There exist various options in which wavelet filter to use (Habimana, 2017). The specific choice of wavelet filter depends on features of the underlying data; such as the length of the data, complexity of the spectral density function, and the shape of the data to achieve balance between frequency and time localization, should be considered when selecting wavelet filter (Gençay et al. 2010).

10 The advantage of using the db(4) wavelet is that it is good at finding the right frequency of the data, but the disadvantage is that it has border problems (Percival & Walden, 2013). This issue is addressed by extending the time-series using half-point symmetrisation. However, this issue is not too big of a deal when it comes to for example real GDP growth rates, as this time-series is usually a mean reverting stationary process, and so extending the borders with the half-point symmetrisation method will replicate the original series sufficiently.

11 For example, Andrle, Brůha & Solmaz (2017), Caporale (1993) and Quah (2013) uses PCA to evaluate if the eurozone is an optimal currency area, while Selover (1999) and Sethapramote & Thepmongkol (2018) uses PCA to find a common business cycle in the ASEAN, finally Kose, Otrok & Whiteman (2003), Kose, Otrok & Prasad (2012) and Ductor & Leiva-Leon (2016) uses it to investigate a global business cycle.

variance and so on. The transformation thus results in a vector of uncorrelated PCs ordered by the degree of variability in the original data set (Jackson, 1988; Jolliffe, 2002).

After the components from the PCA has been obtained, we will perform an orthogonal rotation that maximizes the varimax criterion. The varimax rotation maximizes the sum of the variance of the squared loadings within each rotated principal component (Jolliffe, 2002). The sub-space found with PCA includes many interpretationally difficult components. The reason for using the varimax rotation is that we obtain few, clearly differentiated and easily interpretable components, while keeping orthogonality between them (Kaiser, 1958). There exist many methods for choosing the number of PCs to include, many of which are ad hoc rules of thumb[12], but for the objective of this paper, we will use varimax rotation on two components[13]. Focusing solely on two components have several advantages. The main advantage is that from an economic theoretical viewpoint, business cycle synchronization should be able to be explained only by a few set of components for there to be evidence of it, so choosing two PCs seem appropriate. Another advantage comes from the fact that it will be easier to explain and interpret the results from the PCA if it is investigated by two components alone[14]. A requirement for PCA is that the data is stationary, otherwise it will provide spurious results (Joliffe, 2002). As the data has been decomposed into cycles, this is not a problem since cycles are, by definition, stationary.

All computations will be done in MATLAB version R2017b. The wavelet coherence of the CWT will be computed using code provided by Grinsted et al. (2004). The DWT will be computed by Mallats (1989) proposed pyramid algorithm using the Wavelet Toolbox. After decomposing the business cycles using the DWT, the varimax rotated PCA will be performed on the correlation matrix (obtained by z-scoring).

[12] A simple method is to choose the number of components so that the cumulative variance of these exceeds a predetermined percentage (usually between 70% - 95%). Another common method is given by Kaiser's rule (Kaiser, 1960) which advocates that the number of components should be equal to the number of eigenvalues of the correlation (or covariance) matrix that is greater than 1. One can also look at a scree plot of the eigenvalues ordered by size and choose the number of components that appear prior to the "elbow". Various other non-traditional options also exist (Jolliffe, 2002).
[13] Technically, after rotating the components using the varimax criterion, they are not principal components anymore. For simplicity's sake, I will however refer to them still as principal components.
[14] Nevertheless, as will be evident later, two varimax rotated principal components are sufficiently able to account for much of the variance in the data, hence using only two components is an adequate decision.

4 Data and Variables

To answer the sentiment of business cycle synchronization in Europe, we will use a sample comprising of the EU-15 countries. The EU-15 countries are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and United Kingdom. The time-period considered is quarterly data from 1995Q1 to 2017Q4. The choice of countries and period depend mainly on available data. However, the EU-15 countries include three countries which do not use euro as its currency; Denmark, Sweden and United Kingdom. It is therefore interesting to analyse whether a formal participation in the EMU compared to not joining it has led to different performance regarding the synchronization of business cycles.

To investigate business cycle synchronization between the EU-15 countries, this paper uses two variables. They are real GDP growth and the unemployment rate. Using a similar methodological approach as this paper when studying synchronization of economic output in Europe, the real GDP growth rate is the most common choice (see e.g. Hughes Hallet & Richter, 2006a, 2006b, 2008; Crowley & Mayes, 2008; Crowley & Lee, 2005), followed by the Industrial Productivity Index (IP) (see e.g. Aguiar-Conraria et al., 2011) and the Economic Sentiment Indicator (ESI) (see e.g. Aguiar-Conraria et al., 2013). Far fewer studies investigates synchronization of the unemployment rate cycles. Considering this however, these variables have not been used before using the exact same research method as this paper to study business cycle synchronization.

Since the variables are collected at a quarterly frequency, they are naturally seasonally adjusted to exclude any seasonal component that might infer with the underlying trends and cycles in the data. Both variables were extracted from the Organisation for Economic Co-operation and Development (OECD) database (OECD.stat)[15]. In total, across the EU-15 countries during the sample period and from the business cycles at various time horizons, 16 560 observations are gathered to investigate the synchronization of business cycles in Europe.

[15] The real GDP growth rate was transformed from data on the real GDP expressed in domestic currency (to avoid exchange rate shocks). For some countries there was missing data at the beginning of the sample for the real GDP, but this was solved by directly downloading real GDP growth rates calculated by OECD instead. For the unemployment rate data, Greece was missing some observations in the beginning of the sample. It was however on an interval, so this was solved by doing linear interpolation.

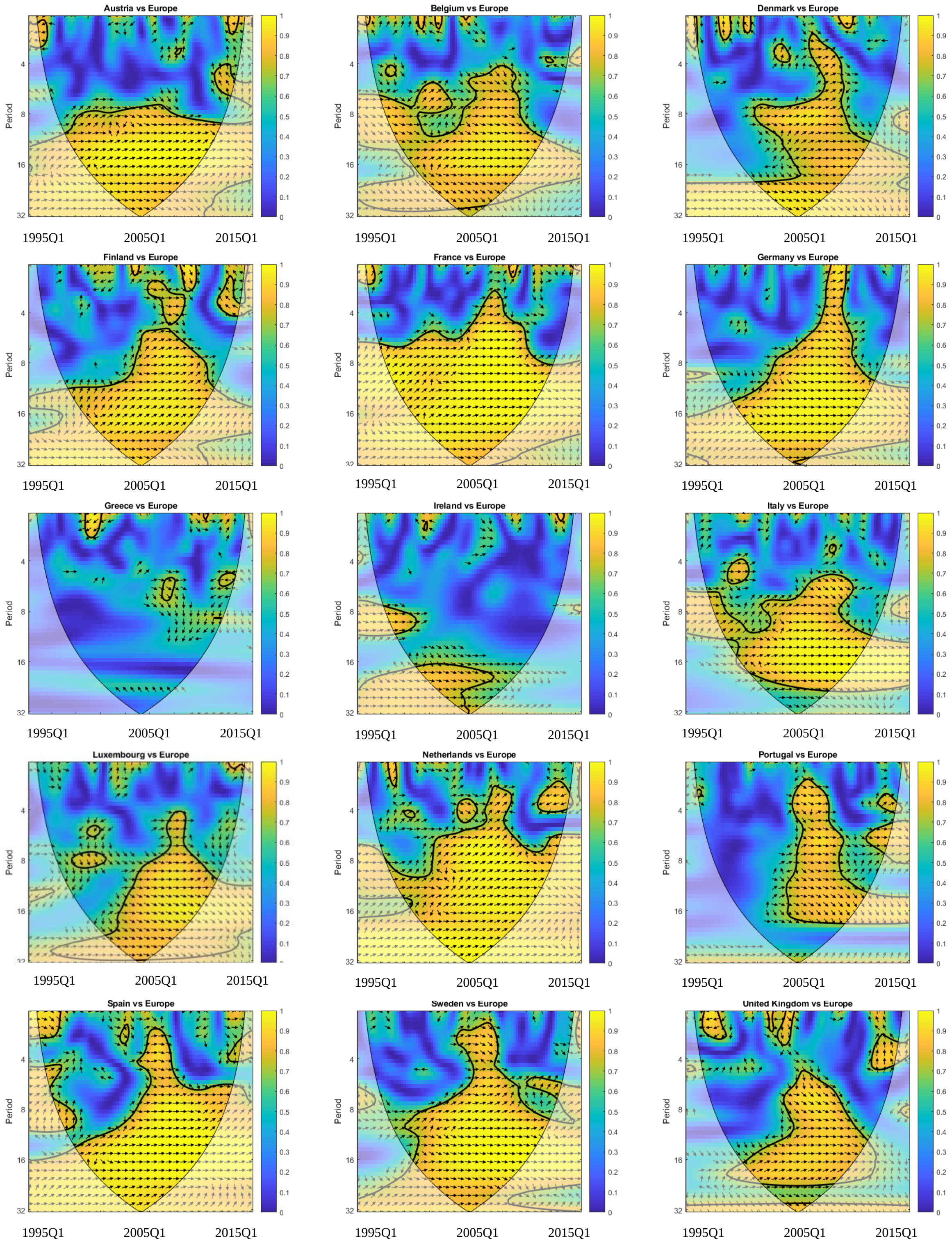
5 Empirical Analysis

5.1 Results from the Continuous Wavelet Transform

In Figure 1 and Figure 2, the results from the wavelet coherence of the CWT calculations are presented. They plot the individual EU-15 country against the average EU-15 countries, excluding the individual country investigated in each coherence plot. The wavelet coherence plots will provide us with useful information regarding a preliminary descriptive evidence of business cycle synchronization between the EU-15 countries.

Following the standard way of interpreting the econometric result of wavelet coherence from similar studies (see e.g. Aguiar-Conraria et al., 2012, 2013), it may be summarized as follows. On the right-hand side is the level of correlation shown, ranging from the lowest amount of correlation, 0, which is shown in the plot as a deep blue colour, to the highest amount of correlation, 1, which is shown as a clear yellow colour. For areas of high synchronization, we are therefore looking for areas that have this clear yellow colour, as it indicates that the co-movement of the countries' business cycles synchronize. On the x-axis is the time-period shown, ranging from the start of the sample in 1995Q1, to the end of the sample in 2017Q4. On the y-axis is the period shown. The periods show the time horizons, i.e. the 4 represents the 4-quarter long cycles, between the 4-8 period is the 1-2 year long business cycles, between the 8-16 period is the 2-4 year long business cycles and between the 16-32 period is the 4-8 year long business cycles. The thick black contour in the coherence plot shows areas where the wavelet coherence is significant at the 5% level against red noise estimated from 1000 Monte Carlo simulations using phase randomized surrogate AR(1) coefficients. The inverse bell-shaped cone is called the cone of influence (COI). It shows the region in the plot which is of important power, where the lighter shade is the significant region (Grinsted et al., 2004). Furthermore, the direction of the phase-difference arrows inside the plots show whether the two time-series are in-phase or leading/lagging each other. If the arrow is pointed to the right, it indicates that both time series are in phase with each other and if it is pointed to the left, it indicates anti-phasing. If the arrow is pointed up, the first time-series is leading the second, and if the arrow is pointed down, the first time-series is lagging the other.

Figure 1. Wavelet coherence plots of real GDP growth correlation



The first pattern revealed by the wavelet coherence plot of the real GDP growth (Figure 1) is that there is no significant episode of out of phase business cycle co-movement. Inside the cone of influence and for all significant coherencies, the arrows are pointed to the right (they are in-phase), which thus indicates that the correlation of business cycles synchronization is positive in the time and frequency dimensions. A first conclusion which can be drawn is therefore that there exist episodes of business cycle synchronization between the EU-15 countries. Another general global conclusion that can be made is that there are more areas of significant coherencies for the 1-2 year, 2-4 year and 4-8 year business cycles compared to the 1-4 quarter cycles. This should be a result from the business cycle being at least one year long, thus, any cycles of shorter frequencies are just seasonal deviations.

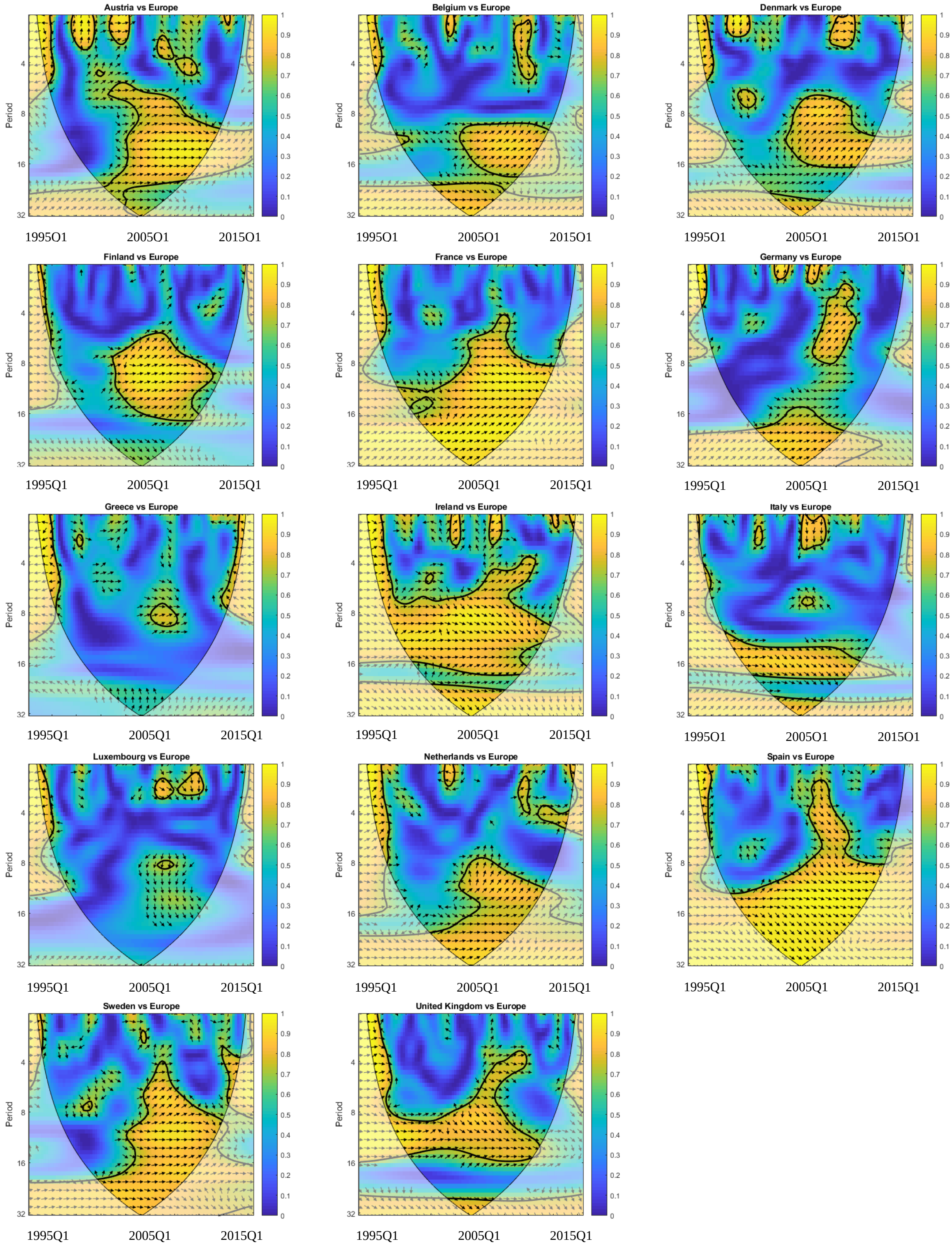
When analysing Figure 1 we can group the Euro area countries into two groups. The first group is the countries that have the most significant coherencies with the rest of EU-15 and thus the most predominant business cycle synchronization, and the second group is the countries that have the least. The first group consist of Austria, Belgium, Finland, France, Germany, the Netherlands and Spain, and the second group consist of Greece, Ireland, Italy, Luxembourg and Portugal. An interesting (but perhaps unsurprising) fact of this division is that the first group consist of many of the considered European core countries, while the second group consist of the peripheral countries (see e.g. Gouveia & Correira, 2008). Over the entire sample period, France is the country that synchronize most with the rest of EU-15 at every relevant business cycle length, showing significant coherency for the 1-2 year, 2-4 year and 4-8 year cycles. Greece and Ireland are the two countries with a clear less degree of synchronization, showing virtually no significant coherencies for any of the cycle periods.

Studying the wavelet coherencies of the three non-Eurozone members, Denmark and Sweden co-move relatively more with the EU-15 countries compared to United Kingdom. Denmark, which have pegged its national currency to the euro, show an increase in synchronization after 1999, which could be an effect from the creation of the EMU. But pegging the national currency to the euro is not a necessary condition for synchronization, as is evident from Sweden's coherence. This is a contrasting result compared to what Aguiar-Conraria et al., (2013) found.

Another global conclusion from Figure 1 is that, for most of the countries, there seem to be an increase in significant coherencies after 2005, meaning that the degree of business cycle increased after this period. The evidence of this is most clear for the co-movement of Denmark's, Germany's, Luxembourg's, Portugal's, Spain's and Sweden's business cycles with the rest of EU-15. As this occurs after 2005, the increase of business cycle synchronization may not be from the creation of the EMU, but instead might be because of the economic and financial situation in Europe (and the rest of the world) at the time. The evidence from the CWT thus suggests that the financial crisis contributed to an increase in business cycle synchronization between the EU-15 countries. Some time after the crisis however, the synchronization decreases for some countries. These results are in line with similar studies (Aguiar-Conraria et al. 2013).

Figure 2 turn instead to studying the wavelet coherencies and phase-differences of the unemployment rate cycles between the EU-15 countries.

Figure 2. Wavelet coherence plots of unemployment rate correlation



Regarding the phase-difference arrows of Figure 2, much of the same conclusions which was previously drawn from Figure 1 holds. It shows that for the significant coherence regions and inside the cone of influence, the unemployment rate cycles between the EU-15 countries co-move positively (i.e. in the same direction) as all arrows are pointing to the right. However, comparing Figure 2 with Figure 1 reveals that the area of significant wavelet coherencies is less for the unemployment rate cycles compared to the real GDP growth cycles. Still, the same general conclusions can be made. Note that wavelet coherence of Portugal is not present because of computational problems which could not be remedied.

Grouping together the Euro area countries into two groups showing the most coherencies versus the least reveals no clear divide between core and peripheral countries. The countries with the relative most area of significant coherencies is Austria, France, Ireland, the Netherlands and Spain, and the countries with the relative least amount are Belgium, Finland, Germany, Greece, Italy and Luxembourg. Again, France shows the most amount of significant coherence with the rest of EU-15, and Greece together with Luxembourg shows the lowest. Ireland, which was one of the countries with the lowest area of significant coherence for the real GDP growth rate cycles, show now evidence of high synchronization with the rest of EU-15 for the unemployment rate cycles. Furthermore, Denmark, Sweden and United Kingdom shows an almost equal amount of area of significant coherence as the first group of Euro area countries. Again, for most countries, there seems to be a tendency of increased synchronization leading up to and during the financial crisis of 2007-2008.

To summarize Figure 1 and 2, the results from the CWT generally show signs of positive business cycle synchronization for the 1-2 year, 2-4 year and 4-8 year cycles between the EU-15 countries. The evidence of this is more prominent when the business cycle is measured by the variable of real GDP growth compared to the unemployment rate. There seem to be a tendency of increased synchronization after 2005, which should stem from the economic and financial situation at that time. For some countries however, the synchronization decreases some period after the crisis, probably due to the time of recovery occurring at different times for different countries (Gomez et al, 2013). The most synchronized country with the rest of Europe is France, while the least synchronized is Greece, and signs of a core versus peripheral division is evident from the real GDP growth cycles but not for the unemployment cycles. The three non-Eurozone countries have a significant area of coherence with Europe for both variables, thus they synchronize positively.

5.2 Results from the Discrete Wavelet Transform

This section presents the empirical results from the varimax rotated principal components of the DWT decomposed real GDP growth and unemployment rate cycles. Firstly, the explained variation of each PC will be shown for both variables. The results of the component loadings are then divided into two sub sections. The first section shows the econometric result from the whole sample, i.e. 1995Q1-2017Q4, while the second section analyses and compares the results from before and after the financial crisis of 2007-2008.

As is evident from Table 2, the first two varimax rotated PCs can explain most of the variation in the data. Furthermore, the two varimax rotated PCs can explain more of the variation for the longer business cycles compared to the shorter business cycles. Considering the baseline sample of 1995Q1-2017Q4 for example, the two components explain 26.7% of the variation for the 2–4 quarter cycles and 94.1% for the 8–16 year real GDP growth rate cycles.

When splitting the sample into the period before and after the financial crisis, evidence show that business cycle synchronization increased for the real GDP growth cycles at every time horizon after the crisis, because both components can explain more variation. This result is however ambiguous for the unemployment rate business cycles. Again, it shows that the components of the longer cycles (4-8 year) have a higher explained variation than the components of the shorter cycles. Furthermore, the period from 2010Q1 to 2017Q4 reveals that the amount of variation explained is almost the same as the period of 2008Q1-2017Q4. This may be a surprising result, as we expect the degree of business cycle synchronization to be somewhat high during the time of the crisis, but that this degree is lower some period after the crisis (Gomez et al, 2013).

Table 2. Principal Component Results, Explained Variation (%)

Real GDP growth cycles								
	1995Q1 - 2017Q4		1995Q1 - 2007Q4		2008Q1 - 2017Q4		2010Q1 - 2017Q4	
	PC1	PC2	PC1	PC2	PC1	PC2	PC1	PC2
2-4 quarter cycles	14.0	12.7	16.5	14.3	23.0	15.5	24.4	14.5
1-2 year cycles	47.5	10.7	34.5	14.9	59.6	13.9	33.3	19.9
2-4 year cycles	51.5	17.2	50.6	19.2	60.8	18.3	66.1	15.3
4-8 year cycles	72.7	14.7	79.1	12.3	75.6	21.6	71.1	26.1
8-16 year cycles	87.0	7.1						
trend	76.6	17.6						

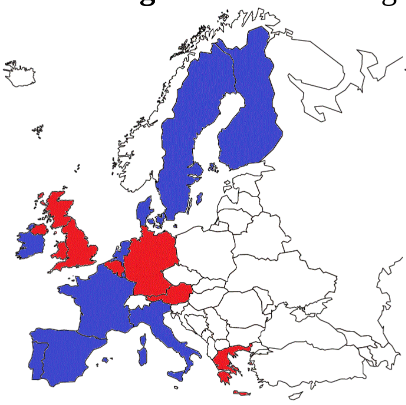
Unemployment rate cycles								
	1995Q1 - 2017Q4		1995Q1 - 2007Q4		2008Q1 - 2017Q4		2010Q1 - 2017Q4	
	PC1	PC2	PC1	PC2	PC1	PC2	PC1	PC2
2-4 quarter cycles	19.0	11.6	17.1	15.7	28.4	13.3	26.3	18.5
1-2 year cycles	25.4	16.9	27.1	17.8	31.7	28.6	39.2	21.4
2-4 year cycles	66.7	9.9	45.2	25.4	76.9	8.4	66.8	11.8
4-8 year cycles	38.1	34.0	55.1	33.7	48.8	35.7	52.8	33.4
8-16 year cycles	58.3	27.9						
trend	56.3	40.5						

Since the first component explain much of the variation for both variables, the result suggests that PC1 shows business cycle synchronization across the EU-15 countries, whereas PC2 may capture clusters of synchronizing countries. Furthermore, as the explained variation is higher for the longer cycles, it could be that the countries synchronize over the long term, but short-term synchronization is also due to core and peripheral clustering. In any case, there is a need to investigate this matter. Let us therefore do this by studying how each individual country contributes to the component loadings at each frequency.

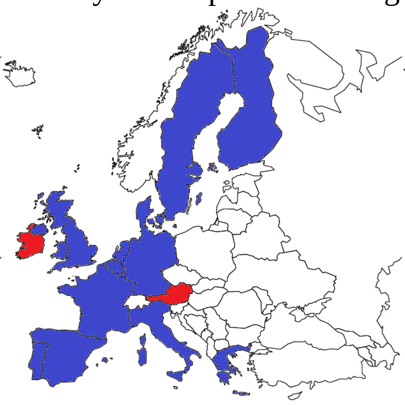
5.2.1 Baseline Case Results

Figure 3 and 4 present the result from the two varimax rotated principal components for the real GDP growth cycles, while Figure 5 and 6 present the result for the unemployment rate cycles. They show the component loading of each EU-15 country at each time horizon. Countries that are coloured blue share the same sign of the component loading, and countries coloured red share the same sign. Hence, if all countries have the same colour (i.e. the same component loading sign) it is interpreted as complete business cycle synchronization between all countries. If on the other hand some countries have the same colour while others do not, it is to be interpreted as country-clustering business cycle synchronization shared by the countries of the same sign. Even if the sign of just a few countries deviate from the rest, it may still be interpreted as business cycle synchronization if most of the countries share the same colour. As the baseline case, we begin by investigating business cycle synchronization for the whole sample period, i.e. from 1995Q1 to 2017Q4. No in-depth analysis will be carried out on the 2-4 quarter cycles, as it is on a too short time frame to discern any business cycle.

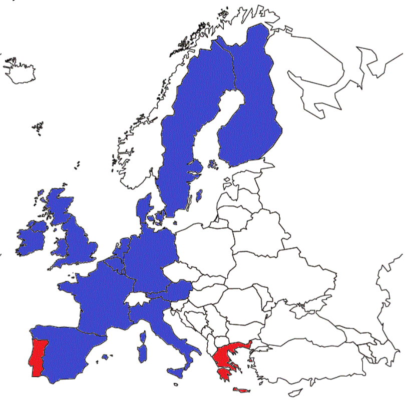
Figure 3. Real GDP growth cycle component loadings, varimax rotated PC1.



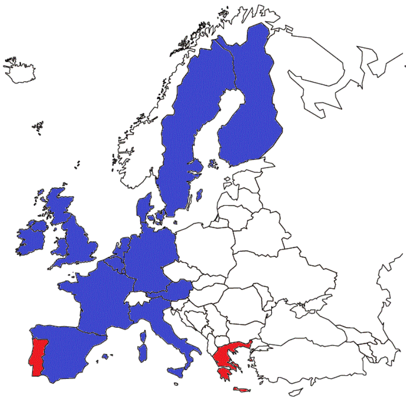
Panel A: 2-4 Quarter cycles



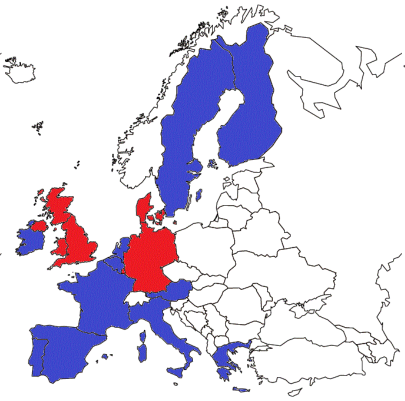
Panel B: 1-2 Year cycles



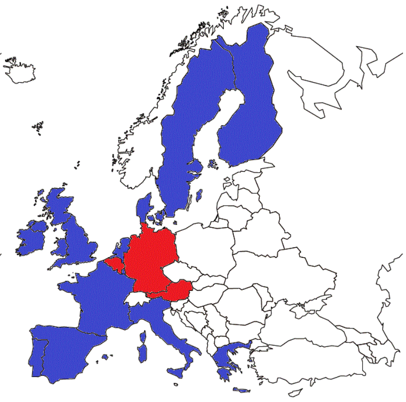
Panel C: 2-4 Year cycles



Panel D: 4-8 Year cycles

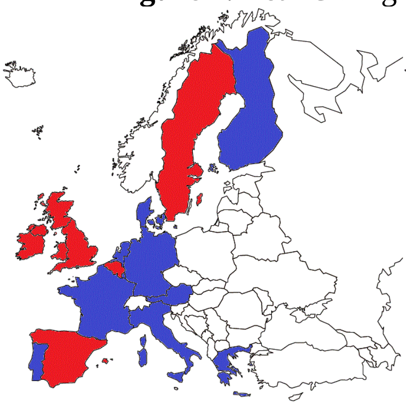


Panel E: 8-16 Year cycles



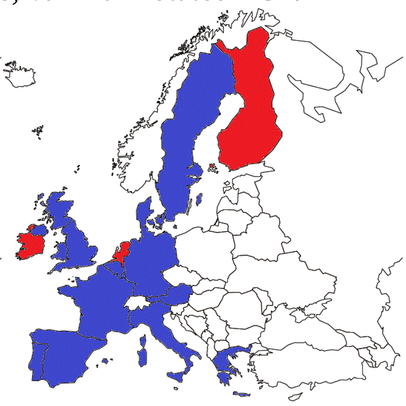
Panel F: Trend

Figure 4. Real GDP growth cycle component loadings, varimax rotated PC2.

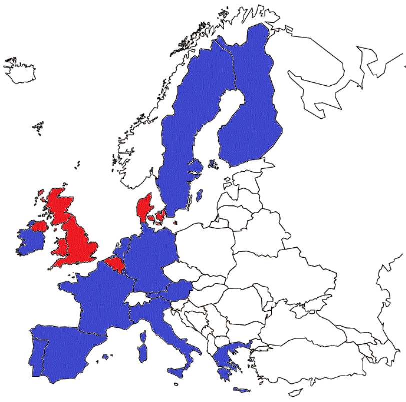


Panel A: 2-4 Quarter cycles

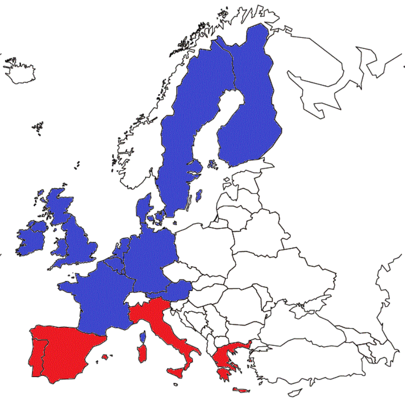
Panel B: 1-2 Year cycles



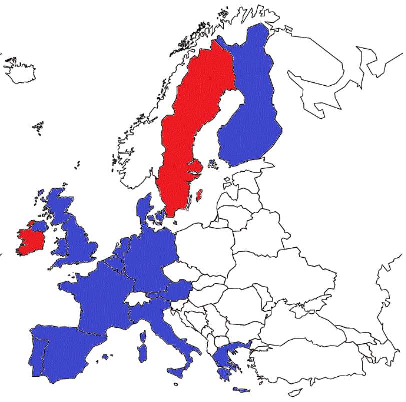
Panel C: 2-4 Year cycles



Panel D: 4-8 Year cycles



Panel E: 8-16 Year cycles



Panel F: Trend

In general, the result from both component loadings (Figure 3 and 4) shows that most of the EU-15 countries share the same component loading sign, suggesting that there is synchronization of the real GDP growth business cycles that holds for all time horizons. It should be noted that the observed result is in general statistically significant, because it is based on significant correlation estimates (see Appendix B). There is some evidence that southern European peripheral countries diverge in synchronization for some time horizons. For the first component, this is visible from Greece and Portugal for the 2-4 year and 4-8 year business cycles, and for the second component, this is visible from Greece (1-2 year cycles) and Greece, Italy, Portugal and Spain (8-16 year cycles).

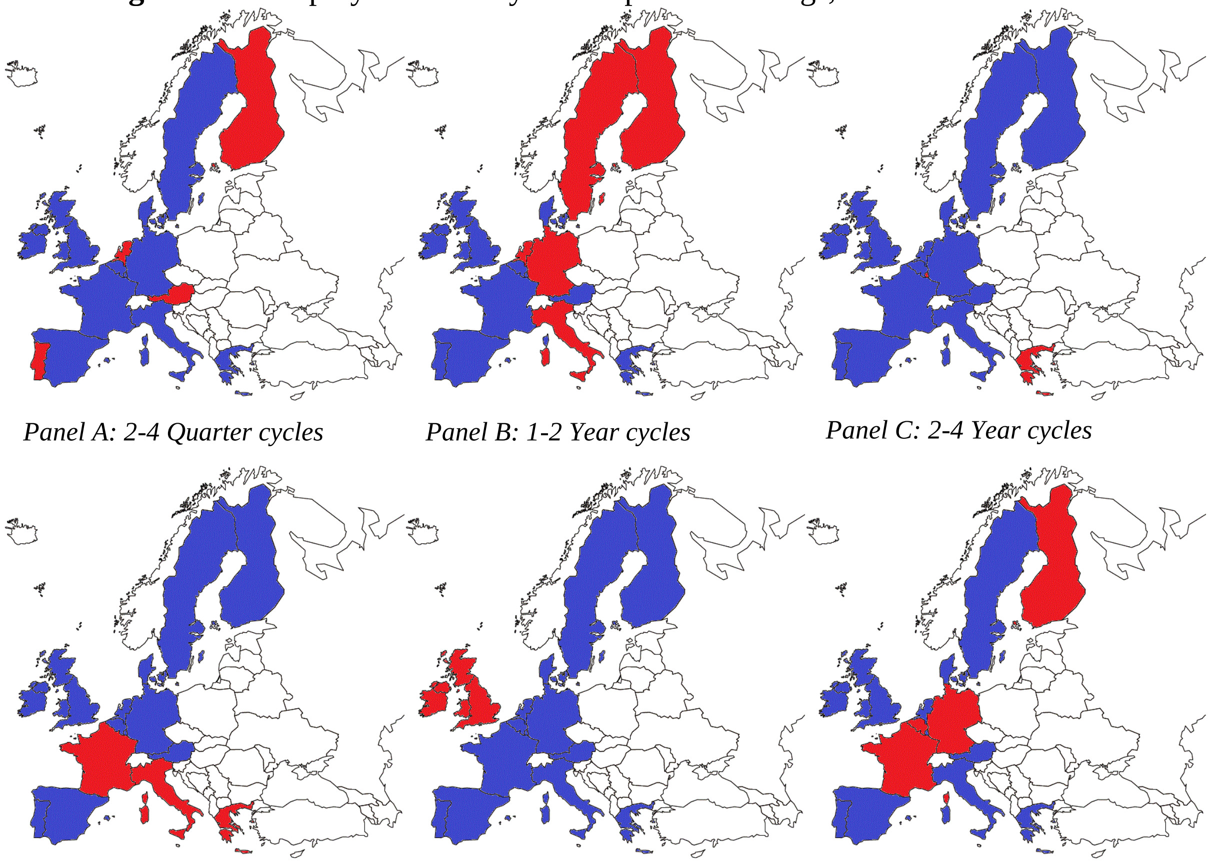
Regarding the three countries that is not in the Euro area, i.e. Denmark, Sweden and United Kingdom, it seems as if Sweden is the one country of the three that synchronizes most often with most of the Eurozone member countries business cycles. Denmark and United Kingdom on the other hand, have diverging synchronization of the long-term business cycle (8-16 year) for PC1, and diverging synchronization of the 4-8 year cycles for PC2.

France is the country that most often have the same loading sign as the majority of the other EU-15 countries, across all business cycle lengths and both components. This was also what was previously seen from the preliminary evidence of the CWT and from similar studies (Aguiar-Conraria & Soares, 2011). France can therefore be viewed as the main core country of Europe. Interestingly for PC1, Germany which is arguably the strongest European economy, show divergence of business cycle synchronization at the 8-16 year cycles and the trend. Given Germanys' reputation of being a core European country, one would assume that it would always synchronize with the rest of Europe (see e.g. Aguiar-Conraria & Soares, 2011).

The trend component also shows sign of common synchronization between the EU-15 countries' business cycles, since almost all countries have the same component loading sign. The difference between the two trend components is the countries which do not synchronize with the rest. For PC1, these countries are Austria, Belgium and Germany, and for PC2 these countries are Ireland and Sweden.

Turning instead to the other variable, Figure 5 and 6 presents the results from the varimax rotated principal components of the unemployment rate business cycles.

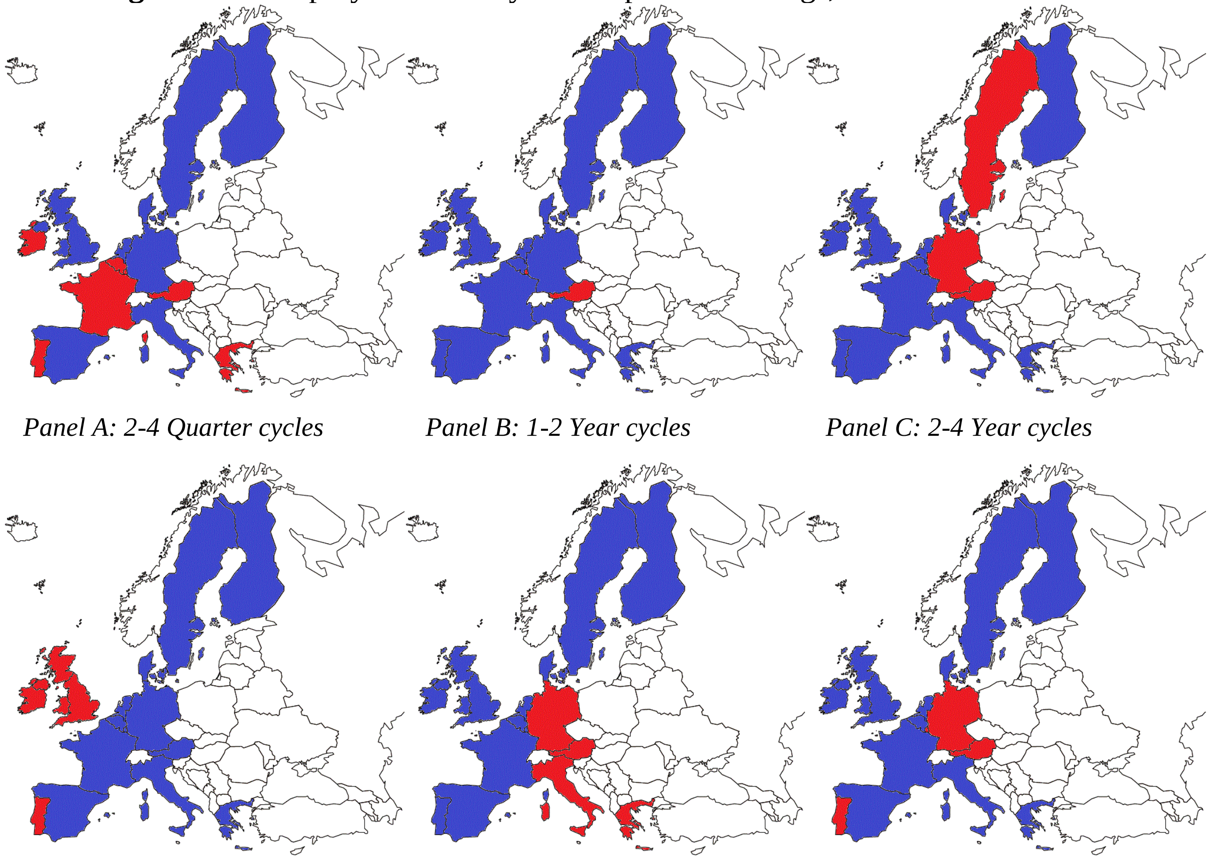
Figure 5. Unemployment rate cycle component loadings, varimax rotated PC1.



Panel A: 2-4 Quarter cycles *Panel B: 1-2 Year cycles* *Panel C: 2-4 Year cycles*

Panel D: 4-8 Year cycles *Panel E: 8-16 Year cycles* *Panel F: Trend*

Figure 6. Unemployment rate cycle component loadings, varimax rotated PC2.



Panel A: 2-4 Quarter cycles *Panel B: 1-2 Year cycles* *Panel C: 2-4 Year cycles*

Panel D: 4-8 Year cycles *Panel E: 8-16 Year cycles* *Panel F: Trend*

The first component loading (Figure 5) for the unemployment rate cycles reveals a more synchronized EU-15 for the 2-4 year cycles (only Greece and Luxembourg diverges) and for the 8-16 year cycles (only Ireland and United Kingdom diverges). For the 1-2 year cycles however, there seem to be a divide into two groups of synchronizing European countries. The first group consists of Austria, Belgium, Denmark, France, Greece, Ireland, Luxembourg, Portugal, Spain and United Kingdom while the second group consists of Finland, Germany, Italy, the Netherlands and Sweden. The 4-8 year cycles show another type of division, where it seems as three southern European countries synchronize with each other (France, Italy and Greece) but diverges from the rest of EU-15. Again, since the estimations are made on relatively significant correlation matrices (see Appendix B), the component loadings are significant.

The second component loading (Figure 6) reveals a similar pattern as the first, but with more clear synchronization. Austria seem to be diverging most often from the other EU-15 countries, as can be seen from the 1-2 year, 2-4 year and 8-16 year cycles. Another interesting result is that some core countries do not share the common loading of PC2, as is the case for Germany for the 2-4 year cycles and for Germany and Italy for the 8-16 year cycles. It also seems as if some peripheral countries diverge from the rest, for example Portugal and Ireland (4-6 year cycles) and Greece (8-16 year cycles).

Regarding the trend component, most synchronization is evident for the second component loading compared to the first. Interestingly, Germany is desynchronized with most other EU-15 countries for both PC1 and PC2. Other core countries also show divergence of the trend component, as can be seen from Belgium and France (PC1) and Austria (PC2), as well as the peripheral countries of Finland (PC1) and Portugal (PC2).

Furthermore, Denmark, Sweden and United Kingdom show a relatively strong synchronization with the Euro area, with only a few cases of the countries diverging. Out of the three however, Denmark is most synchronized with the Euro area, showing common component loadings both for PC1 and PC2 and across the different business cycle lengths with most of the EU-15 countries. While Denmark is synchronized on every frequency of cycles, Sweden tend to diverge on the shorter cycles and United Kingdom tend to diverge on the longer cycles.

To summarize the results from the varimax rotated PCs of the real GDP growth and unemployment rate, there is in general a high degree of business cycle synchronization between the EU-15 countries. Both components for both variables tend to capture synchronization on some cycle frequencies, and some clustering of synchronization on other frequencies. There is however no clear result of differing synchronization at different time horizons, as the short run, medium run and long run cycles all capture a high common synchronization between the EU-15 countries. Furthermore, both components tend to capture synchronization as they show that most of the countries share a common loading. This notwithstanding, the European core is usually synchronized, and the countries that most often do not synchronize are the peripheral countries of Greece, Ireland and Portugal, a result in line with previous findings (Konstantakopoulou & Tsionas, 2011; Gouveia & Correira, 2008). This result holds mostly for the real GDP growth cycles, as the unemployment cycles sometimes capture diverging core countries. However, evidence suggests also that the core country of Germany is desynchronized at different cycle frequencies. The results are in contrast with Hughes Hallet and Richter (2008) who found that the larger countries synchronize in the short run but not in the long run, as our results indicate a high degree of synchronization over every time horizon for these countries.

5.2.2 Business Cycle Synchronization Before and After the Financial Crisis

This subsection is dedicated to investigating if the degree of business cycle synchronization between the EU-15 countries differ before and after the crisis of 2007-2008. To make for a more coherent discussion, this section will just interpret the results. For the figures showing the result of the varimax rotated PCs when splitting the sample to before and after the crisis, the interested reader is referred to Appendix C. There, again, countries coloured blue indicates that they share the same component loading sign, and countries coloured red indicates they share the other component loading sign.

The real GDP growth cycles before and after the crisis

Comparing the result of the real GDP growth cycle first component loadings (Figure 7 and Figure 8) reveals no clear results to whether the crisis contributed to decoupling or increased synchronization of business cycles. It reveals that the EU-15 countries have been more synchronized for the 1-2 year cycles and 4-8 year cycles, but more desynchronized for the 2-4 year cycles. The results suggest however that there is a clear distinction between core and peripheral countries after the crisis. This holds both when including and excluding the period of the crisis, and that Greece is especially desynchronized at each time horizon when excluding the crisis (Figure 11).

The result of the second component loading (Figure 9 and Figure 10) reveals much of the same as what the first did. For the 2-4 year and 4-8 year cycles, not much differs in terms of overall decoupling or increased synchronization between the business cycles, the only difference is the change of which countries that synchronize.

The general conclusion to be drawn from the real GDP growth cycles after the crisis is that the European core is synchronized across each business cycle frequency, while some of the European peripheral countries is not. This is in line with previous findings (Degiannakis et al., 2014). The most desynchronized countries after the crisis are Finland, Greece, Ireland and Portugal both including and excluding the period of the crisis. Furthermore, there is no clear difference in synchronization or desynchronization between different time horizons, as they all capture mostly a common European cycle. This notwithstanding, the real GDP growth cycles of the EU-15 countries are for the most part synchronized both before and after the financial crisis, contradicting the results of for example Papageorgiou et al. (2010) who concluded that business cycle synchronization decreased after the year 2000. Our results suggest therefore that the crisis did not contribute to a start in desynchronization of business cycles within Europe, thus not confirming the result of for example Grigoraș and Stanciu (2016) who found a great disconnect in Europe after the crisis.

The unemployment rate cycles before and after the crisis

The first component loadings of the unemployment cycles (Figure 13, 14 and 17), shows increased synchronization for some time horizons, and increased desynchronization between others. Both when including and excluding the time of the crisis, the 1-2 year cycles and the 4-8 year cycles, show increased synchronization. However, the 2-4 year cycles reveals clear evidence of decoupling of unemployment rate cycles after the crisis. For these cycle lengths, the EU-15 countries perfectly synchronize before the crisis, but after the crisis there are some countries that diverge.

Regarding the second component loading (Figure 15 and 16), there is a clear increase of business cycle synchronization for the short run cycles. Regarding the medium run cycle however (4-8 year), just one country does not synchronize before the crisis, but after the crisis there are six desynchronizing countries (both including and excluding the crisis period). PC2 also reveals a clear distinction between synchronized core countries and desynchronized peripheral countries after the crisis.

The results of the unemployment rate cycles show that there has been an increase of synchronization after the crisis of the 1-2 year and 4-8 year cycles for both component loadings. For the 2-4 year cycles however, PC1 shows a decrease in synchronization and PC2 shows an increase. Still, even though increased synchronization between the EU-15 countries happened, there is a clear pattern of core and periphery synchronization. The least synchronized countries after the crisis are Greece and Portugal.

6 Conclusion

The study of business cycle synchronization in Europe has been thoroughly explored in past research, however yielding contrasting results. After all, it is an important topic to investigate as business cycle synchronization is a cornerstone for an optimal currency area. This stems from the fact that decision makers want the effect of monetary policy to have an even result across the area in which the policy is conducted, and the existence of business cycle synchronization is an indicator of this evenness. In this paper we provide with further investigation of business cycle synchronization in Europe, by studying the real GDP growth and unemployment rate cycles of the EU-15 countries, using wavelet analysis. Both the continuous wavelet transform (CWT), and the discrete wavelet transform (DWT) together with varimax rotated principal component analysis (PCA), is employed to study the sentiment of business cycle synchronization between the EU-15 countries. The purpose of the paper is to study synchronization at different time horizons, such as the short run, medium run and long run, and to evaluate which effect the financial crisis of 2007-2008 had on business cycle synchronization in Europe.

There are some limitations to this present study which should be acknowledged. Firstly, the study is conducted only on fifteen European countries, far fewer than the actual amount of existing European countries. Since many of the EU-15 countries can be regarded as the core, it may be biased to conclude the notion of overall business cycle synchronization in Europe just from the result of these fifteen, since many peripheral European countries not included in the study might infer on this. Moreover, for principal component analysis to produce reliable results, there need to be sufficiently many observations. For the baseline sample, i.e. 1995Q1 – 2017Q4, there should not be any problem with the amount of observations. However, when splitting the sample to the period before and after the crisis, there will be fewer observations that undergo the varimax rotated principal component analysis, which could mean that the results are less reliable compared to the baseline. Furthermore, using the discrete wavelet transform to decompose the time series into business cycles is not without caveats. Since the DWT is defined for a signal with the length of 2 raised to the power of an integer, one such caveat is its problem of border distortion, which means that the beginning and the end of the sample needs to be extended using one of the various existing methods for this.

The evidence from the CWT shows that the EU-15 countries in general have a high degree of positive (in-phase) synchronization across both the short run, medium run and long run. This holds for both variables considered, however, the countries seem to be more synchronized for the real GDP growth cycles than for the unemployment rate cycles. Furthermore, the analysis from the CWT reveals that some countries are more synchronized with the rest of Europe, and that some are more desynchronized. It shows that France is clearly the most synchronized country with the rest of the EU-15 countries, and that Greece is by far the least synchronized with the rest. In general, there is a distinction between synchronized core countries and desynchronized peripheral countries. It also reveals that after 2005, there is a pattern of increased synchronization, which should stem from the economic and financial situation at the time. Therefore, during the period leading up to, and during, the financial crisis of 2007-2008, increased business cycle synchronization is evident in Europe. For some countries however, this synchronization decreases slightly some time after the crisis.

The DWT decomposed the data into 2-4 quarter, 1-2 year, 2-4 year, 4-8 year, 8-16 year and >16 year cycles, and then varimax rotated PCA was used to investigate synchronization on each respective time horizon. The results from this too shows that the EU-15 countries in general are synchronized. This is evident from two component loadings and for each time horizon investigated, as most of the EU-15 countries share a common component loading. There are only a few countries that do not synchronize with the rest over the various time horizons, and these are peripheral countries such as Greece and Portugal. Furthermore, it also shows that business cycle synchronization increased after the financial crisis, but that some peripheral countries diverge from this synchronization.

The results of this paper sheds light on the ramifications of monetary policy by decision makers in Europe. It has been shown that the business cycles of the EU-15 countries in general synchronize with each other both in the short run, medium run and long run, showing a positive image of the Euro area as an optimal currency area. However, mainly Greece but also some other peripheral countries tend to be relatively desynchronized with the rest of Europe, something that should be kept in mind when designing future monetary policy for the Euro area. Since Greece already have a relatively high unemployment and low real GDP per capita compared to most other European countries, conducting common monetary policy in the Euro area may be harmful for Greece. It is therefore advised that Greece attempts to increases its business cycle synchronization with the rest of the Euro area, as it would otherwise mean that it would be even more difficult for Greece to catch up with the rest of Europe. But this advise is not exclusive to Greece. Policy makers in Europe should actively work to keep a high degree of business cycle synchronization between all countries to prevent uneven effects from common shocks. Furthermore, the three countries which do not have Euro as its currency included in the study; Denmark, Sweden and United Kingdom, all show synchronization of their business cycles with Europe, in general. If only considering the business cycle synchronization criterion of an optimum currency area, this means that these three countries can sacrifice the independency of conducting their own monetary policy, by adopting the euro as their currency, without any negative effects on their own economic situation. However, even though they could adopt the euro without any problem, the question is if they should, but answering this question is not within the scope of this paper.

Even though there have been many studies conducted on the notion of business cycle synchronization in Europe, there is always a reason for future research about the subject. Since using wavelet analysis is a relatively new methodological approach in economics, and because of its advantages with decomposing economic time series into business cycles at various time horizons, there is still much room to use this seemingly unexplored tool in future similar business cycle synchronization studies. This paper has only studied the EU-15 countries, so a future possibility is to expand the study by including more European countries. As of now, there are 19 member states in the Euro area, as well as some under the monetary agreement and those who have unilaterally adopted euro as its currency, so including these in the study of European business cycle synchronization would be interesting for additional evidence of whether the Eurozone is an optimum currency area. Furthermore, it would also be interesting to investigate whether some of the countries currently not in the Euro area, such as many of the eastern European economies, synchronize with the rest of the Euro area. This could reveal which countries that are possible candidates of adopting euro as its currency, and those who are not. As of now however, there is a lack of available data for these countries, but it will be possible to investigate this matter in the future. To conclude, seeing how the present political situation in Europe is, it will be interesting to see whether the European countries will keep a high degree of business cycle synchronization in the future.

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Appendix A

Table 3. Summary of the Literature

Authors	Data	Measure of Cycle	Convergence Measure	Conclusions
Camacho et al. (2006)	log of IP, all of Europe, 1962:1-2003:1	Average of three filtering methods	Pairwise correlation of the average of filtering methods	Older EU member economies synchronize more compared to recently added ones, introduction of euro has not increased synchronization, but no evidence of a common European cycle
Jiménez-Rodríguez et al. (2013)	Real output, consumption and investment growth, 1995Q2-2011Q4	Markov switching model	Variance decomposition in factors and idiosyncratic terms	A global European factor, capturing well the crisis of 2008
Granville & Hussain (2017)	10 selected countries, IP, 1960:1-2013:12	Classic cycle: Harding & Pagan (2002) Bry & Boschan (1971) procedure; growth cycle: BK and HP filter	Concordance analysis of when cycles are in phase	Synchronization of growth cycles but not of a common cycle
Grigoraș & Stanciu (2016)	Real GDP, all EU members, 1960Q1-2014Q3	BBQ algorithm	Clustering of turning points, concordance and correlation indicators	No synchronization in Europe post the Great Recession
Aslanidis (2010)	log of IP, CEEC countries, 1993:2-2006:4	threshold seemingly unrelated regression	Contemporaneuous linkage	Hungary synchronizes with Europe, while Czech Republic and Poland does not
Belke et al. (2017)	Real GDP, EA-12 plus four other, 1970Q1-2015Q4	HP filter	Correlation and nonparametric local polynomial regression	Core countries synchronize, while peripheral does not with core
Papageorgiou et al. (2010)	Various macroeconomic variables	HP filter	Correlation and culstering analysis of three sub samples	Increased synchronization in 1992-1999, decreased synchronization in 2000-2009, distinct divergence between core and periphery
Gouveia & Correia (2008)	Real GDP, EMU, 1980Q1-2004Q4	BK filter	Spearman's rank correlation and concordance indices	Nation level and EMU aggregate synchronization, synchronization have varied over time (three subperiods)
Montoya & de Haan (2008)	GVA, NUTS1 region, 1975-2005	HP and CF filter	Regional correlation coefficients	Synchronization have increased on average, except during 1980 and beginning of 1990

Table 3. Continued

Authors	Data	Measure of Cycle	Convergence Measure	Conclusions
Crowley & Lee (2005)	Real GDP, EU-12, 1970Q1 - 2004Q2	MRA using MODWT	Wavelet variance and correlation, co-correlation phasing and dynamic conditional correlation GARCH	Euro area countries fall into three clusters: i) high and dynamic correlations at all frequency cycles, ii) low static and dynamic correlations with low synchronization and iii) low static correlation but high dynamic correlation
Wynne & Koo (2000)	Real GDP and unemployment, EU-15	BK filter	Pairwise correlation using GMM	Correlation between founding EU countries, lower correlation with more recent members, synchronization is increasing over time
Inklaar & de Haan (2001)	IP, all euro area except Portugal plus seven other, 1961:1-1997:12	PAT and HP filter, linear trend	Four subperiods, contemporaneuous correlation coefficient with German cycle	No synchronization after ERM period (opposite result of Artis & Zhang (1997, 1999)
Aguiar-Conraria et al. (2013)	European Sentiment Indicators, 10 eurozone countries, 1985:1-2010:12	Spectral decomposition	Wavelet coherence, phase-difference and wavelet distance	More synchronization after introduction of EMU
Hughes Hallet & Richter (2004, 2006, 2008)	OECD real GDP and European System of Accounts	Spectral decomposition	Time-varying spectra and cross-spectra	Some communality at certain frequencies and some synchronization at different periods, France and Germany are the key to convergence within the Eurozone but coherence between Germany and Eurozone has decreased, not significant synchronization between periphery and core countries
Gomez et al. (2017)	Real GDP, 23 European countries, 1995Q1-2015Q3	HP filter	Cross correlation and Kendall rank correlation, network analysis and group cohesion, distance correlation	Stable synchronization from 1999 until the crisis, after crisis synchronization increased significantly, no evidence of core and peripheral countries
Massmann & Mitchell (2004)	IP, 12 European countries, 1960:1-2001:8	Both parametric and nonparametric measures	Bivariate correlation coefficients	There have been periods of increased synchronization and periods of decreased synchronization, recently more synchronization
Koopman & Azavedo (2008)	Real GDP, 7 European countries compared with GDP of Euro area and US, quarterly 1970-2001	CF filter	Time-varying phase shifts and covariance matrices	Synchronization within the Euro area and France and Germany have a high synchronization with Euro area

Table 3. Continued

Authors	Data	Measure of Cycle	Convergence Measure	Conclusions
Di Giorgio (2016)	Real GDP, 7 CEEC outside EA and aggregate EA, 1993Q1-2014Q1	Markov switching model	Correlation between cyclical fluctuations	High synchronization in low growth regimes and low synchronization in high growth regimes
Crowley & Mayes (2008)	GDP growth, France, Italy and Germany,	MRA using MODWT, spectral decomposition	Variance decomposition, wavelet coherence and phase differences	Coherence and phase between the three euro core members differ, different results in different cycle lenghts
Lehwald (2013)	Output, investment and consumption growth, Euro area, 1991-2010	Kose et al. (2003) filter	Bayesian dynamic factor model, variance decomposition	Introduction of EMU had diverging effect on peripheral (Greece, Ireland, Portugal and Spain) but synchronization increased on core (8 countries), thus EMU have fostered imbalances within the Euro area

Appendix B

Table 4. Correlation of GDP Growth, 2-4 Quarter Cycle (Lower Triangle) and 1-2 Year Cycle (Upper Triangle)

	AUT	BEL	DNK	FIN	FRA	DEU	GRC	IRL	ITA	LUX	NLD	PRT	ESP	SWE	GBR
AUT	1	0.18	0.50*	0.09	0.54*	0.07	0.07	0.17	0.20	-0.09	0.25	0.22	0.12	0.05	0.26
BEL	0.10	1	0.51*	0.74*	0.57*	0.62*	0.50*	0.16	0.57*	0.42*	0.74*	0.64*	0.55*	0.50*	0.41*
DNK	0.04	0.15	1	0.44*	0.82*	0.45*	0.25	0.20	0.46*	0.25	0.52*	0.53*	0.74*	0.57*	0.48*
FIN	0.11	0.11	0.03	1	0.54*	0.74*	0.45*	0.04	0.45*	0.28*	0.64*	0.63*	0.51*	0.39*	0.29*
FRA	0.11	0.01	0.04	0.05	1	0.50*	0.45*	0.28*	0.53*	0.43*	0.59*	0.58*	0.70*	0.51*	0.42*
DEU	0.19	-0.21	-0.04	0.37	0.28	1	0.41*	0.09	0.50*	0.18	0.66*	0.52*	0.51*	0.33*	0.29*
GRC	0.16	-0.10	-0.19	0.24	0.05	0.18	1	-0.25	0.48	0.42	0.45	0.24	0.29	0.30	0.39
IRL	-0.12	0.01	0.07	-0.05	0.11	0.00	-0.06	1	0.25	0.19	0.23	0.36	0.35	0.20	-0.22
ITA	-0.12	-0.04	0.06	0.15	0.23*	0.26	-0.27*	0.01	1	0.49	0.57	0.56	0.60	0.37	0.39
LUX	0.10	0.07	-0.02	0.16	-0.04	-0.06	0.23	0.03	-0.05	1	0.33	0.49	0.28	0.39	0.30
NLD	0.08	0.04	0.29	0.14	0.05	0.27*	-0.09	-0.11	0.18	0.19	1	0.70	0.71	0.53	0.37
PRT	0.09	-0.21	0.08	0.00	0.22	0.01	-0.13	0.21	0.14	0.17	0.03	1	0.67	0.51	0.44
ESP	-0.19	-0.06	0.03	0.18	0.09	-0.10	0.04	0.16	0.09	0.20	-0.04	0.35*	1	0.67	0.48
SWE	-0.24	-0.10	0.12	-0.06	0.01	-0.15	0.12	0.21	0.13	0.14	0.11	0.23	0.29*	1	0.35
GBR	0.07	-0.00	-0.05	-0.10	-0.03	0.11	-0.19	0.10	-0.08	-0.15	-0.06	0.15	-0.13	-0.19	1

Notes: * $p < 0.01$.

Table 5. Correlation of GDP Growth, 2-4 Year Cycle (Lower Triangle) and 4-8 Year Cycle (Upper Triangle)

	AUT	BEL	DNK	FIN	FRA	DEU	GRC	IRL	ITA	LUX	NLD	PRT	ESP	SWE	GBR
AUT	1	0.93*	0.87*	0.97*	0.99*	0.97*	-0.24	0.52*	0.90*	0.84*	0.89*	0.53*	0.70*	0.85*	0.80*
BEL	0.66*	1	0.91*	0.94*	0.94*	0.93*	-0.34*	0.54*	0.87*	0.82*	0.78*	0.42*	0.64*	0.85*	0.87*
DNK	0.58*	0.41*	1	0.90*	0.87*	0.83*	-0.44*	0.41*	0.76*	0.69*	0.83*	0.44*	0.56*	0.67*	0.69*
FIN	0.72*	0.51*	0.21	1	0.98*	0.98*	-0.20	0.46*	0.89*	0.80*	0.90*	0.52*	0.69*	0.84*	0.86*
FRA	0.90*	0.76*	0.43*	0.81*	1	0.98*	-0.24	0.53*	0.90*	0.86*	0.89*	0.54*	0.72*	0.87*	0.80*
DEU	0.61*	0.73*	0.47*	0.47*	0.72*	1	-0.11	0.55*	0.95*	0.79*	0.87*	0.54*	0.74*	0.89*	0.87*
GRC	0.08	0.11	0.27*	-0.16	0.07	0.27*	1	0.19	-0.10	-0.32*	0.03	0.45*	0.30*	-0.05	-0.16
IRL	0.20	0.27*	-0.16	0.05*	0.30*	-0.18	-0.06	1	0.69*	0.58*	0.54*	0.74*	0.89*	0.81*	0.26
ITA	0.68*	0.81*	0.24	0.63*	0.84*	0.71*	0.03	0.21	1	0.71*	0.77*	0.51*	0.78*	0.91*	0.78*
LUX	0.32*	0.45*	0.66*	-0.10	0.31*	0.62*	0.42*	-0.05	0.41*	1	0.73*	0.51*	0.68*	0.87*	0.61*
NLD	0.79*	0.49*	0.54*	0.69*	0.76*	0.32*	-0.25	0.34*	0.61*	0.20	1	0.80*	0.83*	0.76*	0.60*
PRT	0.19	0.34*	0.29*	0.25	0.34*	0.81*	0.24	-0.53*	0.37*	0.39*	-0.00	1	0.92*	0.63*	0.18
ESP	0.79*	0.45*	0.62*	0.68*	0.75*	0.69*	0.02	-0.30*	0.65*	0.36*	0.68*	0.54*	1	0.87*	0.43*
SWE	0.64*	0.68*	0.42*	0.62*	0.84*	0.75*	-0.01	0.24*	0.80*	0.39*	0.71*	0.52*	0.67*	1	0.71*
GBR	0.57*	0.40*	0.80*	0.25*	0.49*	0.60*	0.47*	-0.32*	0.43*	0.59*	0.40*	0.46*	0.77*	0.47*	1

Notes: * $p < 0.01$.

Table 6. Correlation of GDP Growth, 8-16 Year Cycle (Lower Triangle) and Trend (Upper Triangle)

	AUT	BEL	DNK	FIN	FRA	DEU	GRC	IRL	ITA	LUX	NLD	PRT	ESP	SWE	GBR
AUT	1	-0.82*	0.56*	-0.78*	-0.52*	-0.77*	0.76*	0.57*	0.00	0.99*	0.11	0.92*	0.44*	-0.25	-0.16
BEL	0.99*	1	0.00	0.96*	0.86*	0.32*	-0.30*	-0.02	0.49*	-0.80*	0.47*	-0.58*	0.12*	0.75*	0.67*
DNK	0.94*	0.95*	1	0.03	0.39*	-0.92*	0.94*	0.99*	0.78*	0.57*	0.88*	0.78*	0.98*	0.66*	0.69*
FIN	0.94*	0.94*	0.94*	1	0.92*	0.22*	-0.23	-0.02	0.60*	-0.78*	0.49*	-0.59*	0.17	0.75*	0.59*
FRA	0.93*	0.93*	0.88*	0.77*	1	-0.14	0.15	0.34*	0.85*	-0.52*	0.74*	-0.27*	0.52*	0.92*	0.77*
DEU	0.95*	0.96*	0.99*	0.92*	0.91*	1	-0.99*	-0.91*	-0.64*	-0.77*	-0.67*	-0.87*	-0.90*	-0.38*	-0.37*
GRC	0.93*	0.90*	0.76*	0.78*	0.91*	0.78*	1	0.93*	0.64*	0.76*	0.68*	0.89*	0.91*	0.41*	0.42*
IRL	0.82*	0.84*	0.85*	0.65*	0.96*	0.88*	0.75*	1	0.73*	0.60*	0.85*	0.81*	0.97*	0.64*	0.70*
ITA	0.84*	0.79*	0.70*	0.61*	0.93*	0.74*	0.93*	0.84*	1	-0.00	0.91*	0.25	0.88*	0.90*	0.78*
LUX	0.87*	0.88*	0.97*	0.84*	0.86*	0.98*	0.67*	0.90*	0.68*	1	0.14	0.94*	0.45*	-0.23	-0.11
NLD	0.97*	0.96*	0.84*	0.88*	0.91*	0.85*	0.98*	0.76*	0.86*	0.73*	1	0.40*	0.91*	0.93*	0.90*
PRT	0.93*	0.91*	0.77*	0.85*	0.84*	0.77*	0.98*	0.66*	0.83*	0.63*	0.99*	1	0.68*	0.08	0.20
ESP	0.87*	0.85*	0.74*	0.65*	0.97*	0.78*	0.94*	0.90*	0.98*	0.72*	0.90*	0.85*	1	0.75*	0.73*
SWE	0.93*	0.90*	0.86*	0.76*	0.99*	0.88*	0.93*	0.92*	0.97*	0.84*	0.91*	0.86*	0.97*	1	0.95*
GBR	0.85*	0.86*	0.93*	0.76*	0.91*	0.95*	0.70*	0.96*	0.76*	0.98*	0.74*	0.63*	0.80*	0.89*	1

Notes: * $p < 0.01$.

Table 7. Correlation of Unemployment, 2-4 Quarter Cycle (Lower Triangle) and 1-2 Year Cycle (Upper Triangle)

	AUT	BEL	DNK	FIN	FRA	DEU	GRC	IRL	ITA	LUX	NLD	PRT	ESP	SWE	GBR
AUT	1	0.14	0.15	0.19	0.27*	-0.26	0.41*	0.45*	-0.34**	0.60*	0.11	-0.23	0.32*	-0.04	0.22
BEL	0.02	1	0.19	0.18	0.52*	0.04	0.05	0.05	0.04	-0.02	0.27*	0.44*	0.21	0.03	0.24
DNK	-0.06	0.16	1	0.36*	0.04	-0.22	0.28*	0.05	0.23	0.13	0.33*	-0.09	0.19	0.01	0.18
FIN	0.07	-0.13	0.05	1	0.31*	0.07	0.17	-0.13	0.25	-0.07	0.16	-0.02	0.17	0.48*	0.10
FRA	0.05	-0.11	0.36	0.01	1	-0.24	0.32*	0.30*	0.12	0.10	-0.07	0.18	0.46*	0.35*	0.59*
DEU	0.04	-0.13	0.16	0.29	0.13	1	-0.20	0.02	0.15	-0.11	0.08	0.32*	-0.04	0.19	-0.29*
GRC	0.11	0.19	0.16	-0.04	0.01	0.15	1	0.22	0.17	0.52*	-0.01	-0.09	0.32*	0.10	0.25
IRL	-0.17	0.34	0.08	-0.02	0.36	0.15	0.25	1	-0.29*	0.43*	-0.24	0.10	0.64*	0.10	0.64*
ITA	-0.11	-0.00	0.02	-0.10	0.10	0.47	-0.10	0.09	1	-0.41*	0.35*	0.11	-0.06	0.38*	0.12
LUX	-0.15	0.26	0.22	-0.29*	0.28*	0.34*	0.15	0.33*	0.37*	1	-0.34*	0.12	0.43*	-0.21	0.16
NLD	-0.11	-0.13	0.08	0.16	-0.07	0.23	-0.07	-0.02	0.10	0.02	1	-0.00	-0.35*	0.10	-0.17
PRT	0.07	0.04	-0.11	-0.22	0.22	-0.16	-0.03	-0.03	-0.22	0.01	0.19	1	0.25	-0.05	0.20
ESP	-0.08	0.15	0.23	0.10	0.25	0.33*	0.24	0.18	0.11	0.28*	0.04	-0.26	1	0.23	0.78*
SWE	-0.03	-0.11	0.36*	-0.05	0.27	-0.07	0.08	0.08	0.19	-0.07	0.02	-0.07	-0.05	1	0.17
GBR	-0.22	0.22	0.27*	0.12	0.19	0.09	0.12	0.22	0.13	0.21	0.02	-0.26	0.31*	0.17	1

Notes: * p < 0.01.

Table 8. Correlation of Unemployment, 2-4 Year Cycle (Lower Triangle) and 4-8 Year Cycle (Upper Triangle)

	AUT	BEL	DNK	FIN	FRA	DEU	GRC	IRL	ITA	LUX	NLD	PRT	ESP	SWE	GBR
AUT	1	0.81*	0.22	0.47*	0.50*	0.81*	0.06	0.07	0.69*	0.81*	0.72*	-0.05	0.45*	0.48*	-0.34*
BEL	0.79*	1	0.10	0.29*	0.57*	0.84*	-0.06	-0.05	0.59*	0.61*	0.52*	-0.18	0.29*	0.24	-0.37*
DNK	0.68*	0.60*	1	0.61*	0.18	0.20	-0.12	0.96*	-0.11	-0.07	0.20	0.31*	0.86*	0.83*	0.78*
FIN	0.77*	0.81*	0.82*	1	-0.13	0.22	-0.63*	0.65*	-0.10	0.26*	0.83*	0.31*	0.71*	0.83*	0.40*
FRA	0.87*	0.84*	0.73*	0.88*	1	0.68*	0.50*	-0.07	0.50*	0.14	-0.06	-0.50*	-0.05	0.03	-0.29*
DEU	0.81*	0.70*	0.34*	0.53*	0.77*	1	0.02	0.01	0.67*	0.57*	0.37*	-0.40*	0.30*	0.42*	-0.39*
GRC	0.24	0.17	0.46*	0.22	0.29*	-0.00	1	-0.29*	0.48*	0.15	-0.45*	-0.16	-0.23	-0.42*	-0.25
IRL	0.85*	0.69*	0.77*	0.86*	0.93*	0.71*	0.25	1	-0.35*	-0.19	0.19	0.51*	0.85*	0.82*	0.90*
ITA	0.64*	0.78*	0.49*	0.54*	0.64*	0.69*	0.42*	0.53*	1	0.85*	0.30*	-0.49*	0.09	0.00	-0.65*
LUX	0.13*	0.40*	0.28*	0.37*	0.38*	0.23	0.09	0.34*	0.16	1	0.67*	-0.09	0.33*	0.22	-0.52*
NLD	0.64*	0.88*	0.60*	0.68*	0.68*	0.58*	0.40*	0.54*	0.80*	0.51*	1	0.14	0.48*	0.55*	-0.12
PRT	0.81*	0.88*	0.68*	0.71*	0.77*	0.75*	0.26	0.66*	0.79*	0.26	0.81*	1	0.47*	0.27	0.62*
ESP	0.83*	0.87*	0.68*	0.81*	0.88*	0.74*	0.25	0.86*	0.74*	0.49*	0.76*	0.78*	1	0.88*	0.60*
SWE	0.89*	0.76*	0.49*	0.63*	0.86*	0.89*	0.06	0.81*	0.68*	0.14	0.53*	0.72*	0.82*	1	0.51*
GBR	0.65*	0.65*	0.74*	0.84*	0.86*	0.51*	0.47*	0.85*	0.53*	0.49*	0.68*	0.54*	0.77*	0.58*	1

Notes: * p < 0.01.

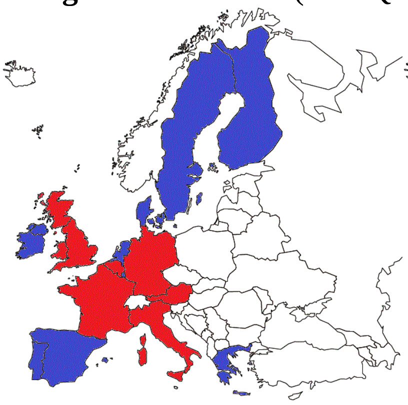
Table 9. Correlation of Unemployment, 8-16 Year Cycle (Lower Triangle) and Trend (Upper Triangle)

	AUT	BEL	DNK	FIN	FRA	DEU	GRC	IRL	ITA	LUX	NLD	PRT	ESP	SWE	GBR
AUT	1	-0.82*	0.56*	-0.78*	-0.52*	-0.77*	0.76*	0.57*	0.00	0.99*	0.11*	0.92*	0.44*	-0.25	-0.16
BEL	0.83*	1	0.00	0.96*	0.86*	0.32*	-0.30*	-0.02	0.49*	-0.80*	0.47*	-0.58*	0.12	0.75*	0.67*
DNK	0.07	0.53*	1	0.03	0.39*	-0.93*	0.94*	0.99*	0.78*	0.57*	0.88*	0.78*	0.98*	0.66*	0.69*
FIN	0.74*	0.89*	0.28*	1	0.92*	0.22	-0.23	-0.02	0.60*	-0.78*	0.49*	-0.59	0.17	0.75*	0.59*
FRA	0.72*	0.97*	0.54*	0.92*	1	-0.14	0.15	0.34*	0.85*	-0.52*	0.74*	-0.27*	0.52*	0.92*	0.77*
DEU	0.97*	0.92*	0.29*	0.76*	0.82*	1	-0.99*	-0.91*	-0.64*	-0.77*	-0.67*	-0.87*	-0.90*	-0.38*	-0.37*
GRC	0.38*	0.16	0.22	-0.23	-0.06	0.41*	1	0.93*	0.64*	0.76*	0.68*	0.89*	0.91*	0.41*	0.42*
IRL	-0.18	0.39*	0.83*	0.35*	0.53*	0.03	-0.35*	1	0.73*	0.60*	0.85*	0.81*	0.97*	0.64*	0.70*
ITA	0.70*	0.42*	0.13	0.10	0.21	0.70*	0.92*	-0.41*	1	-0.00	0.91*	0.25	0.88*	0.90*	0.78*
LUX	0.93*	0.98*	0.36*	0.90*	0.92*	0.97*	0.19	0.20	0.50*	1	0.14	0.94*	0.45*	-0.23	-0.11
NLD	0.88*	0.96*	0.53*	0.79*	0.87*	0.95*	0.39*	0.25	0.63*	0.96*	1	0.40*	0.91*	0.93*	0.90*
PRT	0.34*	0.72*	0.95*	0.41*	0.69*	0.55*	0.37*	0.70*	0.36*	0.57*	0.73*	1	0.68*	0.08	0.20
ESP	0.02	0.55*	0.97*	0.36*	0.61*	0.25*	-0.01	0.94*	-0.07	0.36*	0.48*	0.90*	1	0.75*	0.73*
SWE	0.53*	0.89*	0.62*	0.88*	0.97*	0.66*	-0.23	0.71*	-0.01	0.81*	0.76*	0.70*	0.73*	1	0.95*
GBR	-0.25	0.32*	0.80*	0.30*	0.47*	-0.05	-0.39*	0.99*	-0.47*	0.13	0.18	0.65*	0.91*	0.66*	1

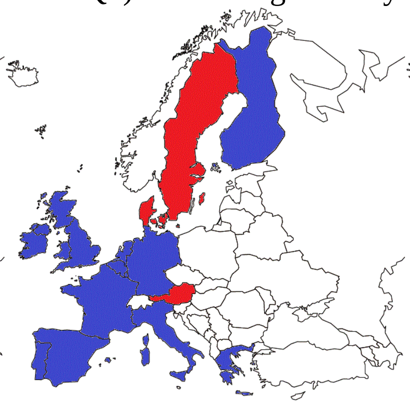
Notes: * p < 0.01.

Appendix C

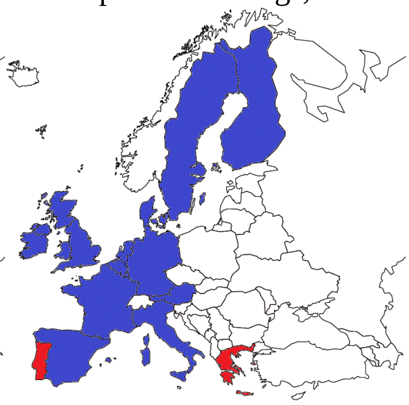
Figure 7. Pre-crisis (1995Q1-2007Q4) real GDP growth cycle component loadings, PC1.



Panel A: 2-4 Quarter cycles



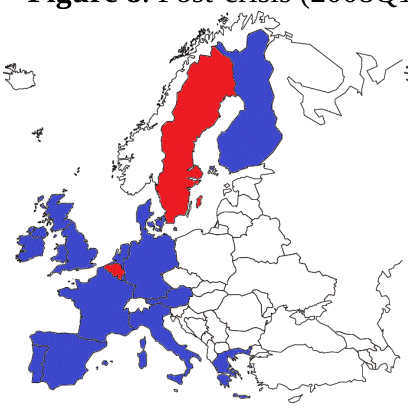
Panel B: 1-2 Year cycles



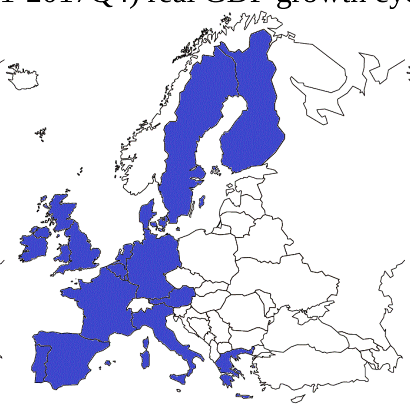
Panel C: 2-4 Year cycles

Panel D: 4-8 Year cycles

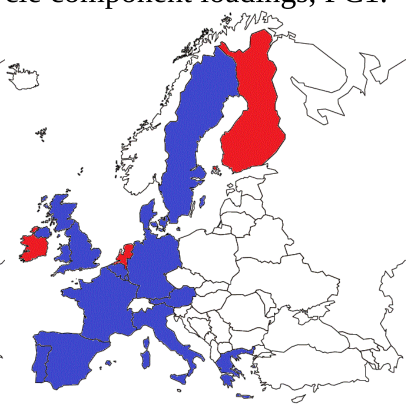
Figure 8. Post-crisis (2008Q1-2017Q4) real GDP growth cycle component loadings, PC1.



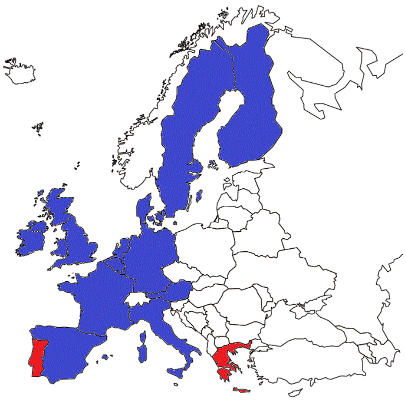
Panel A: 2-4 Quarter cycles



Panel B: 1-2 Year cycles

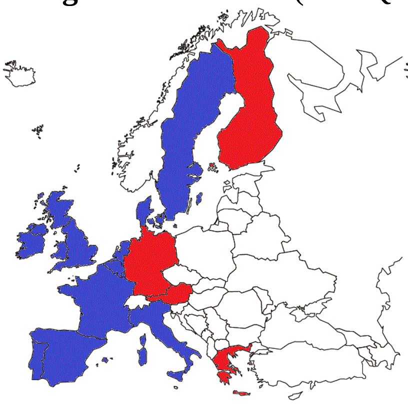


Panel C: 2-4 Year cycles

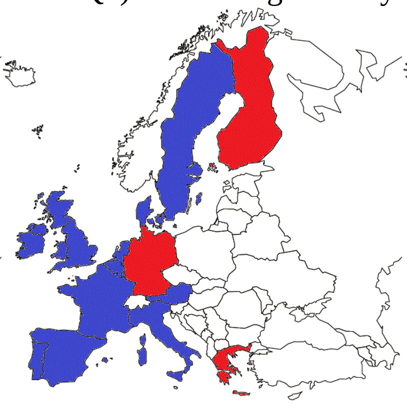


Panel D: 4-8 Year cycles

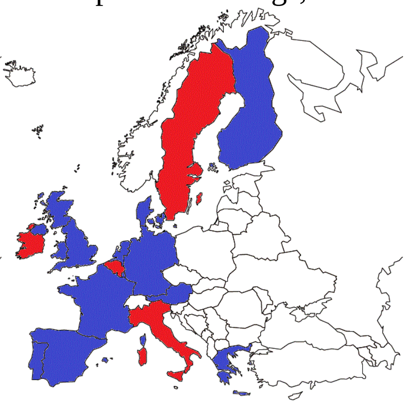
Figure 9. Pre-crisis (1995Q1-2007Q4) real GDP growth cycle component loadings, PC2.



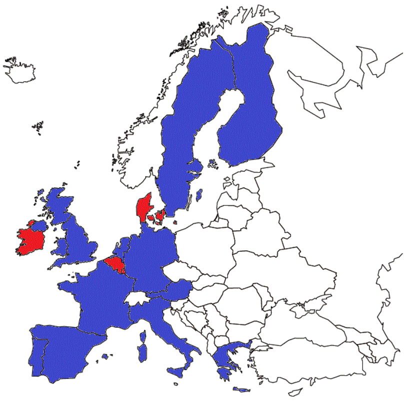
Panel A: 2-4 Quarter cycles



Panel B: 1-2 Year cycles

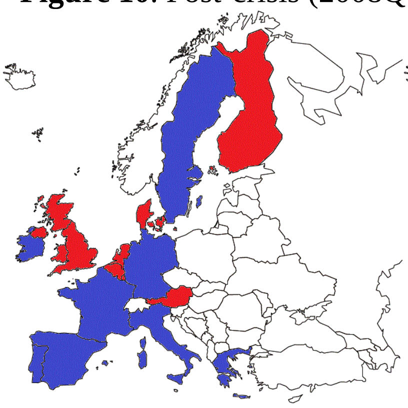


Panel C: 2-4 Year cycles

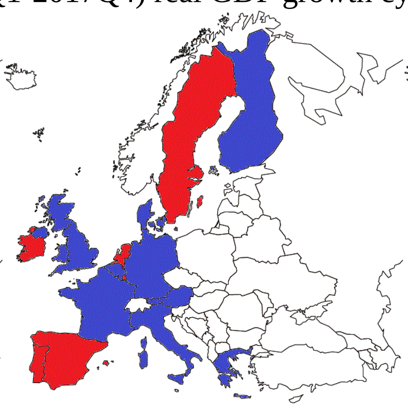


Panel D: 4-8 Year cycles

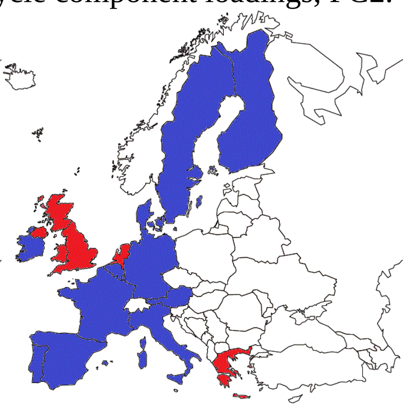
Figure 10. Post-crisis (2008Q1-2017Q4) real GDP growth cycle component loadings, PC2.



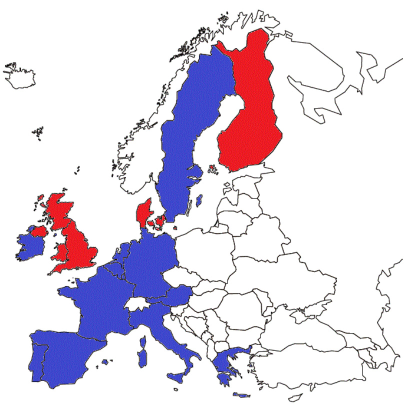
Panel A: 2-4 Quarter cycles



Panel B: 1-2 Year cycles

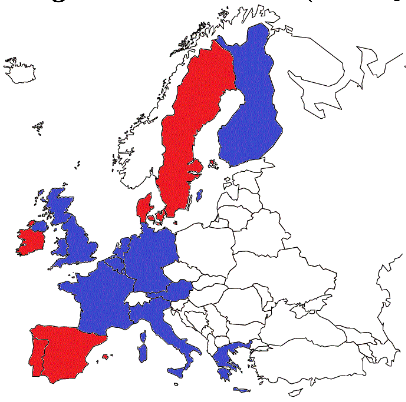


Panel C: 2-4 Year cycles

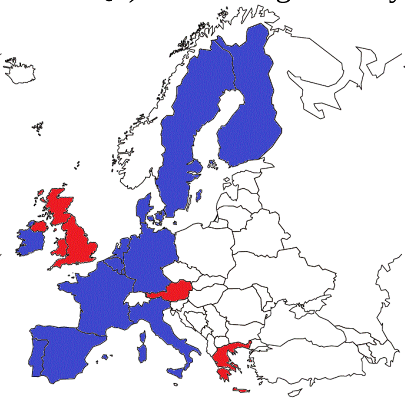


Panel D: 4-8 Year cycles

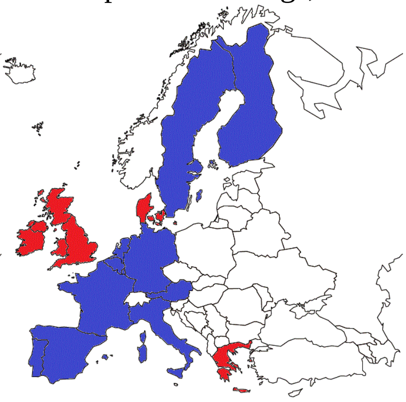
Figure 11. Post-crisis (2010Q1-2007Q4) real GDP growth cycle component loadings, PC1.



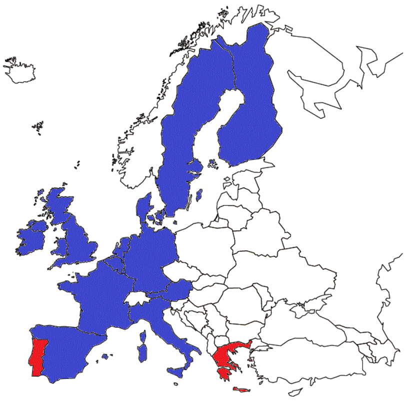
Panel A: 2-4 Quarter cycles



Panel B: 1-2 Year cycles

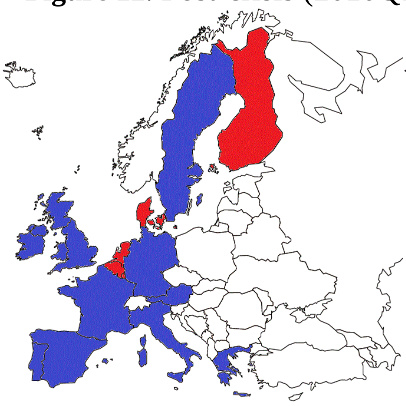


Panel C: 2-4 Year cycles

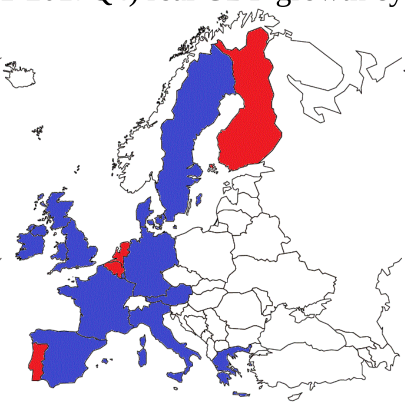


Panel D: 4-8 Year cycles

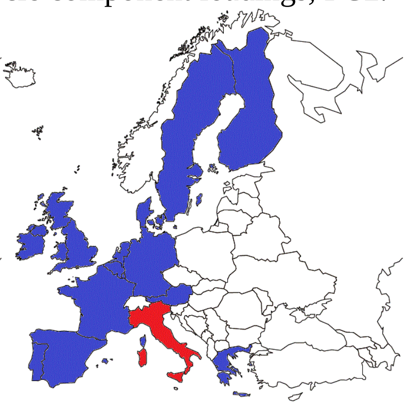
Figure 12. Post-crisis (2010Q1-2017Q4) real GDP growth cycle component loadings, PC2.



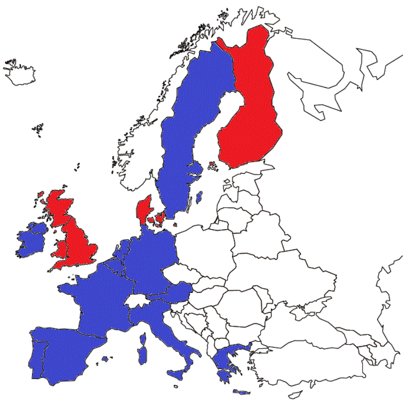
Panel A: 2-4 Quarter cycles



Panel B: 1-2 Year cycles

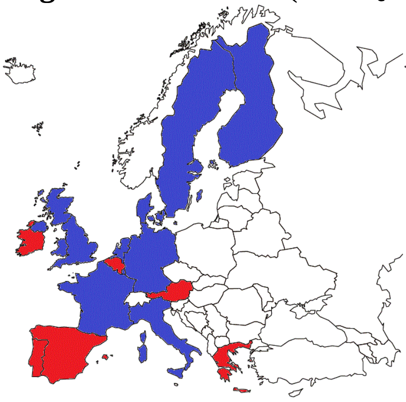


Panel C: 2-4 Year cycles

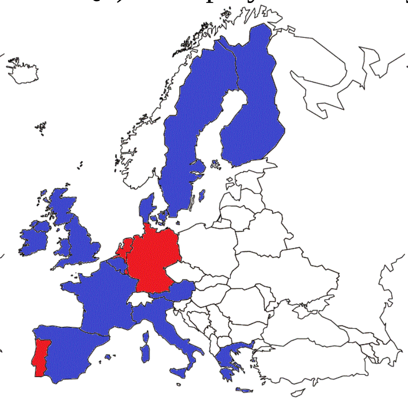


Panel D: 4-8 Year cycles

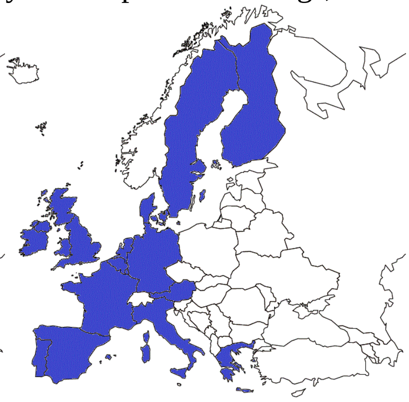
Figure 13. Pre-crisis (1995Q1-2007Q4) unemployment rate cycle component loadings, PC1.



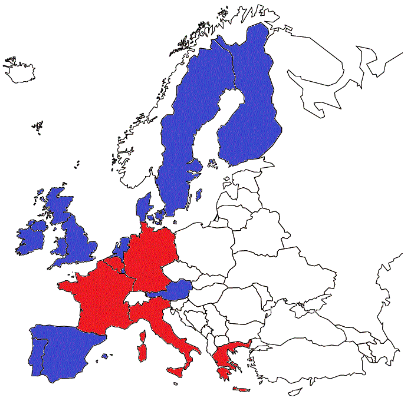
Panel A: 2-4 Quarter cycles



Panel B: 1-2 Year cycles

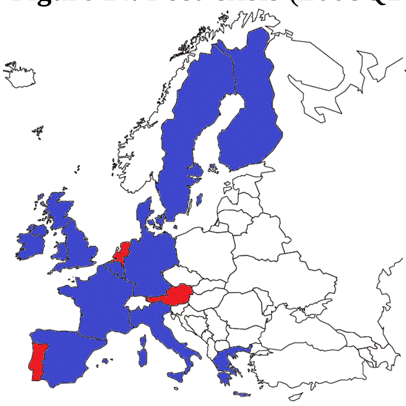


Panel C: 2-4 Year cycles

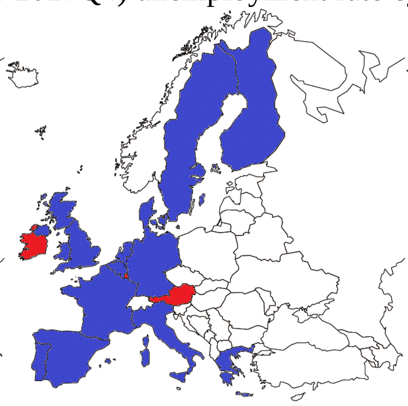


Panel D: 4-8 Year cycles

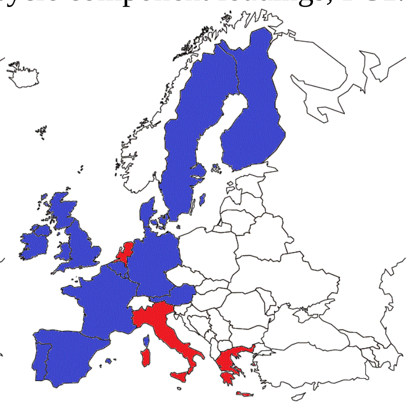
Figure 14. Post-crisis (2008Q1-2017Q4) unemployment rate cycle component loadings, PC1.



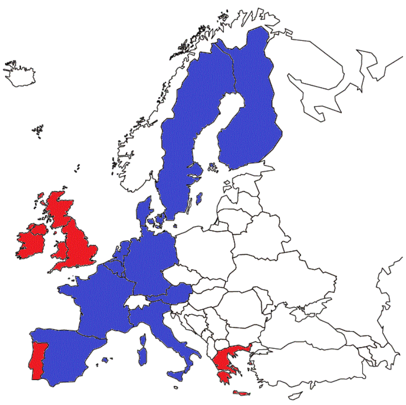
Panel A: 2-4 Quarter cycles



Panel B: 1-2 Year cycles

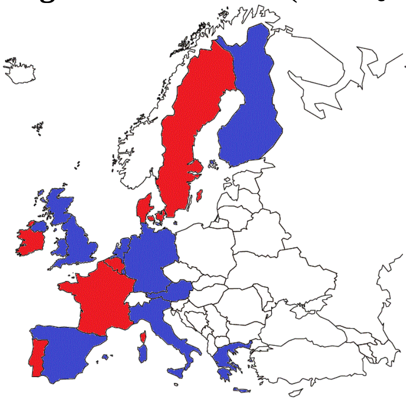


Panel C: 2-4 Year cycles

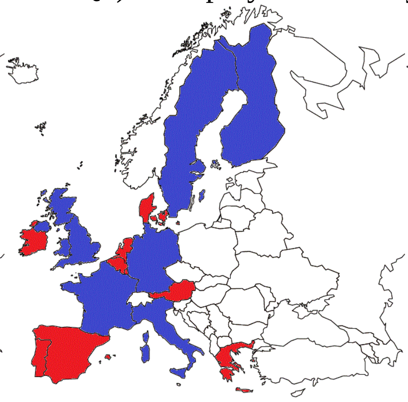


Panel D: 4-8 Year cycles

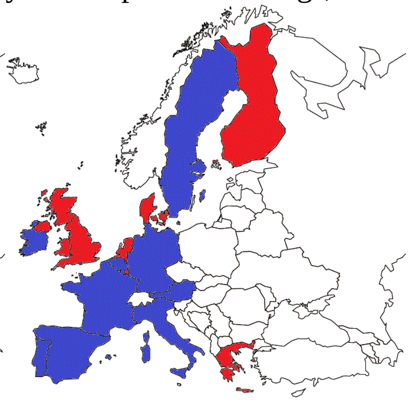
Figure 15. Pre-crisis (1995Q1-2007Q4) unemployment rate cycle component loadings, PC2.



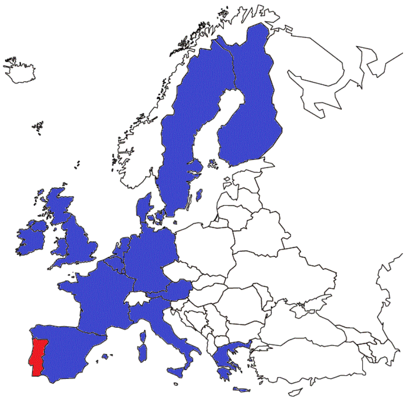
Panel A: 2-4 Quarter cycles



Panel B: 1-2 Year cycles

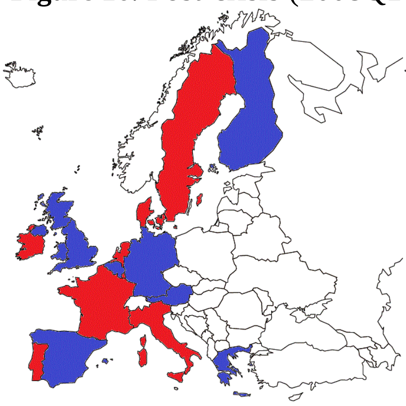


Panel C: 2-4 Year cycles

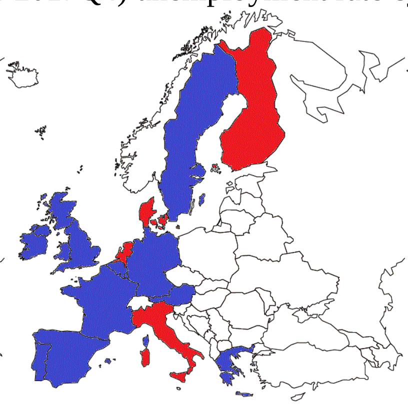


Panel D: 4-8 Year cycles

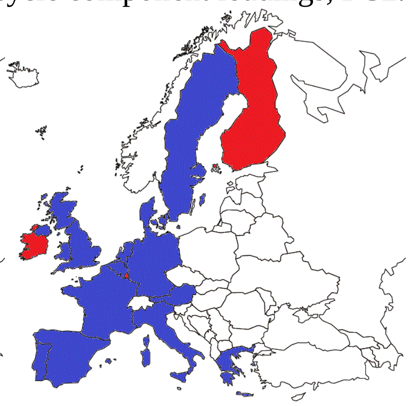
Figure 16. Post-crisis (2008Q1-2017Q4) unemployment rate cycle component loadings, PC2.



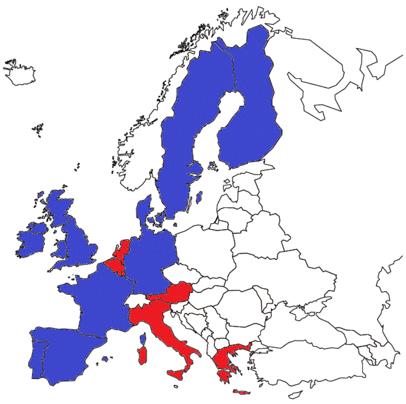
Panel A: 2-4 Quarter cycles



Panel B: 1-2 Year cycles

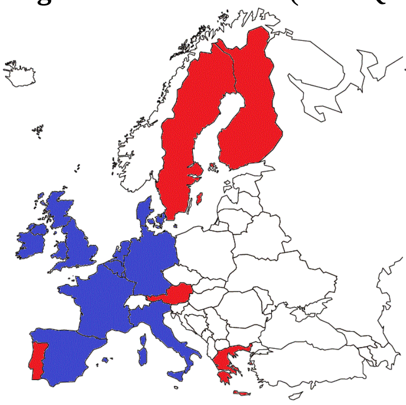


Panel C: 2-4 Year cycles

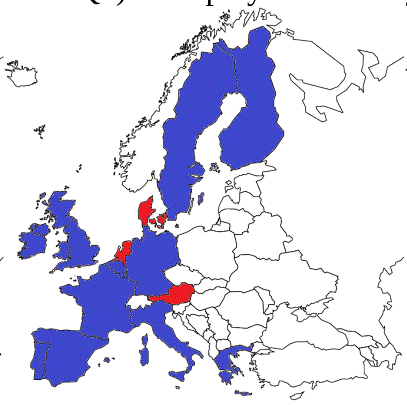


Panel D: 4-8 Year cycles

Figure 17. Post-crisis (2010Q1-2007Q4) unemployment rate cycle component loadings, PC1.

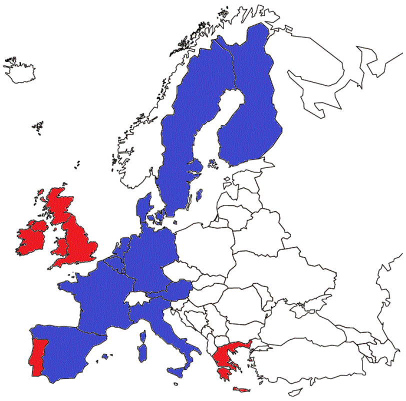


Panel A: 2-4 Quarter cycles



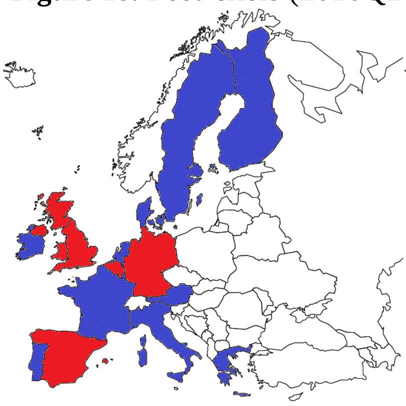
Panel B: 1-2 Year cycles

Panel C: 2-4 Year cycles

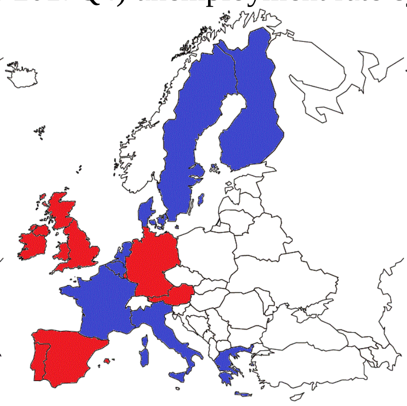


Panel D: 4-8 Year cycles

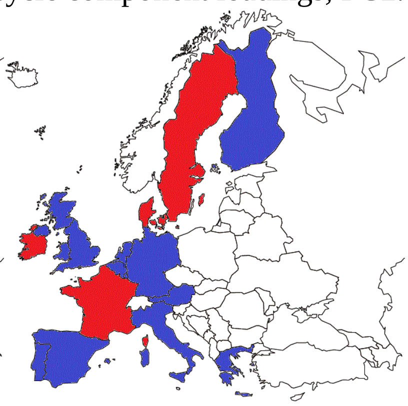
Figure 18. Post-crisis (2010Q1-2017Q4) unemployment rate cycle component loadings, PC2.



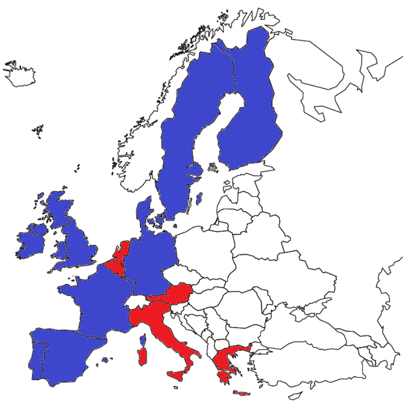
Panel A: 2-4 Quarter cycles



Panel B: 1-2 Year cycles



Panel C: 2-4 Year cycles



Panel D: 4-8 Year cycles