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Eduardo Bandres
María Dolores Gadea-Rivas
Ana Gomez-Loscos

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Regional Business Cycles Across Europe *

Eduardo Bandres †
University of Zaragoza

María Dolores Gadea-Rivas ‡
University of Zaragoza

Ana Gomez-Loscos §
Banco de España

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†Department of Applied Economics, University of Zaragoza. Gran Vía, 4, 50005 Zaragoza (Spain). Tel: +34 9767 61846, fax: +34 976 761840 and e-mail: ebandres@unizar.es

‡Corresponding author: Department of Applied Economics, University of Zaragoza. Gran Vía, 4, 50005 Zaragoza (Spain). Tel: +34 9767 61842, fax: +34 976 761840 and e-mail: lgadea@unizar.es

§Banco de España, Alcalá, 48, 28014 Madrid (Spain). Tel: +34 91 3385817, fax: +34 915310059 and e-mail: agomezloscos@bde.es

Abstract

Large contractionary shocks such as the Great Recession or the sovereign debt crisis in Europe have rekindled interest in analyzing the overall patterns of business cycles. We study these patterns for Europe both at the national and the regional level. We first examine business cycles' comovements and then, using Finite Mixture Markov Models, we obtain a dating of the different business cycles and identify clusters among them. We also propose an index to analyze within-country homogeneity. Our main findings are the following: (i) we find evidence of just one cluster amongst the European countries while, at the regional level, there is more heterogeneity and we identify five different groups of European regions; (ii) the groups are characterized as follows: the first contains most of the Greek regions; groups two and three include, in most cases, regions from Germany (plus a couple of regions from southern European countries in group two and some regions of the core countries in group three); group four is populated mainly by regions belonging to northern European countries; and group five is the largest and is composed of the rest of European regions; (iii) we notice that the degree of homogeneity of regional business cycles within countries is quite different; (iv) we also observe that spatial correlation increased during the convergence process towards the introduction of the euro and has taken a big leap with the Great Recession, both at country and regional level. In fact, comovements among regions have mainly increased during the last decade. These results have important implications for policymakers in the design of convergence policies at the European level and also in the design of fiscal policies to reduce regional disparities at the country level.

JEL classification: C32, E32, R11

Keywords: business cycles, clusters, regions, Finite Mixtures Markov models

1 Introduction

The last period of global economic crisis, known as the Great Recession, was very wealth-costly due to its severity, its duration and the fact that it was worldwide. Indeed, the Great Recession was the most severe global recession during the postwar period.[1] The severity of this episode, along with the subsequent slow pace of recovery[2] has rekindled interest in business cycle analysis.

In Europe, the crisis evolved from a banking system crisis to a sovereign debt crisis,[3] dramatically affecting economic growth and, as a consequence, the labor market. Several eurozone member states were unable to repay or to refinance their government debt or to bail out over-indebted banks under their national supervision schemes and had to resort to external assistance programs.[4] Many European countries also implemented adjusted government expenditure in order to reduce their budget deficits.

While, some years ago, the adoption of a single currency in some European Union countries raised many concerns about the ability of common policies to deal with country- or region-specific shocks, more recently, the Great Recession seems to have produced significant changes in the overall patterns of business cycle synchronization in Europe. The aim of our work is to analyze the evolution of business cycles in Europe in detail. In the first place, we examine the business cycles of European countries and the comovements among countries, obtaining a dating of the business cycle that allows us to identify possible groups (clusters) among them. In the second place, we carry out a similar analysis for European regions.

[1]For instance, the International Monetary Fund (IMF) considers that there have been four global recessions since World War II (in 1975, 1982, 1991 and 2009). In addition to its severity, the Great Recession was highly synchronized, as it affected advanced economies as well as many emerging and developing economies. See IMF (2009).

[2]See Fernald (2014), Summers (2014) and Fischer (2014), among others.

[3]See Lane (2012).

[4]These programs were monitored by the so-called 'troika', which is formed by the European Commission, the European Central Bank and the International Monetary Fund. Countries under the scrutiny of the troika are Greece, Ireland (no longer in the troika program), Portugal and Cyprus. Spain is a different case, as the program focuses only on conditions for the banking sector.

Much effort has already been devoted in the existing literature to country analysis in the study of European business cycles since the beginning of the project of the creation of the euro. Numerous studies have analyzed the business cycles and the synchronization among the countries that make up the European Monetary Union (EMU).[5] However, as far as we know, the impact of the recent crisis and the subsequent slow recovery has not yet been studied.

The regional dimension has been a relevant concern for European institutions since the establishment of the European Economic Community. Regional policy in the European Union (EU), known as the 'Cohesion Policy'[6] targets all regions and cities in the EU in order to diminish regional disparities across regions. In particular, it aims at fostering job creation, business competitiveness, economic growth, sustainable development, and the improvement of the quality of life. To get an idea of its importance, the budget for this policy during the period 2014-2020 is around a third of the total EU budget.[7]

Regarding business cycle analysis, it has to be borne in mind that analyses at the country level may well hide very different regional cyclical developments, as Gadea et al. (2011) find for the Spanish case. Indeed, these authors show that regional cycles within Spain are quite heterogeneous. Within the EU, large regional divergences imply the inadequacy of only applying common policies. Therefore, analyzing regional business cycles is a key question towards the design of good economic policies. Unfortunately, in spite of the importance of studying regional business cycles, the current literature on this issue is relatively scarce.

Of the few existing papers with a focus on the regional dimension, most study the synchronization of short-term fluctuations in economic activity. These studies usually employ very simple methodologies, such as computing correlations of different measures of regional

[5]See, for example, Camacho et al. (2008), Giannone et al. (2010) and De Haan et al. (2008) for a survey.
[6]`http://ec.europa.eu/regional_policy/en/policy/what/investment-policy/`
[7]'Cohesion Policy' is implemented through three main funds: the European Regional Development Fund (ERDF), the Cohesion Fund (CF) and the European Social Fund (ESF). Apart from funds under this regional policy, there are other funds that could also contribute to regional development, such as the European Agricultural Fund for Rural Development (EAFRD) and the European Maritime and Fisheries Fund (EMFF). All five funds together constitute the European Structural and Investment (ESI) Funds.

economic activity with respect to the cycle of the country or of Europe as a whole.[8]

Our analysis contributes to the existing literature in several ways. First, we use GDP as the measure of economic activity and employ a more comprehensive dataset in terms of both the geographical (213 regions belonging to 16 European countries) and temporal (32 years) dimensions than the previous literature. Second, we use a sophisticated methodology that allows us both to date the business cycles of countries or regions and to identify clusters among them. In particular, we use, for the first time in the regional business cycle literature, Finite Mixture Markov Models. Third, we propose a new index to measure within-country homogeneity.

The main findings of the paper are the following. First, in the country analysis, by examining business cycles' comovements, we observe that the spatial correlation has been increasing since the beginning of the EMU period (1999), and received a new impulse with the Great Recession. We identify some similarities in the business cycles of the European countries studied, such as the huge impact of the Great Recession in 2008-2009, a deceleration at the beginning of the nineties and the slowdown in 2001, although each business cycle presents an idiosyncratic behavior. Using Finite Mixture Markov Models, we also find evidence of just one cluster, i.e., a common cycle, at this geographical level. Second, in the regional analysis, when analyzing comovements, we observe that regional growth rates are quite heterogeneous and the spatial correlation is quite low during the whole period. The evolution of the spatial correlation shows a progressive increase during the convergence process towards the creation of the euro area and a steady rise of comovements among regions during the Great Recession.[9] Third, contrary to the country analysis, where we only identify

[8]These studies are not directly comparable as they use different measures of economic activity and different datasets. For instance, Fatas (1997), Barrios and De Lucio (2003) and Belke and Heine (2006) use employment data, while Acedo-Montoya and de Haan (2008), Barrios et al. (2003) use gross value added, and Clark and van Wincoop (2001) rely on both measures of activity. Acedo-Montoya and de Haan (2008) provide a somewhat dated, but useful review. Marino (2013) also analyzes regional GDP and employment fluctuations but from a different perspective, using dynamic factor models. There are other papers that focus on examining regional convergence, such as Ramajo et al. (2008), Quah (1996) and Sala-i-Martin (1996). Finally, Ozyurt and Dees (2015) study the determinants of economic performance, measured by GDP pc, at the regional level.

[9]This finding agrees with that recently obtained by Gadea et al. (2016), where they analyze the evolution

one common cycle across all European countries, we find five different groups of European regions which share different business cycle characteristics. Group one contains most of the Greek regions. Groups two and three include, mainly, German regions (plus a couple of regions from southern European countries in group two and some regions of the core countries in group three). Group four is, mainly, composed of regions belonging to northern European countries. Finally, group five is the largest and is composed of the other European regions. Fourth, the index proposed to analyze within-country homogeneity allows us to observe that the degree of homogeneity of regional business cycles within countries is quite different. Norway, Denmark and Ireland present the highest degree of business cycle homogeneity, in part due to the fact that they are relatively small countries, while the regional business cycles of Germany, Portugal and the UK are quite heterogeneous. If we correct this result by the total number of regions in each country, we obtain different results. Italy (IT), the UK and France (FR) are the countries experiencing the highest degree of internal synchronization, whereas Portugal (PT) and the Netherlands (NL) present a high degree of business cycle heterogeneity.

If we focus on Spain, we observe that all Spanish regions belong to group five. Furthermore, Spain presents quite a high within-country homogeneity despite of its large economic size, meaning that regional business cycles are quite similar.

Valuable lessons can be learned from the study of regions that are not separated by national borders. Carrying out economic policy measures at the national level could bring about undesirable distortions in some regions and slow down their convergence processes, which would be further evidence of the need to apply specific regional economic measures. This issue is particularly important because we have shown that GDP developments are very different across European regions, a fact which should be taken into account when designing appropriate economic policies. We note that, although regional comovements have increased during the last ten years, they are below the national comovements.

of regional business cycle correlation over time.

Macroeconomic stabilization policies, which are primarily related to the cyclical evolution of the economy, are very constrained in the EU by the common monetary policy and the Stability and Growth Pact. Hence, the design of cohesion policies in the EU to increase regional competitiveness and foster economic growth and employment is very relevant. Additionally, in countries in which public revenue and expenditure decisions have a regional dimension, fiscal policy could be used to reduce regional disparities because, if their regional cyclical shapes are different, policy measures at the national level to fight recessions could be too accommodative for some regions and too tight for others.

The remainder of the paper is organized as follows. In Section 2, we conduct a comprehensive literature review on European business cycles, both at the country and at the regional level. In Section 3, we discuss the advantages and drawbacks of the different methods for dating the business cycle and we present, in detail, the Finite Mixture Markov Models methodology used in this paper. In Section 4, we describe the data and report the main results on our paper both for countries and regions and we construct an index to explore within-country regional business cycle homogeneity. The final section concludes.

2 Literature review on European business cycles

In this section, we review the literature on European business cycles. Given that most of the existing papers on business cycle synchronization in Europe focus on the national level, we first summarize the main features of this strand of literature. Then, we focus on papers aimed at analyzing business cycles at the regional level.

2.1 European business cycles. Country-level approach

There are numerous studies which describe the characteristics of business cycles within the euro area (EA) or the European Union (EU) countries. Camacho et al. (2008), Giannone et al. (2010) and De Haan et al. (2008) provide a comprehensive survey of this literature. However, there is a lack of consensus in the available results. Differences in results could be due to differences in geographical coverage,[10] in the temporal dimension, in the methodologies used[11] or even in the economic variables chosen. Hence, it is quite difficult to report results in a synthetic way. Nevertheless, in the following paragraphs, we summarize some of the main results.

A question commonly addressed in the literature was whether the introduction of the euro would contribute to the synchronization of business cycles or, whether, on the contrary, it would reinforce the divergence of business cycles. Many studies have focused on countries' heterogeneity and look at synchronization to identify the degree of comovement. However, there is a lack of consensus on this question.[12] Some authors have investigated the role played by important milestones in Europe such as the Maastricht Treaty or the introduction of the single currency. However, the importance of institutional changes is not clear for the reasons stated at the beginning of this section, particularly the length of the sample used. A popular approach has been to identify whether business cycles in European countries have a global and/or a European component, allowing one or more separate European business cycles to exist.

The results in the literature about the existence of a single European business cycle over a long sample are not conclusive. For instance, some studies identify the emergence of a European cycle in the nineties, some date it back to the seventies, while others do not find it at all. Among the papers that find a single European cycle, Artis and Zhang (1998), in an article prior to the adoption of the euro (their sample spans from 1961 to 1993), show that there is a core group made up of France, Belgium, Austria and the Netherlands, and two peripheral groups comprising northern and southern countries of the EU, respectively.[13]

[10] Most papers do not consider all euro area countries and include either some large European countries (both member and non-member), the G7 or even a larger number of OECD economies.

[11] Specifically, regarding the methods used to estimate the cyclical component, to measure cross-country synchronization or to date the business cycle.

[12] On the one hand, the strengthening of trade relations could lead to a more symmetrical transmission of shocks among countries. On the other hand, as Krugman (1991) argues, economies of scale and scope in a monetary union could lead individual regions to concentrate more on particular industries, which could reinforce the impact of asymmetrical shocks.

[13] Their sample includes the US, Canada, the UK, Finland, Norway, Sweden, Germany, France, Italy, Netherlands, Belgium, Spain, Portugal and Ireland.

They also find evidence of increased synchronicity after 1979 for countries belonging to the Exchange Rate Mechanism (ERM). Lumsdaine and Prasad (2003) examine industrial production indexes for seventeen OECD economies over the period 1963-1994 and identify a clear European business cycle from 1973 to 1994.[14] Artis, Krozlig and Toro (2004) conclude that there is clear evidence of comovement in output growth among nine EA countries, suggesting the existence of a common business cycle. Canova et al. (2008) study the G7 cycle using a multi-country Bayesian panel VAR model with time variation, unit-specific dynamics and cross-country interdependences for the period 1979-2002 and show no European cycle prior to the mid-80s, while a single EU cycle emerges in the 1990s that is common to EA and non-EA countries. Giannone et al. (2010) document the pattern of business cycle correlations by analyzing business cycles for EA12 from 1970-2006 and they identify two groups, core countries (Austria, Belgium, France, Germany, Italy and the Netherlands) and non core countries (Finland, Greece, Ireland, Luxembourg, Portugal and Spain).[15] Kauffman (2003) finds that, for the period 1978-2001, there is a common growth cycle for EA countries and, when the analysis includes Australia, Canada and the US, she observes that, under a long-term perspective, these three countries form one group, while most European countries fall into the other group. Finland and Ireland follow more closely the first rather than the Euorpeab cycle, while the UK and Japan clearly fall into the group of European countries. Nevertheless, this classification varies in shorter term horizons.[16]

Although it is not the aim of our analysis, we should note that some of the previous papers emphasize the link between the US and the EA business cycle [Canova et al. (2005), Del Negro and Otrok (2008) and Giannone et al. (2010)].

With respect to the papers that do not identify a European business cycle, Artis (2003) uses data from 1970 to 2001 and concludes there is no European cycle with a sample of

[14]However, they show that all countries have a strong positive correlation with the common component in international fluctuations, confirming the existence of a ?world business cycle? after 1973.

[15]They also identify that, in neither of the two groups, were business cycle characteristics altered by the inception of the single currency in 1999.

[16]She also shows an increase in synchronization over time in the European countries.

twenty three countries (fifteen of the total are European countries). With a wider focus, Helbling and Bayoumi (2003) find little synchronization across the G7 countries from 1973 to 2001, although there were strong cross-country correlations during recessions. They notice that Germany was more synchronized with Anglo-Saxon countries than with France. In the same line, Camacho et al. (2006) study more than thirty countries [including most European countries and four industrialized economies (Canada, US, Norway and Japan)] for the period 1962-2003 and they reveal that there is no evidence of a European attractor that brings European cycles together. Del Negro and Otrok (2008) examine the evolution of the business cycle for nineteen countries with data from 1970 to 2005 and find no change in average cross-country correlation of EA business cycles for a large set of European countries.

Some papers have also tried to characterize the EA business cycle with a focus on the dating of recessions and expansions of levels of economic activity or on the growth cycle. Kauffman (2003) gets a dating of the grouped EA countries based on Finite Mixture Markov Switching modes. Altissimo, et al. (2001) also provide a business cycle chronology based on the cyclical components. Artis, Krolzig and Toro (2004) propose a dating of the business cycle, both for an index of industrial protection and GDP, and both chronologies appear to be consistent. Artis et al. (2005) date EA turning points with data from 1970 to 2003 and find that the timing of EA cyclical phases is similar to that of the US, as reflected in the National Bureau of Economic Research (NBER) chronology. However, Giannone and Reichlin (2005) show that EA turning points lag behind US ones.

Finally, some papers assess the propagation of shocks across countries on the basis of structural or semi-structural models. Bayoumi and Eichengreen (1992) identify demand and supply shocks, through VAR models, on output growth and inflation for the twelve EA countries from 1960 to 1988. On the basis of these results, they identify a core group (Germany, France, Belgium, the Netherlands and Denmark) whose supply shocks are both smaller and more correlated across neighboring countries and a periphery group (the UK, Italy, Spain, Portugal, Ireland and Greece) with large and weakly correlated shocks. Giannone and Reichlin (2006) study the response of the output growth of EA countries to a EA-wide shock for the 1970-2005 period and find that a large part of business cycles is due to common shocks while idiosyncratic fluctuations are limited, but persistent.

To sum up, this review shows that the literature on the main facts of European business cycles is far from having reached a consensus. Results depend on samples, variables of analysis or methodologies.

2.2 European business cycles. Regional-level approach

The literature on regional business cycles is considerably more limited than that on national business cycles. Moreover, available studies that analyze European regional cycles use different methodologies and datasets, which makes it difficult to compare their results. Tables 1 and 2 summarize the main features of this regional business cycle literature. In the tables, for each paper, we provide the geographical and temporal coverage, the type of variables used, the statistical techniques applied and the main findings.

Most of the literature that has focused on describing overall regional economical patterns among European regions can be divided into two different strands: the first focuses on analyzing the synchronization of regional business cycles (Table 1. Literature review (1)), while the second studies regional convergence (Table 2. Literature review (2)).

The first strand is more directly related to our work than the second. Most of these studies focus on examining synchronization among short-term fluctuations in regional real economic activity. Four types of methodologies are considered: pairwise correlations, dynamic factor models, regime switching approaches and clustering techniques. Most of the regional literature focuses on simple pairwise correlations. Specifically, in most papers, the series are transformed by using, mainly, the Hodrick-Prescott filter[17] and then pairwise correlations are computed based on the filtered data. Different measures of economic activity are used; for example, Fatas (1997), Barrios and De Lucio (2003) and Belke and Heine (2006) use employment data while Acedo-Montoya and de Haan (2008) use gross value added (GVA)

[17]The Christiano-Fitzgerald and the Baxter-King filters are also used.

and Barrios *et al.* (2003) work with GDP series. Finally, Clark and van Wincoop (2001) work with GVA and employment measures of real activity to compare synchronization patterns among European countries and US Census regions. Regarding dynamic factor models, Marino (2013) analyzes regional fluctuations of GDP and employment. With respect to the regime-switching approach, in a recent paper, Gadea et al. (2016) combine regime-switching models and dynamic model averaging to measure time-varying synchronization for GDP.[18] The line that we explore in this paper intends to account for the correlation across states by modeling regional recessions, i.e., following Fruhwirth-Schnatter and Kaufmann (2008), we allow the data to define regional groupings (which, as is standard in the statistical literature, we designate as 'clusters') on the basis of a business cycle dating. Moreover, we employ the most comprehensive measure of real economic activity, that is, real GDP data, as the literature on national business cycle synchronization usually does.

We can observe in Table 1 that the geographical coverage also differs among studies. Many papers deal with a short number of European regions, which are quite aggregated. The nomenclature of territorial units for statistics (NUTS) 2013 classification lists 98 regions at NUTS1 level, 276 regions at NUTS2 level and 1,342 regions at NUTS 3 level in the European Union. Almost all of the regional studies work with the NUTS1 aggregation level. All in all, compared to our paper, most previous studies consider a smaller number of European regions (NUTS1). However, there are two exceptions. One is the recent paper by Gadea et al. (2016) that incorporates the same database as the one used in this paper. The second is the paper by Barrios and de Lucio (2003) that uses regions at the NUTS2 level, although they limit their attention to a sample of 20 regions belonging to Spain and Portugal.

An additional dimension of interest in this literature is the temporal dimension. Unfortunately, the majority of papers in Table 1 consider samples ending before 1999, just prior to the introduction of the euro. Therefore, the subsequent synchronization developments are not considered. There are two exceptions, Acedo-Montoya and de Haan (2008), whose

[18] Applied to the US states, Hamilton and Owyang (2012) develop a framework for inferring common Markov-switching components in a panel data set with large cross-sectional and time-series dimensions.

sample ends in 2005, and Gadea et al. (2016), whose sample finishes in 2011.

In terms of overall coverage, that is, combining the geographical coverage and the temporal dimension, we note that Acedo-Montoya and de Haan (2008) consider 53 regions from 12 countries for the period 1975-2005; Barrios and De Lucio Fernandez (2003) include 20 Iberian regions for a sample spanning from 1988 to 1998; Belke and Heine (2006) work with 30 regions from 6 countries for the period 1989-1996; Fatas (1997) uses 38 regions from 4 countries for a sample covering the 1966-1992 period; and, finally, Marino (2013) employs 107 regions (30 NUTS1 and 77 NUTS2 regions) from 9 countries for a sample spanning from 1977 to 1995.

This literature obtains different results depending on the aim of the paper and they are not easy to compare. However, they seem to agree that, in general, synchronization has increased over time, with some exceptions during some periods. Regional correlations seem to be higher in the US and the UK than among EA regions, although the number of papers investigating this issue is limited. Some of the papers identify a border effect, regions belonging to the same country are more synchronized than regions belonging to different countries. Some papers also identify a role of the productive structure in accounting for synchronization, although results differ across papers, which could be due to differences in the definition of sectors, in the specialization measures, in the database and/or in the techniques.

The main features characterizing the second strand of the European regional literature are summarized in Table 2. These papers have a very different approach as they focus on analyzing regional convergence. Some examples are Ramajo et al. (2008), Quah (1996) and Sala-i-Martin (1996). It can be observed that they consider a very different geographical coverage and a different temporal dimension. They also differ in their techniques and their results, which depend on the initial research question. Finally, there is a paper by Ozyurt and Dees (2015) that identifies the determinants of long-term economic performance at the regional level.

All in all, our paper clearly contributes in several aspects to the previous literature: (i) we employ a comprehensive dataset including all European Union countries. Samples in most studies are much more limited, so it is difficult to conclude whether there are one or several groups of European regional business cycles on the basis of the existing literature; (ii) none of the previous studies dates business cycles and makes groups according to that dating; (iii) we also construct an index of within-country homogeneity, (iv) we determine the main explanatory variables behind our results.

3 Methodology

In this section, we first describe the different non-parametric [Bry and Boschan (1971)] and parametric [Hamilton (1989)] methods available to date the business cycle of individual series. Even though non-parametric methods are very effective for detecting turning points and dating the business cycle, they have the drawback of being mainly descriptive methods and, so, inferences about recession or expansion periods cannot be made. Nevertheless, once the chronology is established, these methods are very useful to describe business cycle characteristics. The most popular alternative method that allows both dating the cycle and making inferences about future periods is the Markov Switching (MS) parametric approach. However, this procedure also has some disadvantages, e.g., it is not very robust and it is very sensitive to changes in variance.[19]

Second, we present the methodological strategy used in this paper, called Finite Mixture Markov Models [Frühwirth-Schnatter (2006)], which has some advantages over other approaches, the main one being that they can be used not only to obtain a business cycle dating but also to identify the number of groups or clusters formed according to their business cycle.

[19] See Gadea et al. (2015) for an illustration of the risks of turning a blind eye to volatility when carrying out a business cycle dating using the classical Markov Switching model.

3.1 Methods for dating the business cycle of individual series

The seminal work of Burns and Mitchell (1946) paved the way for methods to measure the business cycle. These authors define the cycle as a pattern in the level of aggregate economic activity and describe it through a two-stage methodology. First, turning points of a series are located by using graphical methods, thereby defining specific cycles. Second, the specific cycle information is distilled into a single set of turning points that identify the reference cycle. These authors also define concepts such as peak (the highest point of an expansion) and trough (the worst moment in a recession period) to determine the cycle length. These terms became standard in any analysis about business cycles undertaken after the publication of that work.

Their approach has important advantages for academics and policymakers because of the ease of computing algorithms to establish the dates at which there were turning points in the business cycle, and because of the intuitive interpretation of the results. Their aggregate cycle was called the business cycle, and their tools were immediately used by the National Bureau of Economic Research (NBER) to study US business cycles in greater depth and, afterwards, became a reference for the study of business cycles in other economies. Nowadays, the NBER continues to publish a single set of turning points for the US economy, updating the series since 1854.

This pioneering work generated a great deal of literature in which the level of sophistication of the statistical tools, but not the definition of the business cycles, evolved a great deal. Bry and Boschan (1971) (BB) developed the most popular non-parametric method to determine when the peaks and troughs, which frame economic recessions or expansions, appear. This algorithm works by looking for local minimums and maximums in a time series and has its own systems of smoothing and controlling the alternation of peaks and troughs. Its main advantage is its robustness against outliers and against changes in volatility, but it has two main drawbacks: it does not allow inferences or predictions to be made.

In the last few decades, many alternative procedures have been suggested. Among them, the Markov-switching (MS) approach proposed by Hamilton (1989) stands out.[20] Unlike the BB method, the MS first fits a statistical model to the data and then uses the estimated parameters to determine the turning points of a series. Since the well-known paper of Hamilton (1989), there have been several papers that use this method as an alternative to classical business cycle measures.[21] The MS models try to characterize the evolution of a variable through a process of a mean conditioned to a state of a specific nature. The changes in value in this dynamic process allow us to differentiate periods of expansions and contractions. Regime shifts are governed by a stochastic and unobservable variable which follows a Markov chain. In general, we consider the following process for the growth of the GDP, computed as the first difference of its log:

$$y_t = \mu_{S_j} + \epsilon_t \tag{1}$$

where y_t is GDP growth rate, μ_{S_j} is the vector of MS intercepts and $\epsilon_t/_{S_j}$ ~N(0, σ). It is standard to assume that these varying parameters depend on an unobservable state variable S_j that evolves according to an irreducible m-state Markov process where p_{ij} controls the probability of a switch from state j to state i.

In this framework, a MS model with 2 states ($j = 1, 2$) and a constant variance for the full period is defined as:

$$\begin{aligned} y_t &= \mu_1 + \epsilon_t \text{ for state 1} \\ y_t &= \mu_2 + \epsilon_t \text{ for state 2} \end{aligned} \tag{2}$$

Assuming a classical cycle, μ_1 and μ_2 are associated with expansion and recession phases, respectively, and $p_{11} = p$ and $p_{22} = q$ represent the probability of being in expansion or recession, respectively, and remaining in the same state. $p_{12} = p$ denotes the probability

[20]See Harding and Pagan (2002 and 2003) and Hamilton (2003) for a debate about the two business cycle dating methods. For a comparison of different business cycle dating methods, see Layton and Katsuura (2001) and Chauvet and Piger (2008).

[21]Krolzig (1997), Artis *et al.* (2004) and Krolzig and Toro (2005), amongst others, have highlighted the ability of this parametric approach to capture stylized business cycle features. MS-VAR models offer more robust statistical tools.

of switching from recession to expansion and $p_{21} = p$ is the probability of switching from expansion to recession

3.2 Dating and clustering business cycles

The main aims of this paper are to establish a regional business cycle dating chronology for the European regions (and countries) and to identify clusters of regions (and countries) that share common features. To do this, we apply an alternative methodological approach: Finite Mixture Markov Models [see Frühwirth-Schnatter (2006) for a detailed revision].

The use of this methodological framework has an advantage over the previous literature in that it not only allows us to obtain a dating of the turning points of the business cycle of the economic units (countries or regions), but also to investigate a broad set of issues. For instance, to find out whether there is a common growth cycle for the European regions (countries) or if, on the contrary, there are several different growth cycles and to identify which regions (countries) belong to each group. We can also determine whether the degree of synchronization within each group has changed over time.

The idea underlying this approach is that we can model the random variable y_t as a mixture of univariate normal distributions, each of them representing the characteristics and distribution of each business cycle that underlies GDP growth.

The Finite Markov Mixture Models combine clustering techniques, finite mixtures and Bayesian approaches, which lead to a rich class of non-linear models.[22] Hence, they are a good choice when the unobservable latent indicator that drives the process is a Markov chain. These models are often used for the purpose of clustering. This approach assumes the existence of K hidden groups and intends to reconstruct them by fitting a K component mixture density. The time series $\{y_1, ..., y_t\}$ is assumed to be a realization of a stochastic process Y_t generated by a finite Markov mixture from a specific distribution family:

$$Y_t | S_t \sim \Upsilon(\theta_{S_t}) \tag{3}$$

[22] Some applications of these techniques to the analysis of the business cycle can be found in Frühwirth-Schnatter and Kaufmann (2008) and Hamilton and Owyang (2012).

Y is said to arise from a finite mixture distribution if the probability density function $p(y)$ of this distribution takes the form of a mixture density for all $y \in Y$

$$p(y) = \eta_1 p_1(y) + ... + \eta_K p_K(y) \tag{4}$$

where S_t is an unobservable K-states ergodic Markov chain, and the random variables Y_1,...,Y_T are stochastically independent, conditional on knowing S_T. For each $t \succeq 1$, the distribution of Y_t arises from one of K distributions $\Upsilon(\theta_1), ..., \Upsilon(\theta_K)$, depending on the state of S_t

$$Y_t | S_t = k \sim \Upsilon(\theta_k) \tag{5}$$

The stochastic properties of S_t are described by the KxK transition matrix ξ where

$$\xi_{jk} = P(S_t = k | S_{t-1} = j), \forall\ j, k \in \{1, ..., K\} \tag{6}$$

For the double stochastic process $\{S_t, Y_t\}_{t=1}^{T}$, the marginal distribution of Y_t is

$$p(y_t|\varphi) = \sum_{k=1}^{K} p(y_t|S_t = k, \varphi) p(S_t = k|\varphi) \tag{7}$$

with $\varphi = (\theta_1, ..., \theta_k, \eta)$. Because S_t is a stationary Markov chain, we can obtain the unconditional distribution of Y_t as a finite mixture of $\Upsilon(\theta)$

$$p(y_t|\varphi) = \sum_{k=1}^{K} p(y_t|\theta_k)\eta_k \tag{8}$$

In our case, the units are formed by the GDP growth rates of countries or regions. So, we have $\{y_{it}\}$, being $t = 1, ..., T$ the time series observed for N units, $i = 1, ..., N$. Following Frühwirth-Schnatter and Kaufmann (2008), we can formulate a time series model for each univariate time series y_i=$\{y_{i1}$,...,$y_{iT}\}$ in terms of sampling density $p(y_{it}|\varphi)$. We assume that the N time series arise from K groups, whereby within each group, say k, we can apply the same econometric model for all time series it contains and use it for inference and forecasting. Summing up, we can pool all time series within the cluster.

We apply clustering based on finite mixtures of dynamic regression models. The idea is to pool time series to obtain posterior inferences but without being necessary an overall pooling within clusters. Hence, this methodology benefits from the robustness of time series techniques in the panel when estimating the coefficient of an individual time series. This means that, within a panel of time series, only those that display similar dynamic properties are pooled to estimate the parameters of the data generating process. That is, the appropriate grouping is estimated along with the model parameters, rather than forming groups before estimation. This is achieved within the Bayesian framework by applying Markov Chain Monte Carlo (MCMC) and data augmentation methods to estimate the posterior probabilities.[23] The whole process follows various steps:

1. Define a latent group indicator S_i for each time series y_i, which takes a value out of the discrete set $1, ..., K$, indicating the group to which the time series belongs and defining the unit-specific parameters $p(y_i|\varphi - S_i)$. We also assume that $P(S_i = k)$ is equal to the relative size η_k of group k.

2. The model is specified as follows:

$$y_{it} = \mu_k^G + \delta_{1,k}^G y_{i,t-1} + ... + \delta_{p,k}^G y_{i,t-p} + (I_{kt} - 1)(\mu_K^R + \delta_{1,k}^R y_{i,t-1} + ... + \delta_{p,k}^R y_{i,t-p}) + \epsilon_{it} \quad (9)$$

   where y_{it} represents the GDP growth rate of unit i (country or region) in time t, k is the state and p the order of autogressive dynamics. Note that this model allows for autorregresive dynamics in the means in contrast to the classical Hamilton (1989) Markov Switching model. Therefore, μ_k^G and $\delta_{j,k}^G$ for j=1...p are the group-specific effects and μ_k^R and $\delta_{j,k}^R$ the state-specific effects. The group indicator is defined as $S_i = k$ with $k = 1...K$. Periods of expansion (also called above-average growth periods) are denoted by $I_{kt} = 1$ with conditional growth rate μ_k^G and periods of recession (also called below-average growth periods) are denoted by $I_{kt} = 0$ with conditional growth rate $\mu_k^G - \mu_k^R$. We consider that the autoregressive dynamics is different for each

[23]We have followed the approach of Frühwirth-Schnatter and Kaufmann (2008).

group, thus $\delta^G_{j,k}$ and $\delta^G_{j,k} - \delta^R_{j,k}$, $j = 1, ...p$. Denoting the full set of parameters by θ, we estimate K, the number of states of the hidden Markov chain, the state-specific and group-specific parameters, the transition matrix $\xi_{k,jj}$ and the size of each group: $\varphi = (\theta, \eta, \xi)$. Disturbance terms have unit-specific variances $\epsilon_{it} \sim N(0, \sigma_i)$.

3. We use independent priors with the hyperparameters recommended by Frühwirth-Schnatter and Kaufmann (2008):[24]

   - $\eta_1, ..., \eta_k \sim D(1, ...1)$
   - $\sigma^2 \sim G^{-1}(1, 1)$
   - $\xi_{k,jj} \sim B(3, 1), j = 1, 2$
   - $mu^G_k \sim N(0, 4)$ y $c^G_k - c^R_k \sim N(0, 4)$
   - $\delta^G_{l,k} \sim N(0, 1)$
   - $\delta^G_{l,k} - \delta^R_{l,k} \sim N(0, 1)$
   - $l = 1, ..., p$, for $k = 1, ..., K$.

   where D denotes a *Dirichlet* distribution; G, a *Gamma* distribution; and B, a *Beta* distribution.

4. We use a Bayesian approach with Markov Chain Monte Carlo methods and Gibbs Sampling to estimate the posterior probability $p(\varphi|S, y)$. For estimation purposes, 5,000 draws and non-informative priors are considered.[25] The estimation process is carried out by iterating in three steps:

   - Classification of the fixed parameters
   - Estimation of the fixed classification

[24] For a more detailed discussion about priors selection in finite mixtures and Markov Switching models, see Frühwirth-Schnatter (2006).

[25] All the calculations have been done using the Matlab Toolbox provided by Frühwirth-Schnatter (2008) and the specific codes that Silvia Kaufmann kindly shared.

- Simulating the Markov chain I_k and the transition matrices ξ_k in each group

5. The number of components, K, can be selected by informal methods, such as the point process representation, or according to maximum likelihood. We apply three different criteria to estimate the likelihood function: importance sampling, bridge sampling and reciprocal sampling.[26]

6. The last issue of this approach is identification. In this regard, we use the combination of two restrictions. The first one identifies states by $\mu_K^R > 0$, $\forall K$ to ensure that $\mu_K^G > \mu_K^G - \mu_K^R$, that is, the mean in expansion is above the mean in recession. The second identifies states within each group. In this case, different groups of parameters can be used. This empirical strategy consists of trying the following three alternatives of identification: either $\delta_G(1) < \delta_G(2) < ... < \delta_G(K)$, $\mu_R(1) < \mu_R(2) > ... < \mu_R(K)$ or $\mu_G(1) > \mu_G(2) > ... > \mu_G(K)$. The combination of the two restrictions yield three possible clusters. Then, we select the most suitable clustering according to a visual inspection of scatterplots and the ability of the identified model to separate groups unequivocably. The aim is to get the largest possible number of units within on group or another. The units are placed in a group according to their probability, computed using expression 8, which has to be above 0.5%.

4 Business cycles across Europe

4.1 Data

Business cycle analysis is usually carried out using quarterly data. Nevertheless, the availability of regional data on a high frequency basis and for a long span is scarce. Therefore, to analyze the synchronization of regional business cycles we employ annual real GDP data,

[26] Empirical evidence shows that, in general, bridge sampling performs better than the other techniques. For a detailed discussion about the different ways to construct marginal likelihood, see Frühwirth-Schnatter (2006).

as quarterly data are not available.[27] It has to be acknowledged that annual data could be even more reliable to establish robust facts on real economic activity in spite of the loss of information on short-term dynamics.

The nomenclature of territorial units for statistics (NUTS) provides a single, uniform breakdown of the economic territory of the European Union. Indeed, NUTS is the territorial breakdown for compiling regional accounts. We use the NUTS 2013 classification[28] which lists 98 regions at NUTS1 level, 276 regions at NUTS2 level and 1,342 regions at NUTS 3 level. Although socioeconomic analysis of regions is made up to NUTS3 level, the regions eligible for support from the Cohesion Policy are defined at NUTS 2 level.[29]

The European Union (EU) comprises 28 member states, of which 19 belong to the euro area (Austria, Belgium, Cyprus, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Greece, Latvia, Luxembourg, Malta, The Netherlands, Portugal, Slovenia, Slovakia and Spain). There are also 7 non-euro area member states (Bulgaria, Czech Republic, Croatia, Hungary, Poland, Romania and Sweden) and 2 member states with an opt-out option (Denmark and the UK).[30]

In this study, in order to have a balanced dataset, we consider 213 NUTS-2 regions corresponding to 16 European countries, namely, the 12 Euro area (EA12) member states [Austria (AT), Belgium (BE), Finland (FI), France (FR), Germany (DE), Ireland (IE), Italy (IT), Luxembourg (LU), the Netherlands (NL), Portugal (PT), Spain (ES) and Greece (EL)], three EU member states [Denmark (DK), Sweden (SE) and the UK (UK)] and Norway (NO), which is not a member state of the EU. Regarding Germany, prior to 1991, the regional and national data do not include the eastern Landers and Berlin.[31] However, from 1991 onwards, they are included and incorporated into the national total. See Appendix 1 for a list of regions, countries and corresponding codes used in the empirical analysis.

[27]Even if available, quarterly data are short series, not homogeneous accross countries and, generally, artificially constructed by interpolating annual data.

[28]This classification is valid from January 1st 2015.

[29]More details in `http://ec.europa.eu/eurostat/web/nuts/overview`.

[30]See `http://ec.europa.eu/economy_finance/euro/adoption/euro_area/index_en.htm` for details.

[31]In particular, the six following regions: DE3, DE4, DE8, DED, DEE and DEG.

The series cover a period of 32 years, from 1980 to 2011. Thus, we analyze, for the first time, the possible effect of the Great Recession on the regional business cycle of the European countries.[32] Although this dataset is the most comprehensive in terms of regional coverage compared to previous literature, we have sacrificed an even wider range of regions (of those countries that do not have data from the eighties) in order to cover longer series to properly capture business cycles.

The source of the data is the Cambridge Econometrics database, which is mainly based on Eurostat's REGIO database and supplemented with data from AMECO, a dataset provided by the European Commission's Directorate General of Economic and Financial Affairs (DG EcFin).[33] This database does not include extraregio territories, which are made up of parts of the economic territory of a country which cannot be attached directly to a single region.[34]

In order to provide robustness to our results, we have replicated our analysis using GDP data on NUTS-2 level regions from a Eurostat database. However, these results are not directly comparable as this dataset has several limitations with respect to the previous one: (i) nominal data (millions of euros), instead of real ones; (ii) shorter sample size (1995-2011);[35] (iii) less coverage, it consists of 134 regions belonging to 14 European countries.[36]

4.2 Countries. A first picture of European business cycles

Before studying the European business cycles at the regional level, we analyze the national cycles to see whether some general patterns can be identified. We first examine the evolution of country GDP growth rates. Data of the growth rates, calculated as the first logarithmic

[32] However, as the sample ends in 2011, we have difficulties in capturing the latest recovery.

[33] The GDP series is already deflated to 2005 constant price euros using deflators obtained from AMECO.

[34] The extraregio territory consists of, among others, national air-space, territorial waters and the continental shelf lying in international waters over which the country enjoys exclusive rights; territorial enclaves, embassies, consulates, military and scientific bases; deposits of energy and natural resources outside the continental shelf of the country, worked by resident units.

[35] Additionally, the introduction of the European System of National and Regional Accounts (ESA 2010) in September 2014 made data transmission in the context of ESA 1995 no longer mandatory for member states for years before 2000 and several of them made use of this provision. So, it should be generally assumed that there is a break in this series between 1999 and 2000.

[36] Although the original sample was 18 countries and 209 regions, regions with missing data and extraregio territories have been removed because they provoke outliers. These results are available upon request.

difference, are displayed in Figure 1. We observe some similarities in the business cycles of the European countries, such as the huge impact of the Great Recession in 2008-2009, a deceleration at the beginning of the nineties or the slowdown in 2001. However, all countries exhibit some idyosincratic behavior, with differences in the duration and depth of recession phases and also in the duration and speed of growth of recoveries.

The boxplot of these growth rates is displayed in Figure 2, which divide the dataset into quartiles and offer information about the minimum and maximum value of each series, as well as their outliers.[37] We find that Ireland (IE) and Luxembourg (LU) are the countries that have registered the highest growth rates during the whole period considered, followed by Finland (FI) and Spain (ES). On the contrary, the countries with the lowest growth rates were Italy (IT) and Belgium (BE). Regarding volatility, Luxembourg (LU) and Ireland (IE) also show the highest variances, together with Greece (EL), although the latter presents a lower growth rate. Meanwhile, France (FR) and the UK (UK) stand out because of their low variability. Finland (FI) is the country that presents the higher number of outliers whereas, in most of the remaining countries only one outlier is detected.

The analysis of comovements completes this preliminary description section. The top of Figure 3 displays GDP growth rates for each country (blue lines) together with the median and quantiles 25 and 75 of the sample (red lines). Although the inter-country dispersion of business cycles is high, when we focus on the red lines, we are able to distinguish quite a common cyclical pattern. Two cyclical events are observed. On the one hand, the deceleration of the beginning of the nineties and, on the other hand, and more clearly, the huge decline in the median output growth rates at the time of the Great Recession.

In order to analyze how the series move together over the sample and, specifically, if

[37]The body of the boxplot is represented by a blue box, which goes from the first quartile (25% of the data below this value) to the third quartile (25% of the data above this value) and the red line inside the box represents the median (50% of the data is greater than that value, that is, it is the middle of the dataset). Two horizontal lines, in dotted lines, named whiskers, extend from the upper side and the lower side of the box. The upper whisker goes from the first quartile to the smallest non-outlier in the dataset (it represents the minimum, that is, the lowest value excluding outliers) and the lower whisker goes from the third quartile to the largest non-outlier of the sample (that is, it is the maximum, the highest value excluding outliers). Outliers are plotted separately as red crosses on the chart.

comovements have intensified during the Great Recession, we compute Moran's modified statistic, following Stock and Watson (2010), which summarizes the possible time-varying comovements among GDP growth rates.

The measure proposed by Stock and Watson (2010) is based on Moran's spatial correlation index and captures the comovements over time across all the countries through the rolling cross-correlation logarithmic growth rates. It has the following expression:

$$\begin{aligned} &\widehat{I}_i = \frac{\sum_{j=1}^{N}\sum_{j=1}^{i-1}\widehat{cov(y_{it},y_{jt})}/N(N-1)/2}{\sum_{i=1}^{N}\widehat{var(y_{it})}/N} \\ &\widehat{cov(y_{it},y_{jt})} = \frac{1}{k}\sum_{s=t-12}^{t+10}(y_{is}-\overline{y_{it}})(y_{js}-\overline{y_{jt}}) \\ &\widehat{var(y_{it})} = \frac{1}{k}\sum_{s=t-int(k/2)}^{t+int(k/2)}(y_{is}-\overline{y_{it}})^2 \\ &\overline{y_{it}} = \frac{1}{k}\sum_{s=t-int(k/2)}^{t+int(k/2)} y_{is} \end{aligned} \tag{10}$$

where y_{it} is the real GDP growth of region i in time t, k is the rolling window and N=16.

The outcome, time series $\widehat{I}_t$, with k=5[38] is plotted at the bottom of Figure 3. We observe that the synchronization of comovements is around 0.5, on average, and quite volatile throughout the period. Comovements increased after the mid-nineties and sharply decreased in 1999. However, this index also confirms that spatial correlation has been increasing since the beginning of the European Monetary Union period (1999). This trend continued during the Great Recession, when it received a new impulse.

Finally, we apply the Finite Mixture Markov Models methodology, described in the previous section, in order to identify the business cycle dating of European countries and to find out into how many clusters these cycles can be classified. To select the best model, we estimate the likelihood function applying three different criteria: importance sampling, bridge sampling and reciprocal sampling. Results in Table 3 show that the likelihood (using bridge sampling criteria) is maximum in two models: the first one allows for two groups and includes four lags (i.e., K=2 and p=4) and the second one considers four groups and incorporates four lags (i.e., K=4 and p=4). Using importance or reciprocal sampling methods to

[38]Higher values of k yield similar conclusions but with a softer pattern.

compute marginal likelihood, the choices would be a group and four lags (K=1 and p=4), two groups and two lags (K=2 and p=2) and four groups and one lag (K=4 and p=1).

To identify the most suitable classification, we present the scatterplots of the Markov Chain Monte Carlo draws and the probabilities of the regions being in each group. We observe that the scatterplots of the Markov Chain Monte Carlo draws for the K=2 and K=4 grouping and the K=4 and p=4 grouping do not reflect a clear distinction of groups (see Figures 5 and 6), which is also evident in the probabilities of belonging to each group (see Figures 7 and 8). We also display the scatterplot corresponding to the model K=1 and p=4, see Figure 4.

Taking into account both pieces of information, and given the impossibility of identifying which countries would belong to each group if there is more than one, we select the model which pools all the countries into one group (that is, K=1 and p=4), meaning that there is just one single business cycle across the sixteen European countries under analysis. The details of the posterior estimation of the model parameters are available in Table 4. We observe that the two states specification is significant as $\mu^G_{S_i}$ and $\mu^G_{S_i} - \mu^R_{S_i}$ are significantly different from zero. It should be noted that, due to the standardization, the coefficients $\mu^G_{S_i}$ and $\mu^G_{S_i} - \mu^R_{S_i}$ are not directly interpretable as yearly growth rates. They represent above-average and below-average periods with respect to the mean. We distinguish an expansionary cycle, with an average growth of 0.52%, and a recessionary cycle with a mean contraction of -2.02% (0.52-2.56).

The probabilities of recession and the chronology of cyclical phases appear in Figures 9 and 10, respectively. In particular, Figure 9 allows us to identify three recessionary periods ($I_t = 0$), namely, the crisis at the beginning of the nineties, the deceleration of 2001 and the Great Recession, in chronological order. This business cycle dating is shown in Figure 10, where the top chart shows 1993, 2001 and 2008-2009 as recessionary phases. The Euro Area Business Cycle (EABC) Dating Committee of the Centre for Economic Policy Research

(CEPR)[39] identifies just two recessions in this sample: 1992.2-1993.2 and 2008.2-2009.2.[40] Both chronologies are quite close. Nevertheless, we identify a deceleration at the beginning of the noughties which does not appear in the official dating. This episode was not so clear, as shown by the probability of being in recession, which is only slightly above 0.5%. Furthermore, it should be noted that we do not only deal with a different sample of countries but also with a different frequency and temporal dimension.

The regime switches are quite distinct and also present a different persistence for periods of recovery and slowdown. Table 4 documents that the mean persistence of the states, $I_t = 1$ and $I_t = 0$ ($\xi_{11}^{S_i}$ and $\xi_{00}^{S_i}$), is 0.89% and 0.57%, respectively. Hence, the persistence of remaining in expansions is higher than that for recessions. On average, above-average growth periods are expected to last more than nine years, whereas the expected duration of below-average growth periods is around two years.

Finally, the distribution for each country according to its relative mean growth in recession and expansion is shown in Figure 11.[41] For each cyclical phase and country, we compute the average of the demeaned real GDP growth rates. We observe that there have been important differences in the growth performance of the different countries, but two extreme cases deserve comment. First, Ireland (IE) stands out for having both the most dynamic GDP growth rates during expansion phases and the hardest declines during recession periods. Second, Norway (NO) has less variability in its business cycle, the growth rates being very low during recoveries and experiencing small negative growth rates during recessions.

Figure 12 displays unit-specific variances after estimation according to expression 9. If we compare this figure with Figure 2, we observe that the variance of GDP growth rates is properly captured for most countries. However, the fit is not so good in EL and DE and, to a lesser extent, IE, LU and FI.

[39] `http://cepr.org/content/euro-area-business-cycle-dating-committee`

[40] It has to be borne in mind that our dating begins in 1985 because our selected model has four lags. Hence, we do not capture the recession of 1980.2-1983.3 that is identified by the EABC Dating Committee.

[41] The average state-dependent mean can be computed for each country based on the estimate of the state indicator (cyclical phase), which is common for all the countries in the same cluster.

4.3 Regions. Dating and clustering regional business cycles in Europe

In this section, we examine the evolution of regional business cycles in Europe. On the basis of these results, we obtain, for the first time in the literature, a business cycle dating of the European regions and classify them into different clusters.

To get an overview of our regional data, which consists of 213 regions and 32 years, we calculate the kernel density of the regional growth rates for each year of our sample, which is displayed in the upper panel of Figure 13. We observe a high degree of variability across both space and time. This figure reflects that the high dispersion in regional growth rates could be due to the presence of outliers, which will be treated in the next paragraph.

Figure 14 shows the distribution of the regional dataset. There is a great heterogeneity in the GDP growth rates. Furthermore, the existence of some outliers should not be disregarded (as the numerous red crosses indicate) when estimating parametric models. However, the filtering of outliers is a double-edged sword because we must guarantee that we are only removing authentic outliers that are due, for instance, to methodological or statistical changes and not atypical observations that could actually reflect severe movements in the business cycle, such as those corresponding to the Great Recession. Since we work with annual data, the Tramo-Seats method[42] is not suitable because of the length of the series. So, we have chosen to apply a simpler technique that allows us to, simultaneously, remove outliers and maintain the signal of cyclical phases. Specifically, we have linearly interpolated the observations that exceed four times the standard deviation over the median of each regional time series. Using this methodology, we identify six outliers that correspond to the Spanish regions of Ceuta and Melilla (ES63 and ES64) in 1985, Burgenland in Austria (AT11 in 1995), the Portuguese regions of Norte (PT11) in 1990 and Alentejo (PT18) in 1988 and Ovre Norrland in Sweden (SE33) in 2009. The bottom of Figure 13 shows the density once the outliers have been removed.

[42]See Gomez and Maravall (1996).

After eliminating the outliers, we analyze the patterns of comovements in the regional series. The top panel of Figure 15 represents the evolution of regional growth rates (blue lines) together with the median and the first and the third quartiles (red lines) of the series. In spite of the great number of series and the high variability among them, we can observe quite a smooth cyclical path in which the most outstanding event identified is the Great Recession.

To analyze comovements in GDP growth rates in greater depth, we calculate the rolling average of spatial correlation using Moran's modified statistic, following Stock and Watson (2010) as in the previous section (with N = 213). The results are displayed in the bottom panel of Figure 15. We observe that the synchronization of comovements is slightly above 0.2, on average, and quite stable throughout the period. However, this index confirms that spatial correlation progressively increased during the convergence process towards the European Monetary Union and took a big leap as a consequence of the Great Recession, reaching a value of 0.7.[43]

To obtain a regional business cycle dating and to make up groups of regions, we apply the Markov Mixture method for clustering, as previously described in Section 3. Table 5 presents the log-marginal likelihood of different Markov Switching model specifications considering different autoregressive coefficients for each group. Three sampling likelihood criteria are considered again to select the best model (importance sampling, bridge sampling and reciprocal sampling). All of them agree that the preferred model for European regions includes two lags of GDP and allows for five groups, i.e. p=2 and K=5, respectively. Regarding the identification of groups, we have imposed some restrictions in addition to $\mu_K^R > 0$, $\forall K$, which are detailed in the first column of Table 6. The percentage of regions that are unambiguously located in a group, with a probability greater than 0.5, following these identification restrictions are presented in the second column of Table 6. Notice that considering $\mu_G(1) > \mu_G(2) > ... > \mu_G(K)$ or, which is the same thing, ordering the clusters

[43] Gadea et al. (2016) obtain similar conclusions with a more sophisticated methodology.

from the highest to the lowest growth during an expansion period, we get a classification of almost 100% of the regions.[44]

Scatterplots of the Markov Chain Monte Carlo processes for the different parameters are displayed in Figure 16, which shows the posterior draws following a Bayesian estimation. This figure distinguishes five clear clusters (represented in different colors), corresponding to five European groups of regions. Each point of the scatterplot offers the location of the five clusters considering different estimations of the parameters, specifically, the means and standard deviations of the two states specification.

The probability by region of belonging to each of the five groups is depicted in Figures 17, Figure 18 and Figures 19-19 (Cont.). The distribution of regions into different groups is arranged according to the size of expansionary periods. We assign each region to the group for which its probability of belonging is above 0.5%.[45] As can be seen in Figure 17, the probability of being in each group is, in most cases, close to one. However, there are some regions, mainly in group four, in which the probability is just above 0.5%. The regions that have a similar probability of being in groups four or five are located, principally, in France (FR) and the UK.[46] Figure 18 is a heat map of the same probabilities, the lowest probability of being in a group is illustrated with the lightest colours, whereas the highest probability is represented in maroon. This figure reveals that the probability of belonging to group five, the one that concentrates most of the regions, is also quite high in many of the regions that are classified in other groups.

Having presented some of the features of each of the different groups and the probabilities, we detail the specific regions that belong to each group, indicating the exact probability figures (see Figure 19). The geographical distribution of regional business cycles into different groups is displayed in a map (Figure 20).

The groups are made up of the following regions of each country:

[44] In fact, the only region that is not properly grouped is the Portuguese region of Alentejo (PT18).

[45] In all cases but one (the Portuguese region of Alentejo (PT18)), this probability exceeds 0.5%.

[46] There are also three Spanish regions and one Portuguese region whose probabilities of belonging to group four instead of five are also quite high.

1. The first group is made up of all the Greek regions, but one (12 regions in total): the Greek group.

2. In the second group, we find mostly German regions (11) -half of them, in the south of the country-, plus one Italian and one Portuguese region (13 regions in total): the southern Germany group.

3. The third group includes some German (8) -located, mainly, in the northwest of the country-, Belgian (2) and Dutch (3) regions as well as one Austrian and one Portuguese region (15 regions in total): the core group.

4. The fourth group contains most of the UK regions (21), all the Swedish and Finnish regions (8 and 5, respectively), one Dutch region, one Spanish region and the four French overseas regions (40 regions in total): the northern group.

5. Finally, the fifth group is the largest and is composed of the remaining regions (132 regions in total):[47] the largest group.

Broadly, group five contains the vast majority of the regions (the largest group, in what follows). Groups four and one are clearly located geographically. Group four is mainly composed of regions of the northern countries (the northern group, from now on), while group one gathers most of the Greek regions (the Greek group, in what follows). Additionally, there are two other groups (two and three) that include many German regions. Group three is composed of northwest German regions plus some regions of some of the core European countries (the core group, from now on) and group two contains the rest of German regions (those that are not included in groups five or three) plus a couple of regions of the southern European countries (the southern Germany group, in what follows). The probability of the regions from the northern group belonging to it is not much higher than that of them

[47]PT18 is not formally included in any group. Its most likely location, with a probability of 0.44, is in Group 5.

belonging to the larger group. Nevertheless, they present some peculiarities in their cyclical paths which mean that they are not close enough to belong to group five.

Table 7 summarizes the posterior estimates for the parameters of interest of the chosen model specification for the European regions. It can be observed that the means during expansion and recession ($\mu^G_{S_i}$ and $\mu^G_{S_i} - \mu^R_{S_i}$, respectively) clearly differ among groups. There are different mean growth rates in expansion, as can be seen from the $\mu^G_{S_i}$ values in the five groups, whereas the mean growth rates in recession, $\mu^G_{S_i} - \mu^R_{S_i}$, are more similar. The growth rates for each group during expansionary phases are the following: 2.15% in group one, 1.73% in group two,1.26% in group three, 1.07% in group four and 0.49% in group five. Meanwhile, the mean growth rates during recessionary phases are -0.45% in group one, -1.07% in group two, -1.57% in group three, -1.77% in group four and -2.21% in group five.

For a better understanding of the features characterizing each group, we show the regional GDP growth within each group in Figure 21. For a detailed information about quartiles, minimum and maximum values of each series, as well as their outliers, see Figure 22. We observe that the Greek group shows the lowest average GDP growth and the highest variance with respect to the other groups. The latter are quite homogeneous with regard to their average growth rates and variability. However, group three, namely, the core group, has one atypical region and group five, the largest group, has the highest number of outliers, five.[48]

Additionally, the mean persistence of the states $I_t = 1$ and $I_t = 0$ ($\xi^{S_i}_{11}$ and $\xi^{S_i}_{00}$, respectively) are quite similar among groups and far from non stationarity in all cases. However, the autorregresive parameters imply that the series are more persistent during periods of economic recovery than during periods of economic slowdown. It should be noted that expansionary periods are more persistent in groups four and five than in the others, the least persistent recoveries being in group one. The persistences for each group of expansionary phases are 0.7% in group one, 0.73% in group two, 0.79% in group three, 0.83% in group four

[48] They belong to different countries. They are BE31 (Prov. Brabant Wallon) in Belgium, IE01 (Border, Midland and Western) in Ireland, PT15 (Algarve) in Portugal, NL23 (Flevoland) in Netherlands and Luxembourg (LU00, Luxembourg, Gran-Duche).

and 0.86% in group five. At the same time, the persistences of recessionary phases are 0.56% in group one, 0.55% in group two, 0.57% in group three, 0.67% in group four and 0.57% in group five. In the last column of Table 7, we note that the number of regions clearly differs among groups, group five being the one that concentrates the highest number (more than 60% of the total).

The probability of being in recession is estimated separately for each group in Figure 23. It should be pointed out that there are two recessionary periods that are common to the five groups, namely, that at the beginning of the nineties and that during the Great Recession. The deceleration at the beginning of the nougthies mainly affected the regions in groups two and three (and, to a lesser extent, group one). The probability of being in recession of groups one, two and three also reflects an additional period of growth slowdown in the mid 1980s, after the economic instability of the 70s that was due to the different oil price shocks.

The detailed business cycle of each group is depicted in Figures 24-28, representing recessions and expansions ($I_t = 1$ and $I_t = 0$, respectively). There are some remarkable differences in the cyclical performance of the different groups. Regions in group one (which includes almost all the Greek regions) are in recession for most of the considered sample (eleven years). This group suffered the four recessionary periods mentioned before and with greater severity. However, it also experienced a long-lasting expansionary period of ten years (from 1994 to 2004). Groups two and three underwent downturns in nine years of the sample. The recession of the nineties lasted four years in total in group two (it was interrupted after three years and reappeared in 1996) while, in group three, the duration of the four recessionary episodes was exactly the same, i.e. two years, with the exception of the eighties, where there is also a recession in 1981, the first year of the sample (as in group one). Group four, made up of regions of the northern European countries, was in recession during eight periods. The duration of the recessionary period of the beginning of the nineties was four years while, at the time of the Great Recession, a double dip is observed in 2008, 2009 and 2011. Finally, group five suffered four recessionary years, the downturn of the nineties being very brief (affecting just 1993), although it experienced a double dip during the Great Recession as in group four.

The distribution of each region belonging to each group according to their mean growth rates during expansions and recessions is displayed in Figure 29. It should be noted that the numbers represent the average of the demeaned real GDP growth rates in each cyclical phase and region.[49] In this map we can clearly identify that regions in group five (in blue) have low growth rates during expansions while the dynamics during recessions is more similar to the other groups. Regions in group four present, on average, higher growth rates during expansion, whereas the growth rates during recessions tend to be slightly more negative. In the cases of regions included in groups two and three, the average growth rates during recoveries are even above those of group four. Regions in group one exhibit the most extreme growth rates during expansion and seem to be less negative than in the other groups during recession.

Figure 30 shows the unit-specific variances that can be interpreted as the residual after the estimation procedure for each region. On the whole, we can confirm the ability of the model to properly capture the variability of the regional cycles, although we can also identify some outliers, mostly corresponding to several regions of Portugal, especially the two archipelagos [Azores (PT02) and Madeira (PT03)] but there are also some outliers in Finland, the UK, Netherlands and France.[50]

The stylized features characterizing each of the five groups of European regions are summarized below.

Regarding the timing of the business cycle:

1. All the groups underwent the Great Recession but with a different severity. The greatest intensity is registered in the first group, formed by the Greek regions, in

[49] Regions pertaining to each group are represented in a different color: group one in green, group two in yellow, group three in purple, group four in red and group five in blue. Each cluster has its own business cycle chronology.

[50] In particular, the fit is not so good in North Eastern Scotland (UKM5) and Cornwall and Isles of Scilly (UKK3) in the UK , Aland (FI02) and Pohjois-Suomi (FI1A) in Finland, Groningen (NL11) in Netherlands and Guyane (FR93) in France.

which the recession began in 2008and continued without interruption until 2011, the last year of our data. However, in the remaining groups, either the Great Recession ended before or it hit again after a short expansion (groups four and five), causing a double dip. Furthermore, in group three, it arrived a year later (2009) than in the other groups.

2. The crisis of the beginning of the nineties is also present in all the groups but with a different timing and duration in each of them. The longest duration of the recession was in groups two and four (four years) and the shortest in group five, where it lasted for one year.

3. The deceleration of the beginning of the noughties appeared in groups two and three (including most of the German regions) during 2002 and 2003, although group one also experienced a brief recession in 2005. The deceleration of 2001 did not affect regions belonging to groups four and five

4. We find important differences in the aftermath of the oil crises, that is, during the slowdown of the mid-eighties. Groups one and three suffered a recession in the first year of the sample. After 1985, one or two years of slowdown are also observed in groups one, two and three.

Regarding the intensity of the cyclical phases:

1. The two phases of the business cycle are clearly distinguished in all the groups, although the dispersion across groups is higher during recovery times than during periods of recession. The growth rate during expansion ranges from 0.49% in group five to 2.15% in group one while the growth rate during recessions ranges from -2.84% in group four to -2.6% in group one. In order to interpret these figures, it has to be borne in mind that regions in group one are in recession most of the time so, in spite of the high growth rate during expansion, they do not have a better performance in terms of

cumulated growth. On the contrary, regions in group five only experience a recession during four years, especially intense being the Great Recession, that lasted three years in total.

2. The mean persistence of the states is higher during expansions than during recession and both are quite homogeneous among the groups. The persistences, i.e., the probabilities of remaining in each state, range from 0.7% in group one to 0.86% in group five during recoveries and from 0.55% in group two to 0.67% in group four during recessions.

4.4 Testing homogeneity within country

To get a better understanding of the spatial dimension of European regional synchronization, we measure the homogeneity of regional business cycles associated with each country. This allows us to identify the countries containing regions with more and less homogeneous business cycles. Therefore, we propose an index I_c of *Regional business cycle homogeneity* that it is computed for each country c, as follows:

$$I_c = \sum_{i=1}^{\widetilde{K}-1} \sum_{j=1}^{NR_c} |P_j - 1/K| \, \overline{pr}_i \tag{11}$$

- where P_j is a dummy variable that takes value 1 if a region belongs to group i and 0 otherwise, NR_c being the number of regions in country c.

- $\widehat{pr}_i$ is the mean of the probabilities of the regions in group i and $\widetilde{K}$ represents the K clusters ordered from low to high.

The interpretation of the index is the following: the closer the value is to 0, the higher the degree of heterogeneity, while the closer the value is to 1, the higher is the degree of homogeneity. This index relies on the results of the clustering procedure applied to the regional economic cycles. It combines information on the number of regions of a country that are within the same cluster, and the probability of each region to belong to that cluster. Therefore, it is different from other regional measures of synchronization, such as a standard deviation of regional growth rates, that do not take into account the dating of the business cycle. Because of that, this new measure yields more precise results.

Results are displayed in Figure 31 in blue. The within-country business cycle similarity is quite high in most countries, the value of the index being above 0.5 in twelve of them. Nonetheless, it varies a lot among the different countries. Countries experiencing the highest degree of business cycle homogeneity are Norway (NO), Denmark (DK), Ireland (IE), Luxembourg (LU) and Italy (IT), with values between 0.7 and 0.8, partly due to the fact that the first four countries are relatively small. On the contrary, Germany (DE), Portugal (PT), the UK[51] and the Netherlands (NL) present the highest regional business cycle heterogeneity, with values of between 0.1 and 0.4.

We are aware that this index is biased by the number of regions in each country.[52] Thus, we correct this effect and introduce a penalty which depends on the number of regions in each country. We define a new index $I2_c$ as a linear combination of Ic and NR_c that ranges from 1 to $1/max(NR_c)$ [53] and so $I2_c = \theta I_c + (1-\theta)NR_c$ where θ is the penalty factor. We use a penalty factor of 0.5. The results of this corrected index are shown in red in Figure 31,[54] revealing a different picture. Using the corrected index, Italy (IT), the UK and France (FR) appear as the countries with the highest degree of internal synchronization while Portugal (PT) and the Netherlands (NL) present a high degree of business cycle heterogeneity.

There is lack of consensus in the literature about the effect of national borders, although not comparable to our results as they use less disaggregated datasets and different methodologies. Clark and van Wincoop (2001) confirm the existence of a border effect on within

[51]This result differs from that obtained by Barrios et al. (2003) in which they find a relative homogeneity of cyclical patterns across UK regions. However, they examine just 11 UK regions over the 1966-1997 period and use a different methodology.

[52]In fact, the correlation between I_c and the number of regions in each country, NR_c, is -0.57.

[53]The highest value, 1, corresponds to the UK with 37 regions and the lowest, 1/37, to LU.

[54]The results of Luxembourg have been removed from this figure because, being a one-region country, the construction of this index would not make any sense.

country correlations (of some French and German regions), larger than on cross-country correlations. Acedo-Montoya and de Haan (2008), using clustering techniques and a sample 53 NUTS-1 regions (12 countries), find that most of the regions belonging to the same country are closely located. However, both the previous findings contradict those of Fatas (1997) who suggests that correlation within countries is not very high and has reduced over time for 38 NUTS-2 regions (4 countries).[55]

5 Concluding remarks

In this paper, we provide a robust methodology that allows us both to date the business cycles of countries or regions and to identify clusters among them. In our application, the Finite Mixture Markov Model analyses the common growth pattern of regional (or national) GDP series. Considering an autoregressive panel framework, the GDP growth rate in a country or region is allowed to switch between expansionary and recessionary periods according to a latent indicator that captures the two unobservable cyclical states of the economy. We also estimate the most suitable grouping of the units (regions or countries) according to their similarity in business cycle dynamics along with the model parameters. This means that we do not set an a priori grouping on the basis of some unit-specific features, but rather use our statistical model in order to assign each unit to a group defined in terms of business cycle features.

We employ annual real GDP data because quarterly data are not available at the regional level. Our panel consists of 213 NUTS-2 regions corresponding to 16 European countries, some belonging to the eurozone and others not sharing the common monetary policy. Both these geographical units are analyzed separately. We first analyze countries and then perform a similar analysis for regions. The series cover a period of 32 years, from 1980 to 2011. Having such a broad dataset allows us to examine, for the first time in the literature, issues such as the possible effect of the Great Recession on the regional business cycle of European

[55] Note that the Fatas (1997) sample does not include the common monetary period, which has affected eurozone countries.

countries. All in all, never before has such a comprehensive study (in terms of both regional and temporal coverage) of the regional business cycles in Europe been carried out.

The results obtained can be summarized as follows. We observe some similarities in the business cycles of the European countries, such as the huge impact of the Great Recession in 2008-2009, a deceleration at the beginning of the nineties and the slowdown in 2001, although each business cycle presents idiosyncratic behavior in terms of average growth rate, variability and the presence of outliers. We also analyze the time-varying comovements in the GDP series, using an index proposed by Stock and Watson (2010), finding that spatial correlation has been increasing since the beginning of the Monetary Union period (1999) with a new impulse coinciding with the Great Recession. Applying the Finite Mixture Markov Model, we find evidence of a unique cluster, i.e., a common cycle in the European countries in which the two-states specification is significant and the persistence of expansions, i.e., the probability of remaining in that cyclical phase, is higher than that of recessions. This business cycle dating identifies 1993, 2001 and 2008-2009 as periods of recession.

Regarding the European regions, we, firstly, carry out a preliminary analysis of the data and observe that regional growth rates are quite heterogeneous. Moran's modified statistic reflects a progressive increase in spatial correlation at the beginning of the nineties, during the convergence process towards the introduction of the euro, slightly diminishes afterwards and remains stable until the beginning of the noughties. Comovements among regions steadily rise during the Great Recession. Secondly, we analyze regional business cycles through Finite Mixture Markov Models and identify five different groups of European regions which share different business cycle characteristics. This is in contrast to the country analysis, where we only identify one common cycle across all European countries. Group one contains most of the Greek regions, groups two and three include, mainly, regions of Germany (plus a couple of regions from southern countries in group two and some regions of the core countries in group three). Group four is, mainly, composed of regions belonging to northern European countries. Group five is the largest and it is composed of the other European regions.

Concerning the timing of the cyclical phases, four recessionary periods are identified: the slowdown in the eighties, the recession at the beginning of the nineties, the deceleration around 2001 and the Great Recession. All groups underwent the Great Recession, but with different severity. It was especially long-lasting in the first group, formed by the Greek regions. The crisis of the beginning of the nineties also hit all the groups. Nevertheless, they suffered it with a different timing and duration. The shortest duration of the recession was in group five, where it lasted for one year, and the longest in groups two and four, where it prolonged for four years. The deceleration of 2001 did not affect regions belonging to groups four and five. During the 80s, in the aftermath of the oil crises of the 70s, groups one, two and three suffered a recession.

With respect to the intensity of the cyclical phases, the two phases of the business cycle are clearly distinguished in all groups, the growth rate during expansion ranging from 0.49% in group five to 2.15% in group one, while the growth rate during recession ranges from -2.84% in group four to -2.6% in group one. However, regions in group one are in recession most of the time so, in spite of the high growth rate during expansion, they do not have a better performance in terms of cumulated growth. On the contrary, regions of group five experience a recession only during four years of the whole sample.

We construct an index to study within-country homogeneity. We observe that the degree of homogeneity of regional business cycles within countries is quite different. Norway, Denmark and Ireland present the highest degree of business cycle homogeneity, in part due to the fact that they are relatively small countries, while the regional business cycles of Germany, Portugal and the UK are quite heterogeneous. We propose a second index, corrected by the total number of regions in each country and we obtain different results. Italy (IT), the UK and France (FR) are the countries with the highest degree of internal synchronization, whereas Portugal (PT) and the Netherlands (NL) present a high degree of business cycle heterogeneity.

Regarding the policy implications of our paper, the similarity of regional business cycles in Europe is an important criterion for implementing common European policies: if there are quite different cycles, common policies would not be equally good for all the regions. In turn, idiosyncratic features should be addressed using regional policies. Carrying out economic policy measures at the national level could bring about undesirable distortions in some regions and slow down their convergence processes, which would be further evidence of the need to apply specific economic measures. This issue is particularly important given the fact that we have shown that the usual practice of considering a country's business cycle as an aggregation of the regional cycles is hiding very different rhythms of economic activity. Indeed, we find that, while the spatial correlation of the countries increased with the introduction of the euro, this pattern is not observed for regions. Indeed, although regional comovements have increased during the last ten years, they are below the national comovements. Against this background, given that macroeconomic stabilization policies, which are primarily related to the cyclical evolution of the economy, are very constrained in the European Union by the common monetary policy and the Stability and Growth Pact, the design of Cohesion policies in the European Union, to increase regional competitiveness and foster economic growth and employment, becomes even more important. Additionally, fiscal policy should be used to reduce regional disparities because, if their regional cyclical shapes are different, policy measures to fight recessions could be too accommodative for some regions and too tight for others.

Future lines of work could include (i) to look for a set of explanatory variables that could account for regions belonging to different clusters; (ii) to investigate the effect of the Great Recession in detail, as we can exploit the cross-sectional information; (iii) to examine the pattern of correlation over time in two dimensions, first, taking into account the effects of important milestones in Europe, such as the Maastricht Treaty or the introduction of the euro; and, second, finding whether or not the interdependence increases for regions that belong to different countries and, as a consequence, the economic meaning of national borders disappears; (iv) to analyze the interactions between regional and national business cycles;

(v) to determine the effect of enlarging the sample in order to include, on the one hand, the European countries that have adhered more recently to the euro and, on the other hand, by incorporating all of German regions; and (vi) to carry out the analysis at country level, with the current model specification, but using quarterly real GDP data, which is available for a longer dataset.

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Tables

AUTHORS	GEOGRAPHICAL COVERAGE	VARIABLES	TEMPORAL DIMENSION	METHOD	MAIN RESULTS
Correlation					
Acedo-Montoya and de Haan (2008)	53 NUTS1 (12 EMU countries)	Gross Value Added	1978-2005	Hodrick-Prescott and Cristiano-Fitzgerald filters Correlations	(i) Correlation has increased during the period considered, except in the 80s and the beginning of the 90s (ii) In some regions remained low or even decreased (iii) Existence of a national border effect
Barrrios and de Lucio (2003)	20 NUTS2 (SP and PT) 209 NUTS2 EU	Employment Q Employment A	1988.1-1998.4 1975-1998	Hodrick-Prescott filter Pairwise correlations OLS regression	(i) Border effect lower and less significant between SP and PT regions than among other European regions. It has decreased in Iberian regions, fostered by the integration process (ii) Industrial specialization explains the growing correlation between Spanish and Portuguese regions
Barrios et al. (2002)	11 UK regions 6 EA countries	GDP	1966-1997	Hodrick-Prescott filter GMM correlations OLS Regression (explanatory variables)	(i) UK regions less correlated with the EA than other EU countries and divergence has increased (ii) Sectoral similarity promotes cyclical symmetry (iii) High correlations among UK regions
Belke and Heine (2006)	30 NUTS1 (BE, FR, DE, IE, NET, SP)	Employment	1989-1996	Hodrick-Prescott filter Pairwise correlation (Bravais-Pearson coefficient) Panel (fixed effects)	Decline in regional synchronization is due to differences in regional industry structure
Clark and van Wincoop (2001)	16 NUTS1 (8 FR and 8 DE) 14 EU countries and 9 US regions	Employment and GDP Employment and GDP	Emp: 1970-1992 and GDP: 1982-1996 1963-1997	Hodrick-Prescott and Baxter-King filters Pairwise correlations using GMM OLS regression	Great border effect on regions within France and Germany and correlations have remained practically unchanged over time BC correlations among US regions are higher than among European countries, related to national borders.
Fatás (1997)	38 NUTS1 (FR, DE, UK, IT) 12 EA countries	Employment	1966-1992	Correlations	Regional cross-country correlations have increased over time, while correlations within countries have decreased
Marino (2013)	107 NUTS1 and some NUTS2 (BE, DE, EL, FR, IT, NL, PT, SP and UK)	GDP and employment	1977-1995	Dynamic factor model	(i) Regions are more synchronized in terms of GDP than in terms of employment (ii) GDP dynamics are regional rather than national
Gadea et al. (2016)	213 NUTS2 (18 EU countries)	GDP	1980-2011	Regime switching and Dynamic model averaging	(i) the Great Recession synchronized Europe twice as much asthe EU process in decades (ii) Ile de France acts is the main channel of transmission of business cycle shocks (iii) increases in regional sectoral composition similarity have a positive effect on business cycle synchronization, only for regions that already experience high levels of similarity in their productive structure

Table 1: Literature review (1)

AUTHORS	GEOGRAPHICAL COVERAGE	VARIABLES	TEMPORAL DIMENSION	METHOD	MAIN RESULTS
Convergence					
Quah (1996)	78 NUTS2	Regional pc income	1980-1989	St. Dev, Markov chain distributions	Regional income distribution is converging towards a tighter one. Physical location and geographical spillover matter more than macro factors.
Ramajo et al. (2008)	163 NUTS2 (BE, DE, FR, DE, EL, NL, IE, IT, LU, PO and SP)	Real GDP pc	1881-1996	Exploratory spatial data analysis	(i) EU cohesion-fund countries are converging separately from the rest of the EU regions (ii) Convergence is faster in countries receiving cohesion funds than in the rest
Sala-i-Martin (1996)	73 NUTS2 (DE, UK, FR, IT, NE, BE and SP), 47 US regions, 10 Canadian provinces, 47 Japanese prefectures	Personal income (some years depending on the sample)	EU: 1950-1990 US: 1880-1990 CA: 1961-1991 JA: 1955-1990	β convergence and σ convergence	There are both types of convergence across regions of the US, Japan, Europe, Spain and Canada, at about the same rate.
Ozyurt and Dees (2015)	253 NUTS2 EU	Real GDP pc	2001-2008	Spatial Durbin ramdom-effect panel model Moran index	(i) Social-economic environment and traditional determinants of economic performance are relevant (ii) There are high-income clusters (in Western Europe) with positive effects on development of neighbouring regions

Table 2: Literature review (2)

Table 3: Log-marginal likelihood of different Markov switching model specifications with group-specific autoregressive coeffients

Model K,p	Importance sampling	Bridge Sampling	Reciprocal Sampling
1,1	-944.20	-943.42	-944.17
1,2	-907.82	-907.05	-907.79
1,3	-882.33	-882.54	-882.35
1,4	**-843.79**	-843.01	**-843.77**
2,1	-907.82	-907.05	-907.79
2,2	**-843.79**	-843.01	**-843.77**
2,3	-907.66	-909.59	-909.24
2,4	-846.96	**-842.85**	-845.27
3,1	-882.33	-882.54	-882.35
3,2	-907.66	-909.59	-909.24
3,3	-949.49	-943.72	-947.12
3,4	-850.22	-843.14	-847.44
4,1	**-843.79**	-843.01	**-843.77**
4,2	-846.96	-842.85	-845.27
4,3	-850.22	-843.14	-847.44
4,4	-853.66	**-842.05**	-849.35

Notes: The highest values are indicated in bold. For a detailed description of the different methods of estimating conditional likelihood see Frühwirth-Schnatter, S. (2006).

Table 4: Posterior estimates, K=,1, p=,4

S_i	$I_{S_i,t}=1$						$I_{S_i,t}=0$						num.countries
	$\mu^G_{S_i}$	δ^G_{1,S_i}	δ^G_{2,S_i}	δ^G_{3,S_i}	δ^G_{4,S_i}	$\xi^{S_i}_{11}$	$\mu^G_{S_i}-\mu^R_{S_i}$	δ^R_{1,S_i}	δ^R_{2,S_i}	δ^R_{3,S_i}	δ^R_{4,S_i}	$\xi^{S_i}_{00}$	
1	0.52	0.28	0.11	-0.01	-0.18	0.89	-2.56	1.18	-0.37	-0.72	0.55	0.57	16
	(0.08)	(0.04)	(0.05)	(0.06)	(0.05)	(0.75 0.99)	(0.34)	(0.14)	(0.23)	(0.32)	(0.27)	(0.23 0.91)	

Notes: $I_{S_i,t}=1$ refers to the expansionary cyclical phase, while $I_{S_i,t}=0$ represents the recessionary period. In brackets we display standard errors for coefficients and confidence intervals for persistence.

Table 5: Log-marginal likelihood of different Markov switching model specifications with group-specific autoregressive coeffients

Model K,p	Importance sampling	Bridge Sampling	Reciprocal Sampling
1,1	-14561.98	-14561.28	-14561.98
1,2	-13986.91	-13986.20	-13986.90
2,1	-13986.91	-13986.20	-13986.90
2,2	-13948.44	-13948.00	-13948.71
3,1	-14430.85	-14429.66	-14430.89
3,2	-13795.62	-13794.28	-13795.33
4,1	-13948.44	-13948.00	-13948.71
4,2	-13778.06	-13774.50	-13775.67
5,1	-14361.92	-14419.50	-14419.22
5,2	**-13737.03**	**-13724.26**	**-13730.18**
6,1	-13795.62	-13794.28	-13795.33
6,2	**-13748.13**	**-13743.97**	**-13748.25**

Notes: The highest values are indicated in bold.

Table 6: Identification strategy

$\mu_K^R > 0, \forall K$	% of assigned regions
$\delta_G(1) < \delta_G(2) < ... < \delta_G(K)$	0.0141
$\mu_R(1) < \mu_R(2) > ... < \mu_R(K)$	0.2350
$\mu_G(1) > \mu_G(2) > ... > \mu_G(K)$	0.0047

Notes: The first column indicates the identification restrictions used in combination with the restriction $\mu_K^R > 0, \forall K$. The second column indicates the percentage of regions that are unambiguously located in a group.

Table 7: Posterior estimates, K=5 and p=2

S_i	$I_{S_i,t}=1$				$I_{S_i,t}=0$				num.regions
	$\mu^G_{S_i}$	δ^G_{1,S_i}	δ^G_{2,S_i}	$\xi^{S_i}_{11}$	$\mu^G_{S_i}-\mu^R_{S_i}$	δ^R_{1,S_i}	δ^R_{2,S_i}	$\xi^{S_i}_{00}$	
1	2.15	0.05	0.20	0.70	-2.60	0.67	-0.08	0.56	12
	(0.16)	(0.08)	(0.10)	(0.50 0.89)	(0.28)	(0.32)	(0.18)	(0.31 0.80)	
2	1.73	-0.13	0.41	0.73	-2.80	-0.14	0.44	0.55	13
	(0.20)	(0.10)	(0.10)	(0.55 0.90)	(0.42)	(0.30)	(0.23)	(0.28 0.81)	
3	1.26	-0.27	0.16	0.79	-2.83	-0.45	-0.15	0.57	15
	(0.14)	(0.14)	(0.10)	(0.62 0.95)	(0.24)	(0.42)	(0.15)	(0.30 0.87)	
4	1.07	-0.06	0.05	0.83	-2.84	0.19	-0.25	0.67	40
	(0.09)	(0.10)	(0.08)	(0.68 0.96)	(0.21)	(0.40)	(0.10)	(0.37 0.94)	
5	0.49	0.16	-0.01	0.86	-2.70	0.82	-0.37	0.57	132
	(0.03)	(0.02)	(0.02)	(0.74 0.97)	(0.09)	(0.05)	(0.03)	(0.24 0.89)	

Notes: $I_{S_i,t}=1$ refers to the expansionary cyclical phase, while $I_{S_i,t}=0$ represents the recessionary period. Standard errors in brackets

Figures

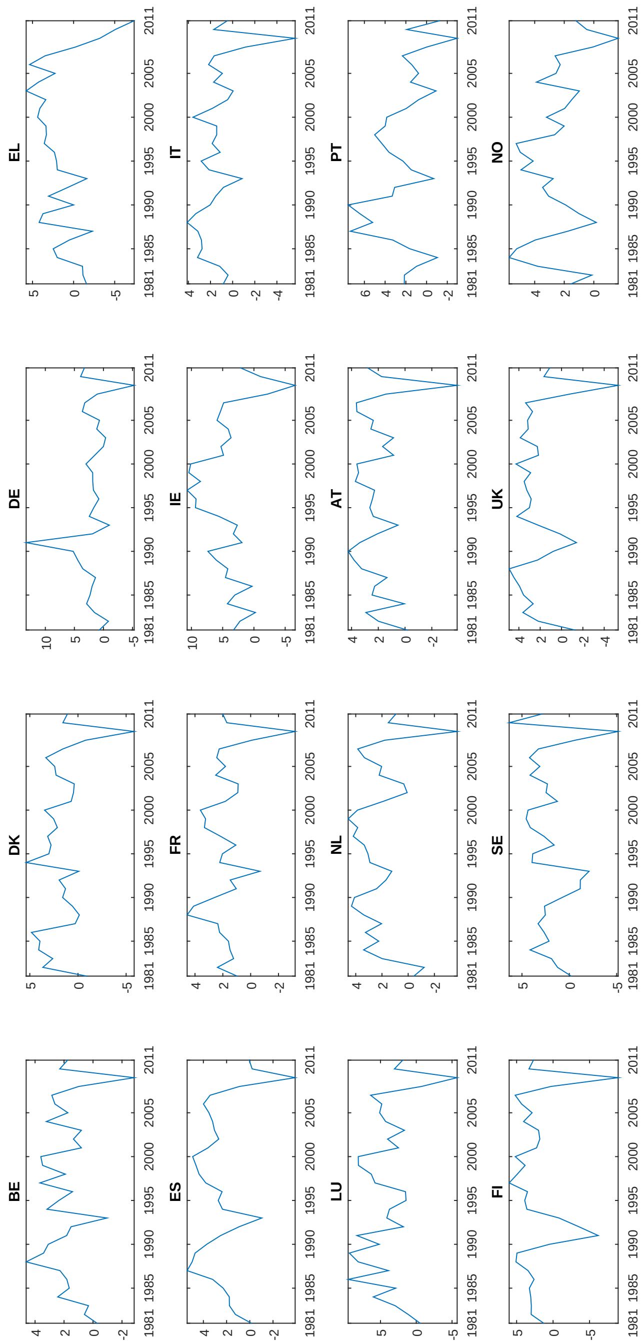

Figure 1: GDP growth rates. Countries

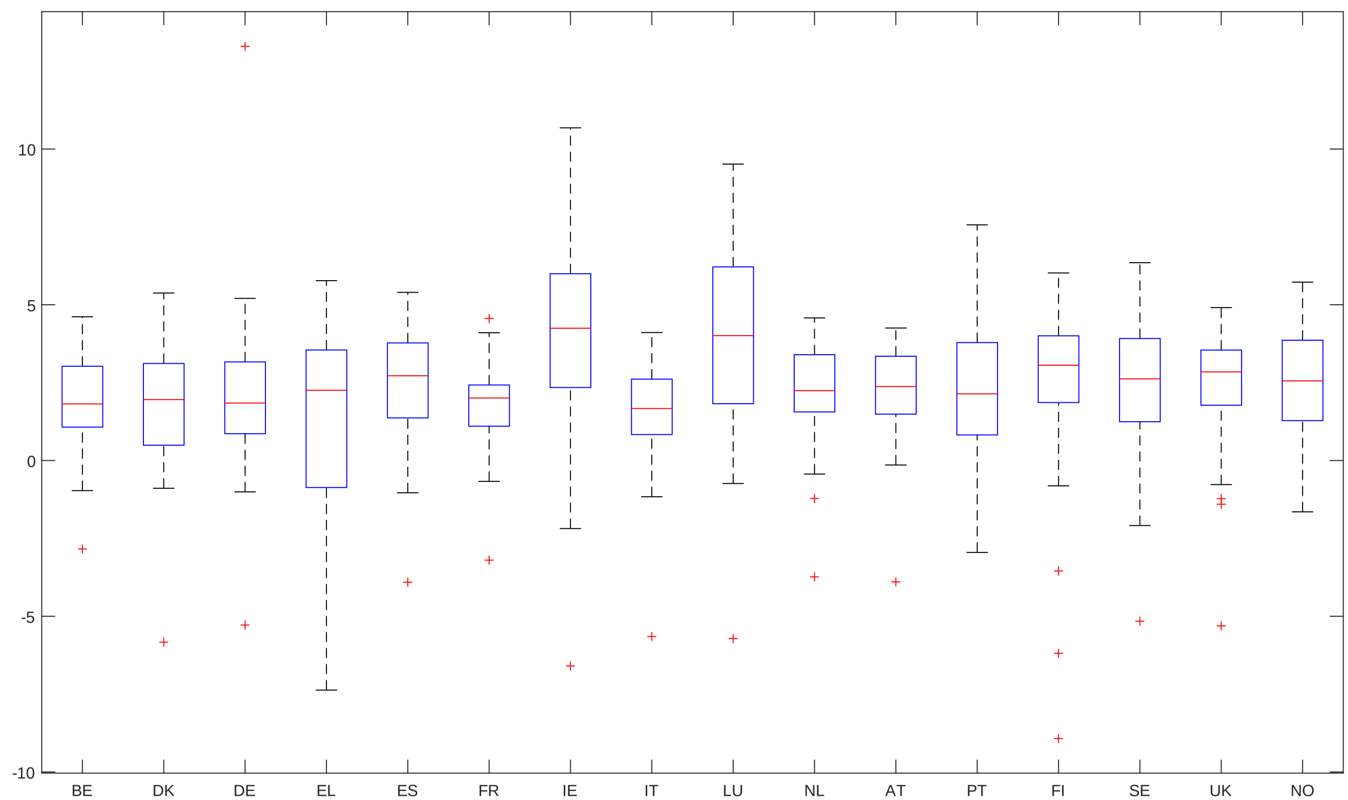

Figure 2: Boxplot of country growth rates

Notes: The body of the boxplot is represented by a blue box, which goes from the first quartile (25% of the data below this value) to the third quartile (25% of the data above this value) and the red line inside the box represents the median (50% of the data is greater than that value, that is, it is the middle of the dataset). Two horizontal lines, in dotted lines, named whiskers, extend from the upper side and the lower side of the box. The upper whisker goes from the first quartile to the smallest non-outlier in the dataset (the minimum value excluding outliers) and the lower whisker goes from the third quartile to the largest non-outlier of the sample (the maximum value excluding outliers). Outliers are plotted separately as red crosses on the chart.

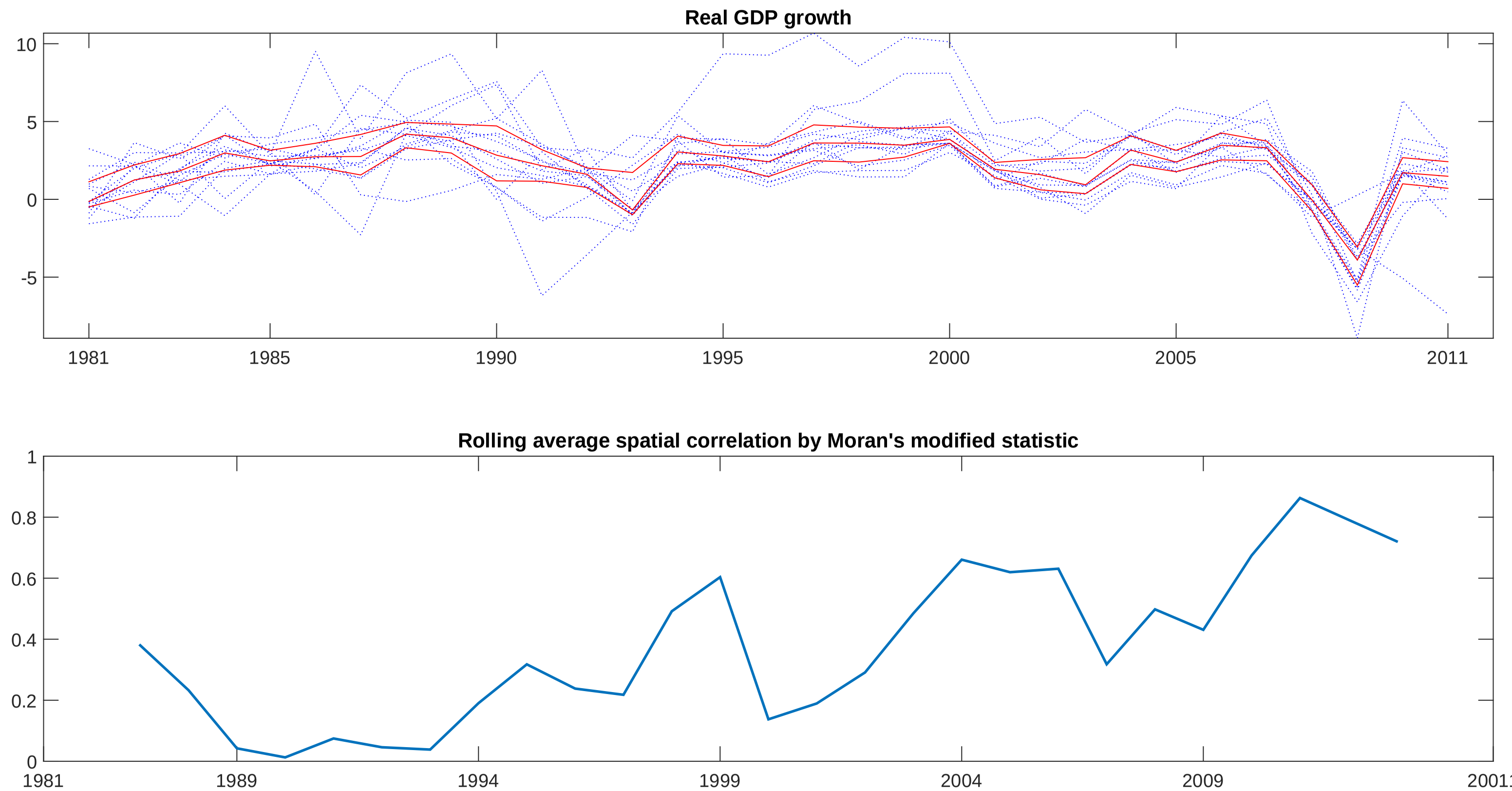

Figure 3: Evolution and comovements between national growth rates

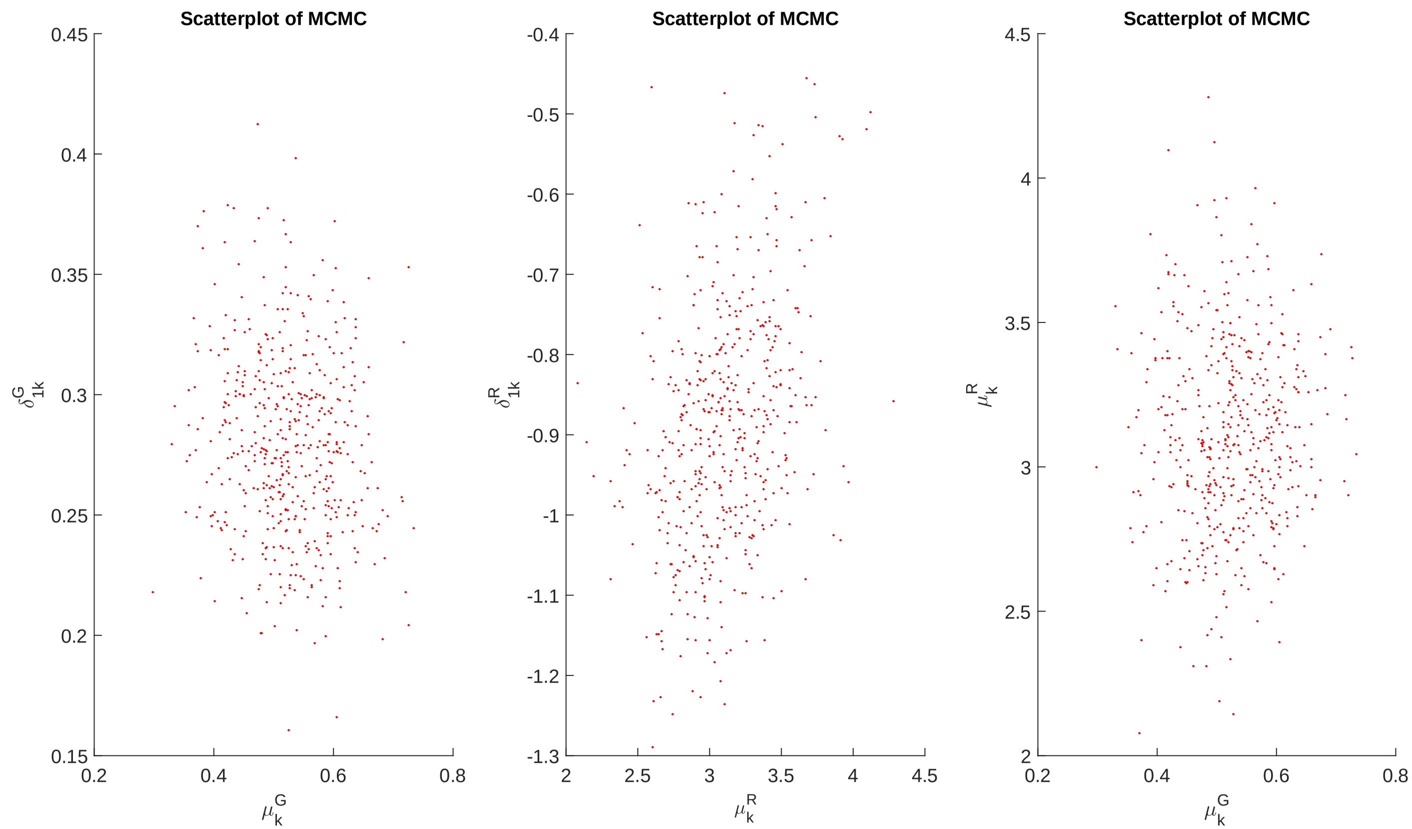

Figure 4: Scatterplot of simulated parameters, K=1, p=4

Notes: From left to right, scatterplot of simulated group-specific parameters μ_k^G against $\delta_{1,k}^G$, scatterplot of simulated state-group specific effects μ_k^R against $\delta_{1,k}^R$ and scatterplot of simulated group-specific parameters μ_k^G against μ_k^R. The scatterplots display values for K=1.

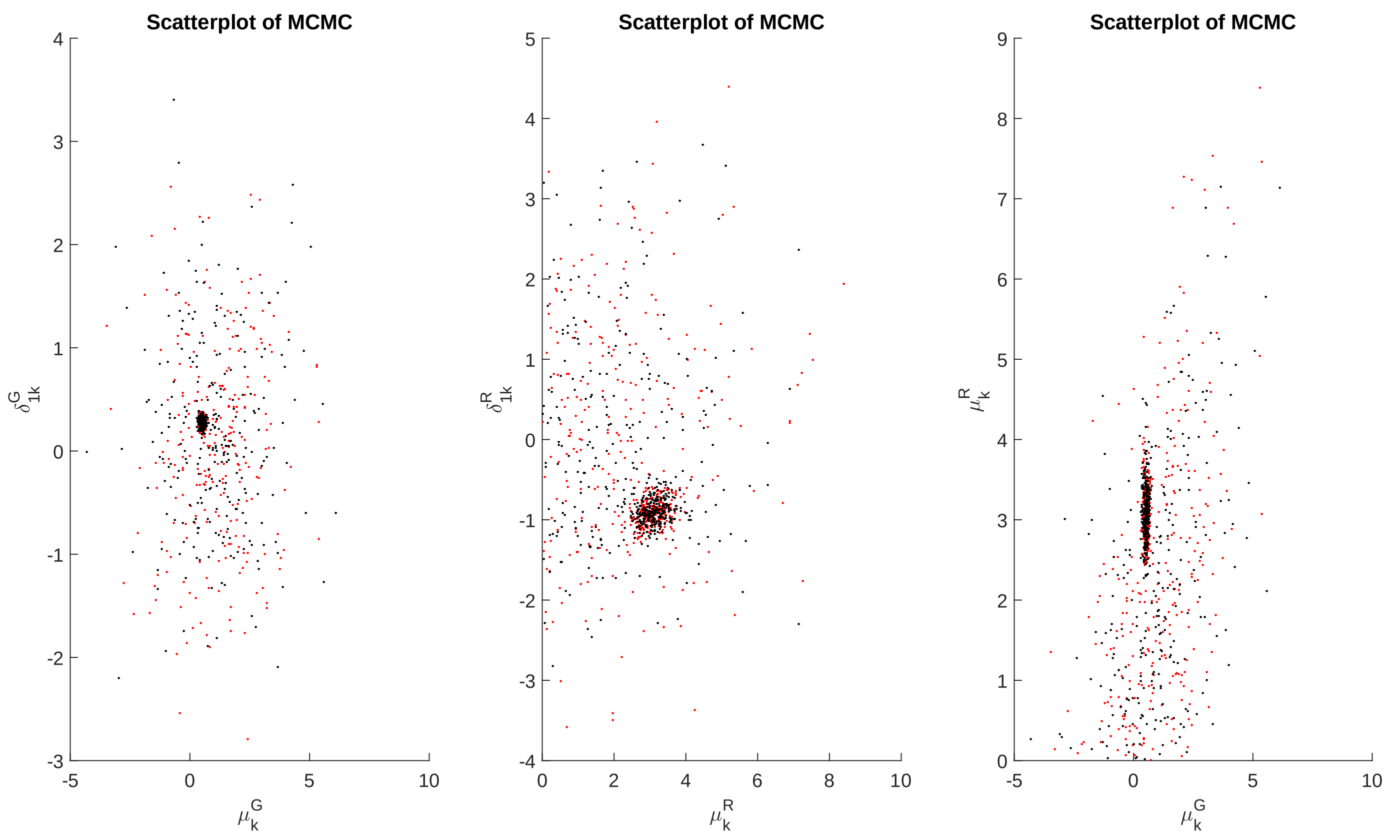

Figure 5: Scatterplot of simulated parameters, K=2, p=4

Notes: From left to right, scatterplot of simulated group-specific parameters μ_k^G against $\delta_{1,k}^G$, scatterplot of simulated state-group specific effects μ_k^R against $\delta_{1,k}^R$ and scatterplot of simulated group-specific parameters μ_k^G against μ_k^R. The scatterplots display values for K=1, 2.

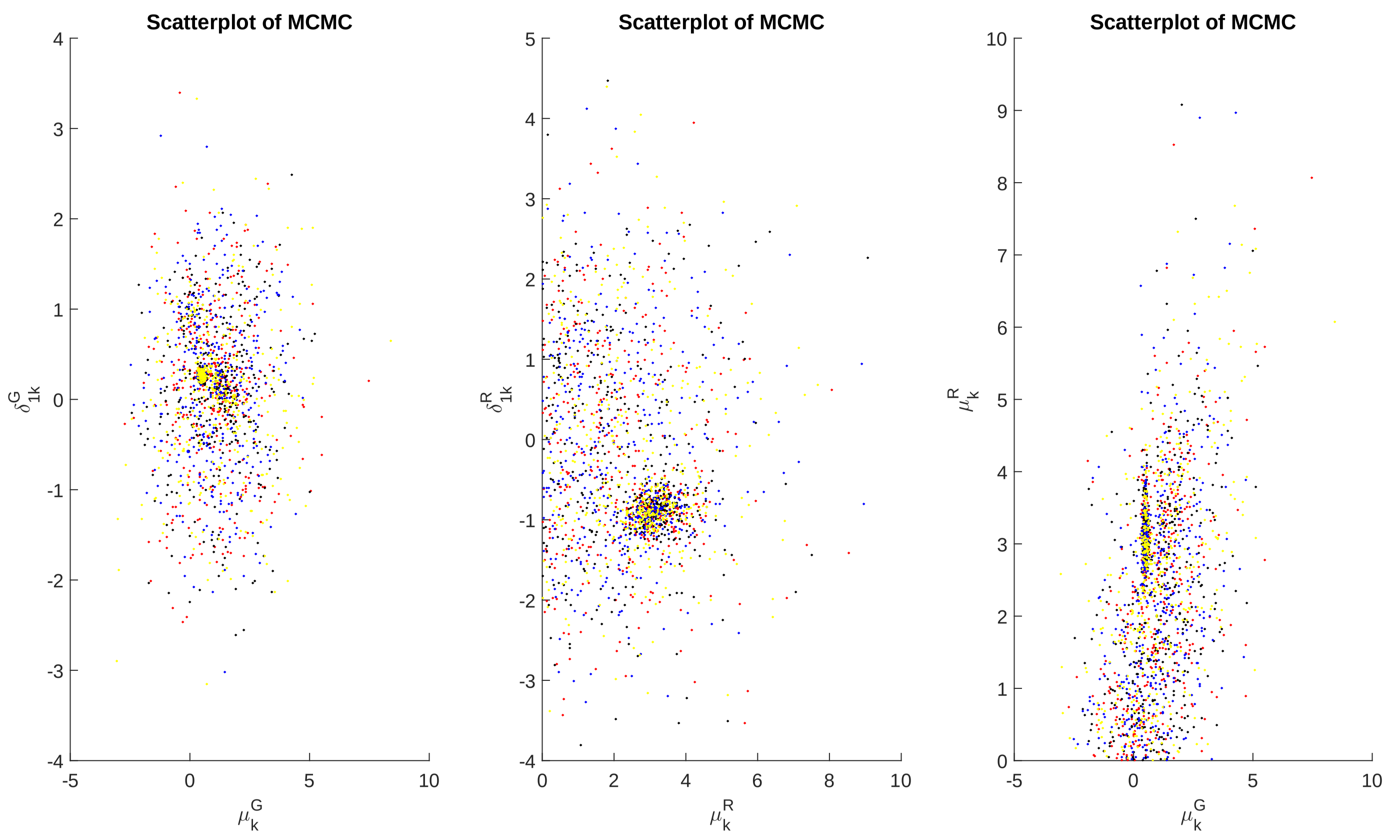

Figure 6: Scatterplot of simulated parameters, K=4, p=4

Notes: From left to right, scatterplot of simulated group-specific parameters μ_k^G against $\delta_{1,k}^G$, scatterplot of simulated state-group specific effects μ_k^R against $\delta_{1,k}^R$ and scatterplot of group-specific parameters μ_k^G against μ_k^R. The scatterplots display values for K=1,2,3,4.

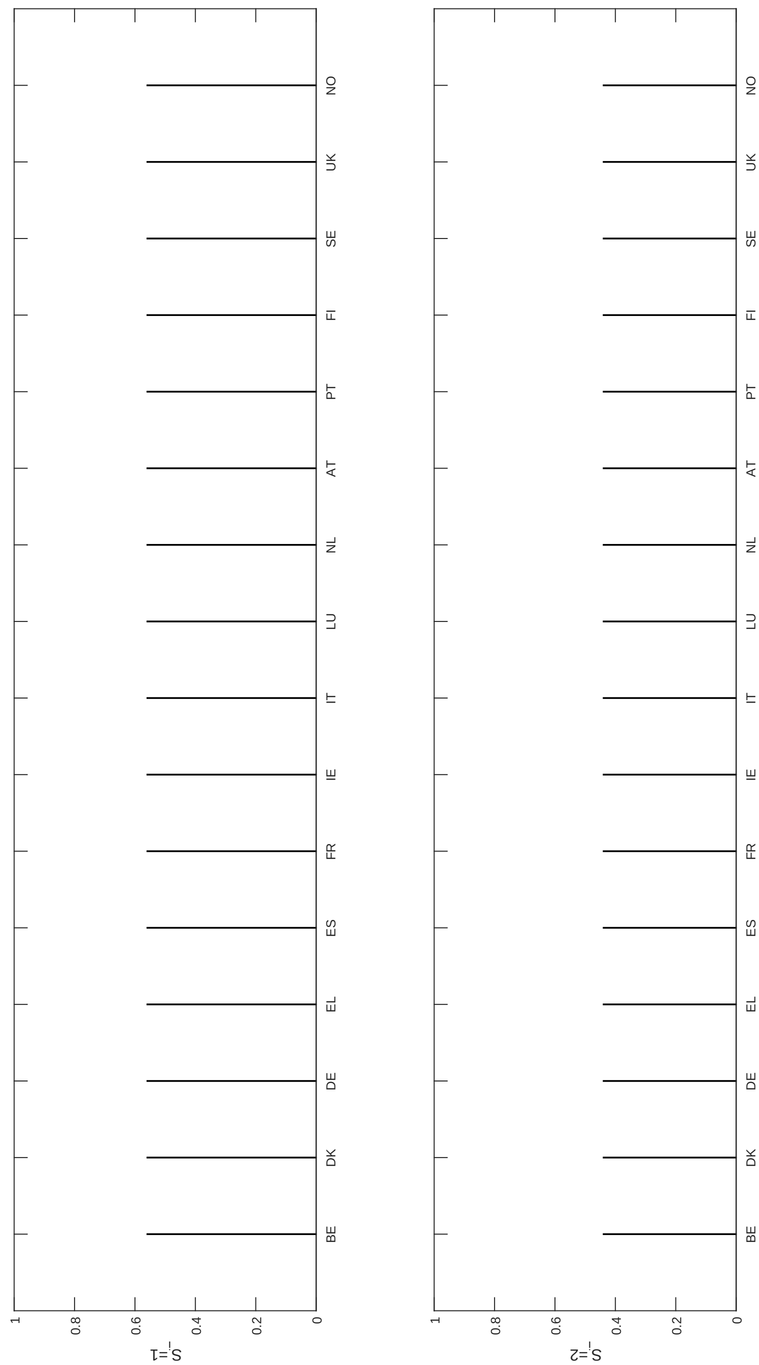

Figure 7: Probability of countries in each group, K=2, p=4

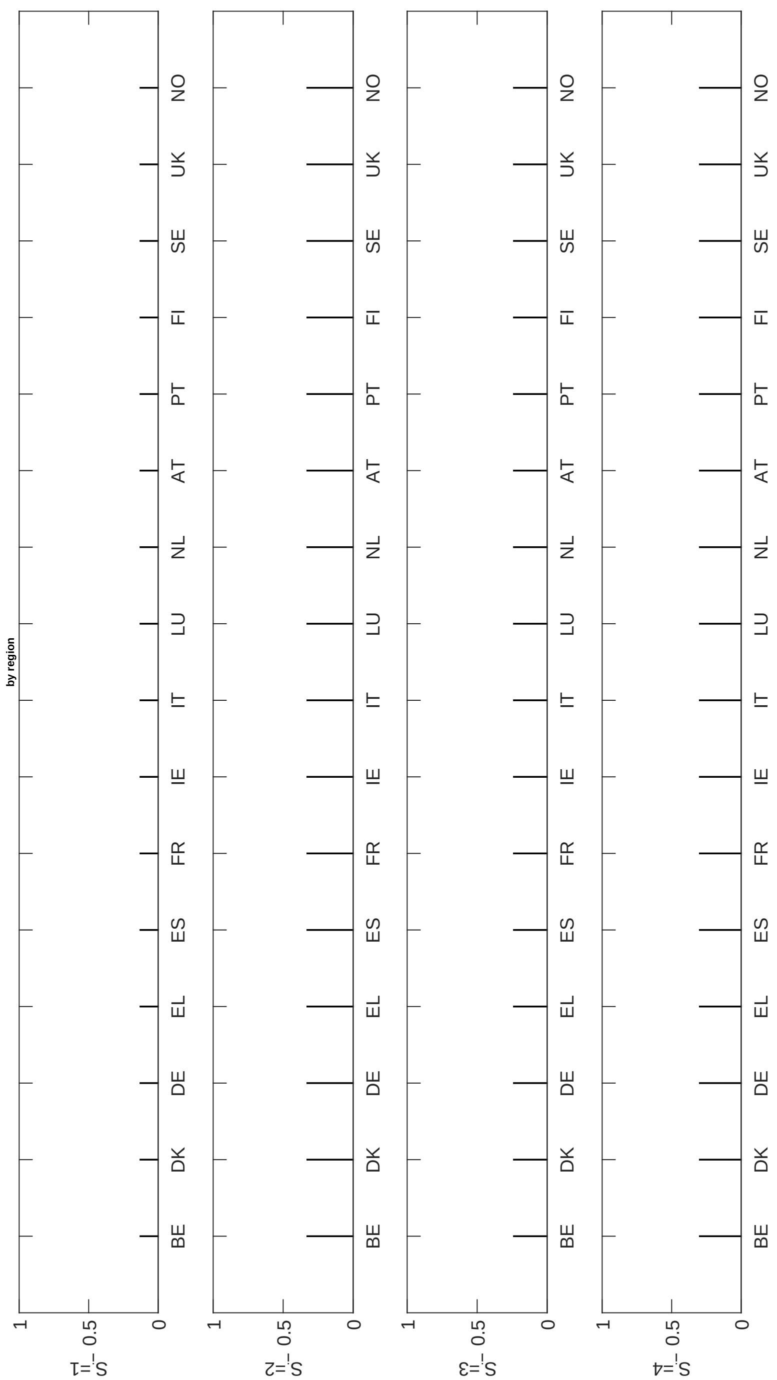

Figure 8: Probability of countries in each group, K=4, p=4

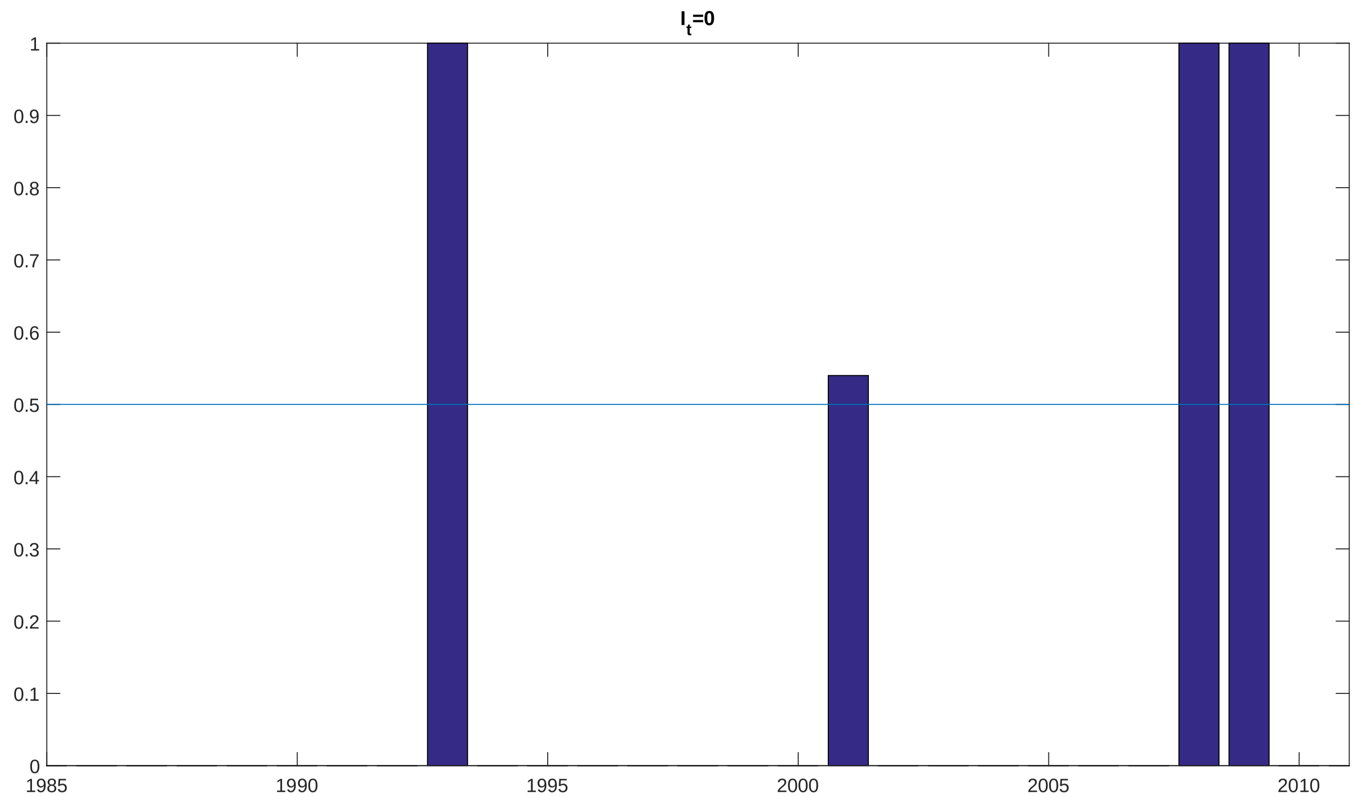

Figure 9: Probability of recessions, K=1, p=4

Notes: The Euro Area Business Cycle Dating Committee of the CEPR identifies two recessions in this sample: 1992.2-1993.2 and 2008.2-2009.2.

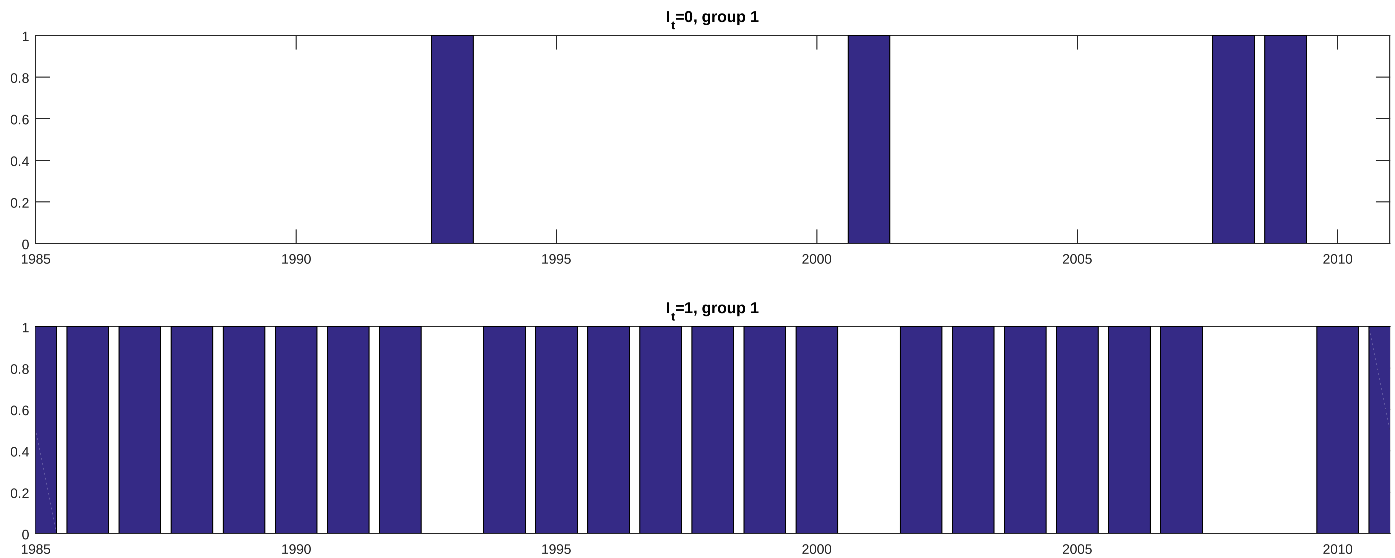

Figure 10: Business cycle, K=1, p=4

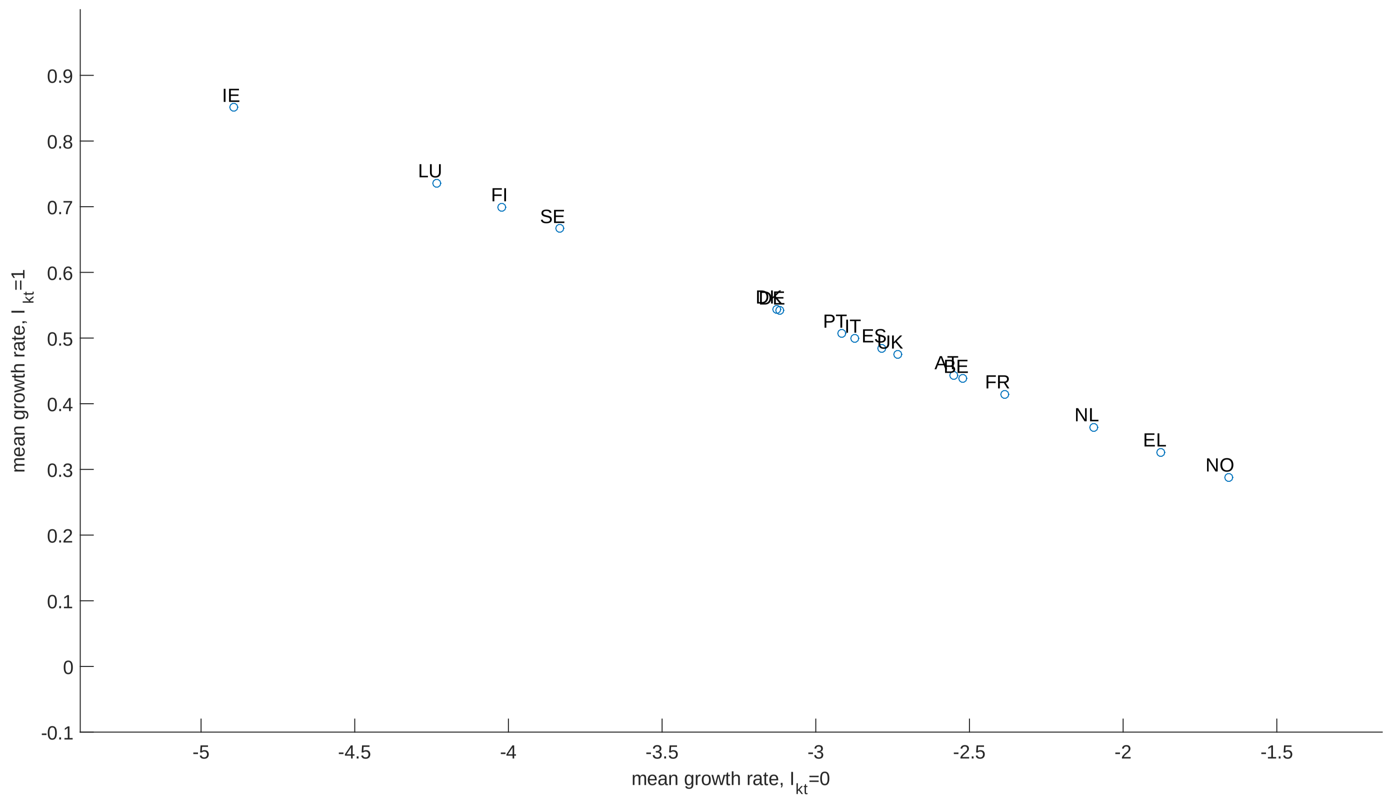

Figure 11: Distribution of countries, K=1, p=4

Notes: The numbers represent the average of the demeaned real GDP growth rates in each cyclical phase and country. Note that demeaning growth rates in each country yields linear correlations between high and low growth rate averages.

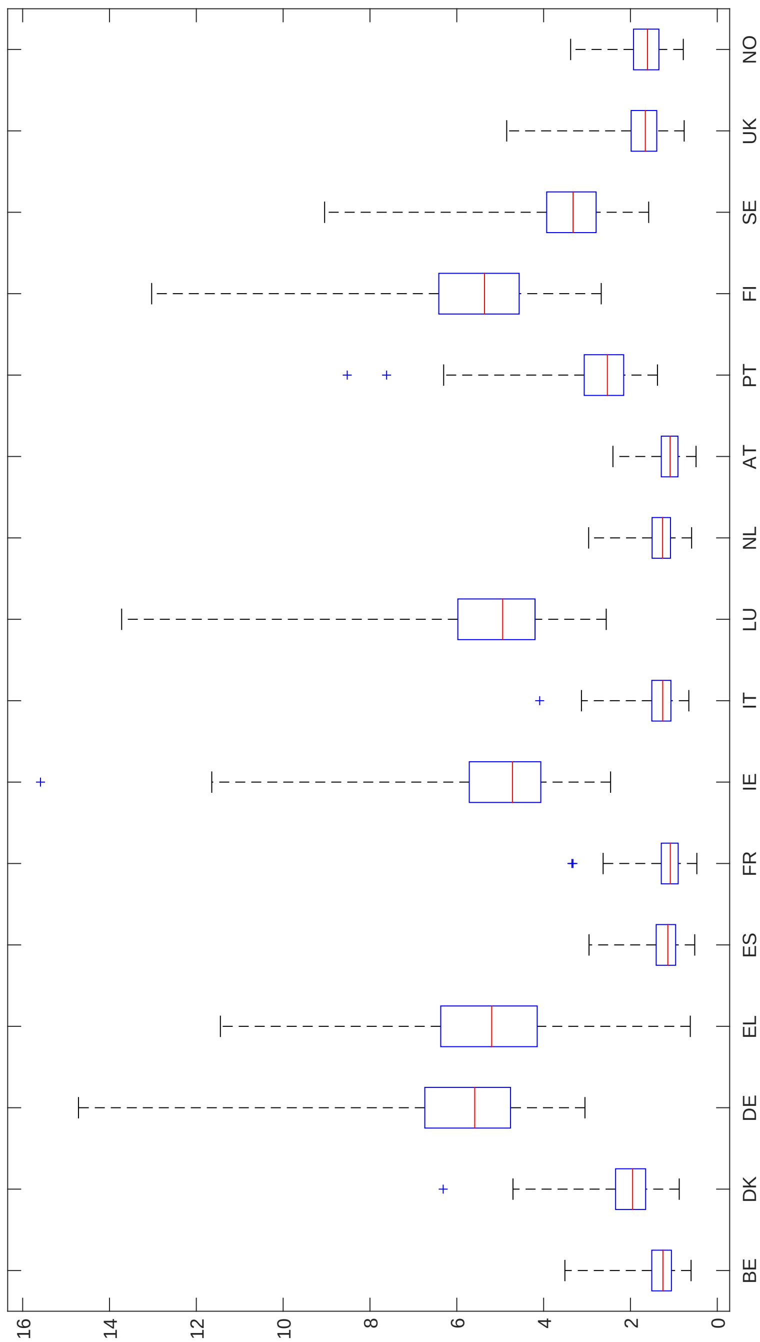

Figure 12: Boxplot of unit-specific variances

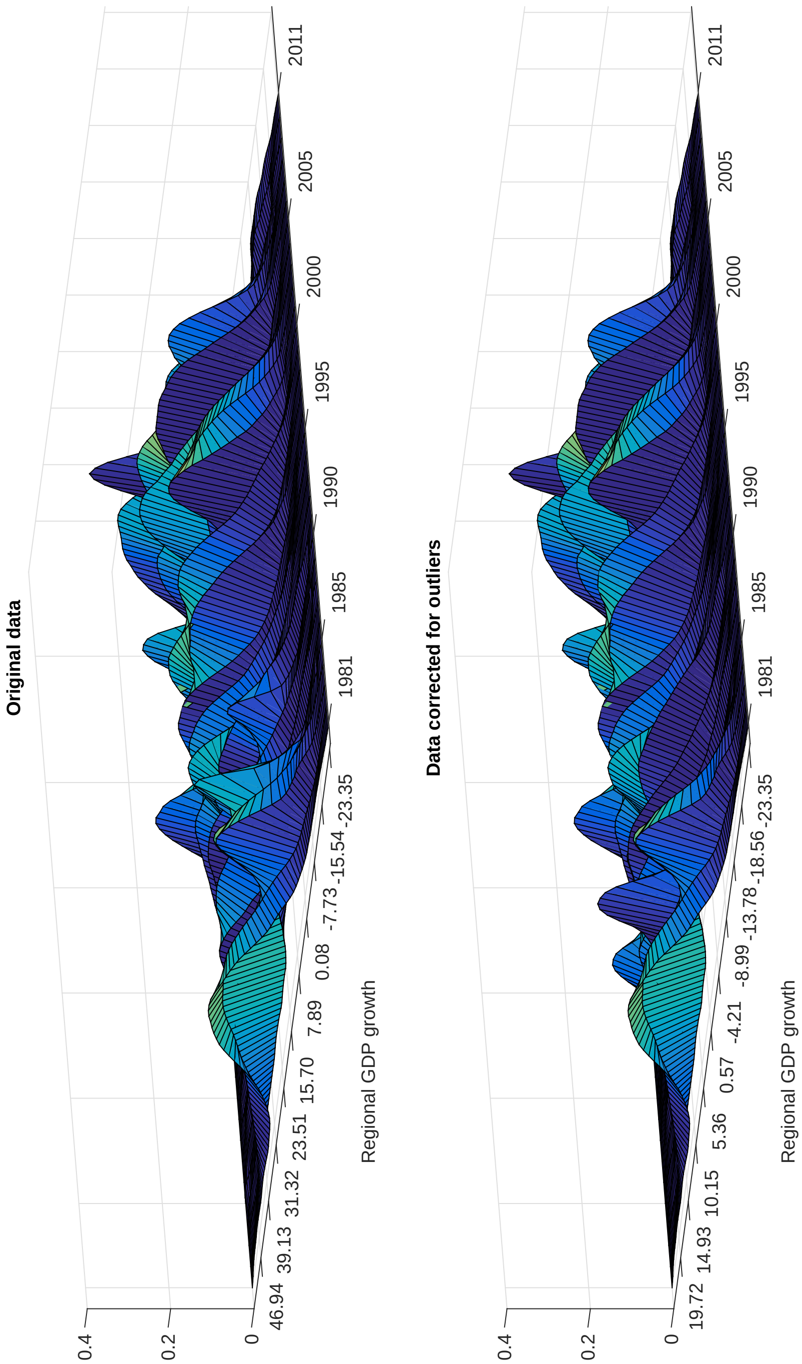

Figure 13: Kernel density over time of regional growth rates

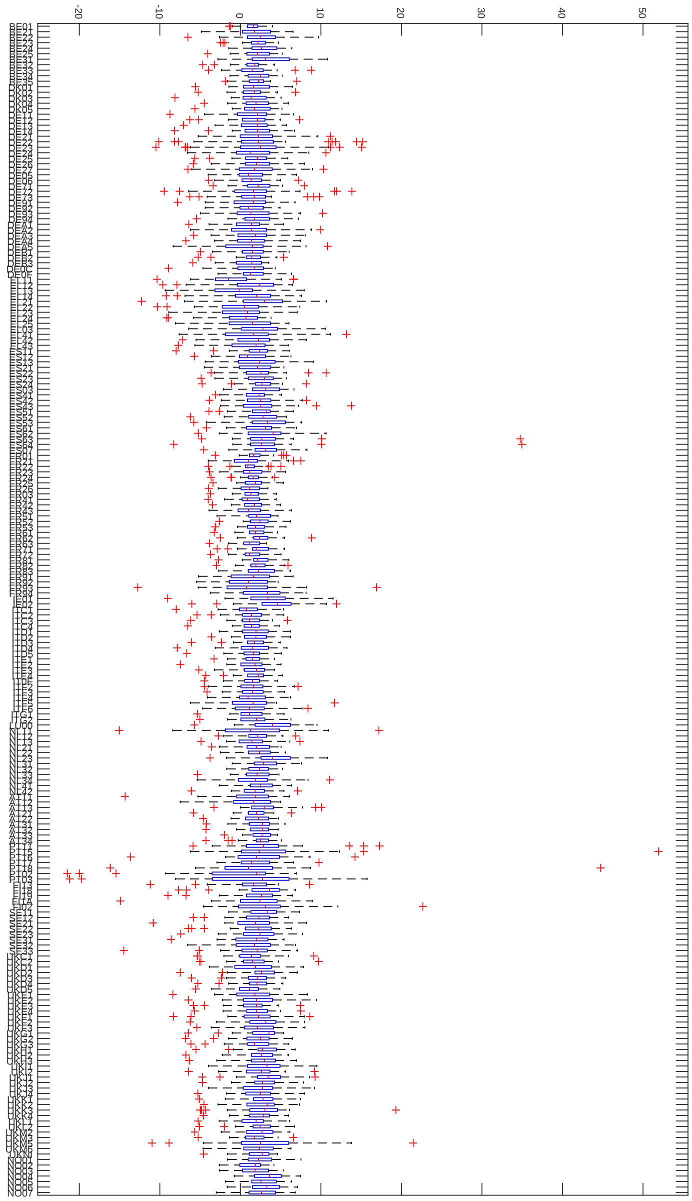

Figure 14: Boxplot of regional growth rates

Notes: The body of the boxplot is represented by a blue box, which goes from the first quartile (25% of the data below this value) to the third quartile (25% of the data above this value) and the red line inside the box represents the median (50% of the data is greater than that value, that is, it is the middle of the dataset). Two horizontal lines, in dotted lines, named whiskers, extend from the upper side and the lower side of the box. The upper whisker goes from the first quartile to the smallest non-outlier in the dataset (the minimum value excluding outliers) and the lower whisker goes from the third quartile to the largest non-outlier of the sample (the maximum value excluding outliers). Outliers are plotted separately as red crosses on the chart.

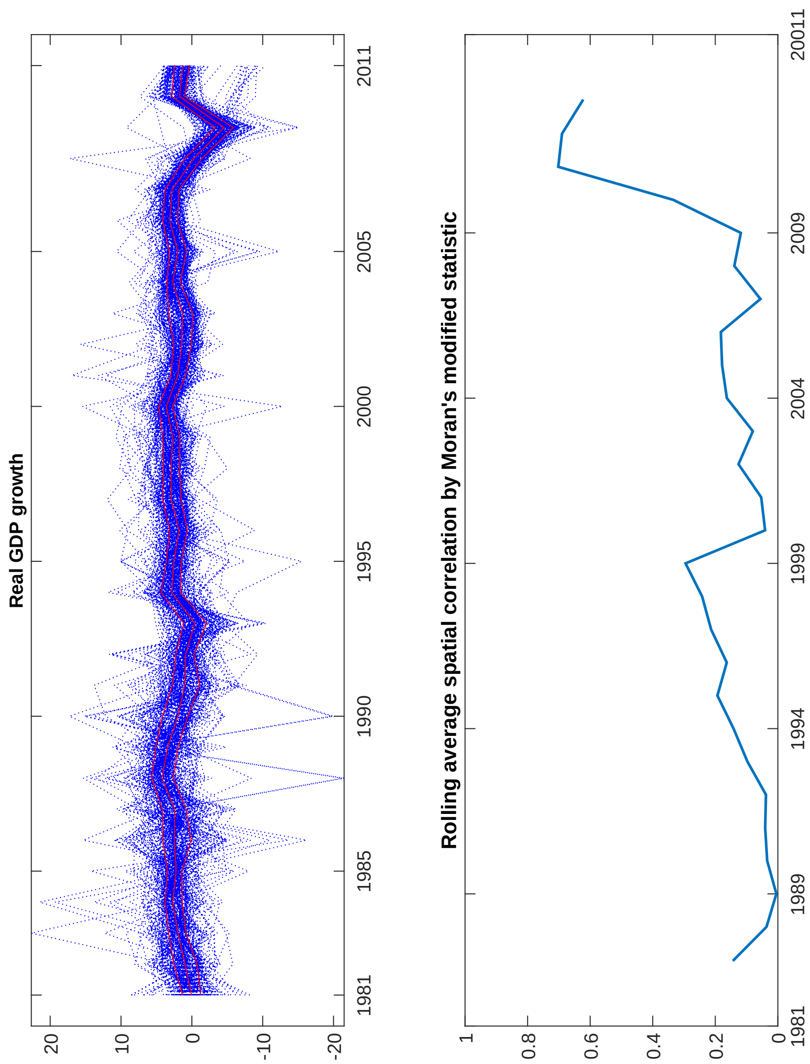

Figure 15: Evolution and comovements between regional growth rates

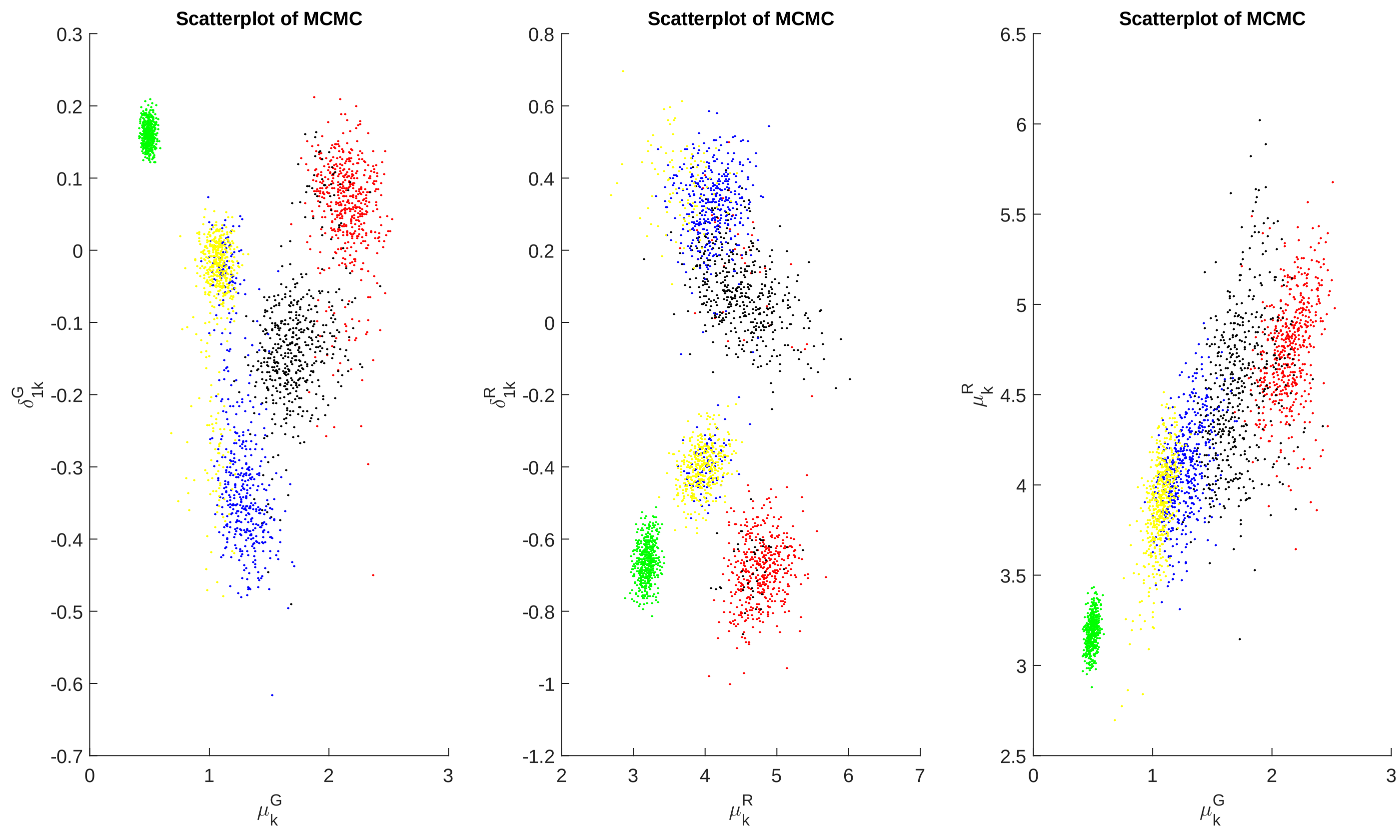

Figure 16: Scatterplot of Markov Chain Monte Carlo draws

Notes: From left to right, scatterplot of simulated group-specific parameters μ_k^G against $\delta_{1,k}^G$, scatterplot of simulated state-group specific effects μ_k^R against $\delta_{1,k}^R$ and scatterplot of simulated group-specific parameters μ_k^G against μ_k^R. The scatterplots display values for K=1,2,3,4,5.

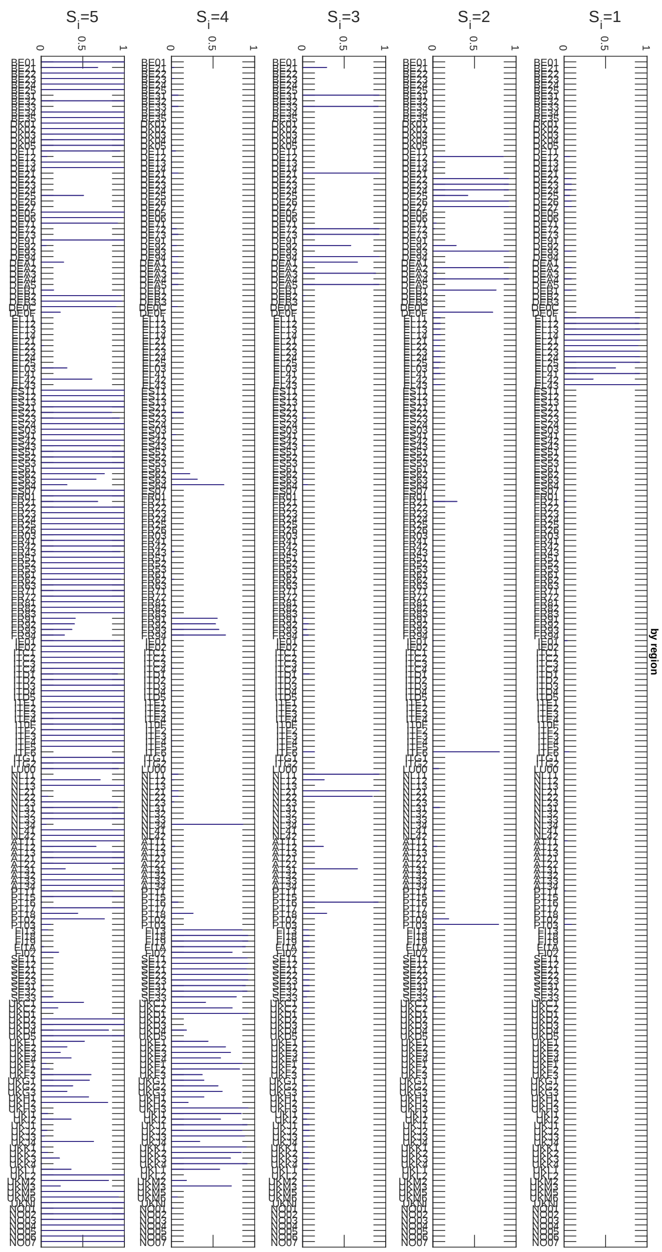

Figure 17: Probability by region of being in each group

Notes: S_i indicates the group.

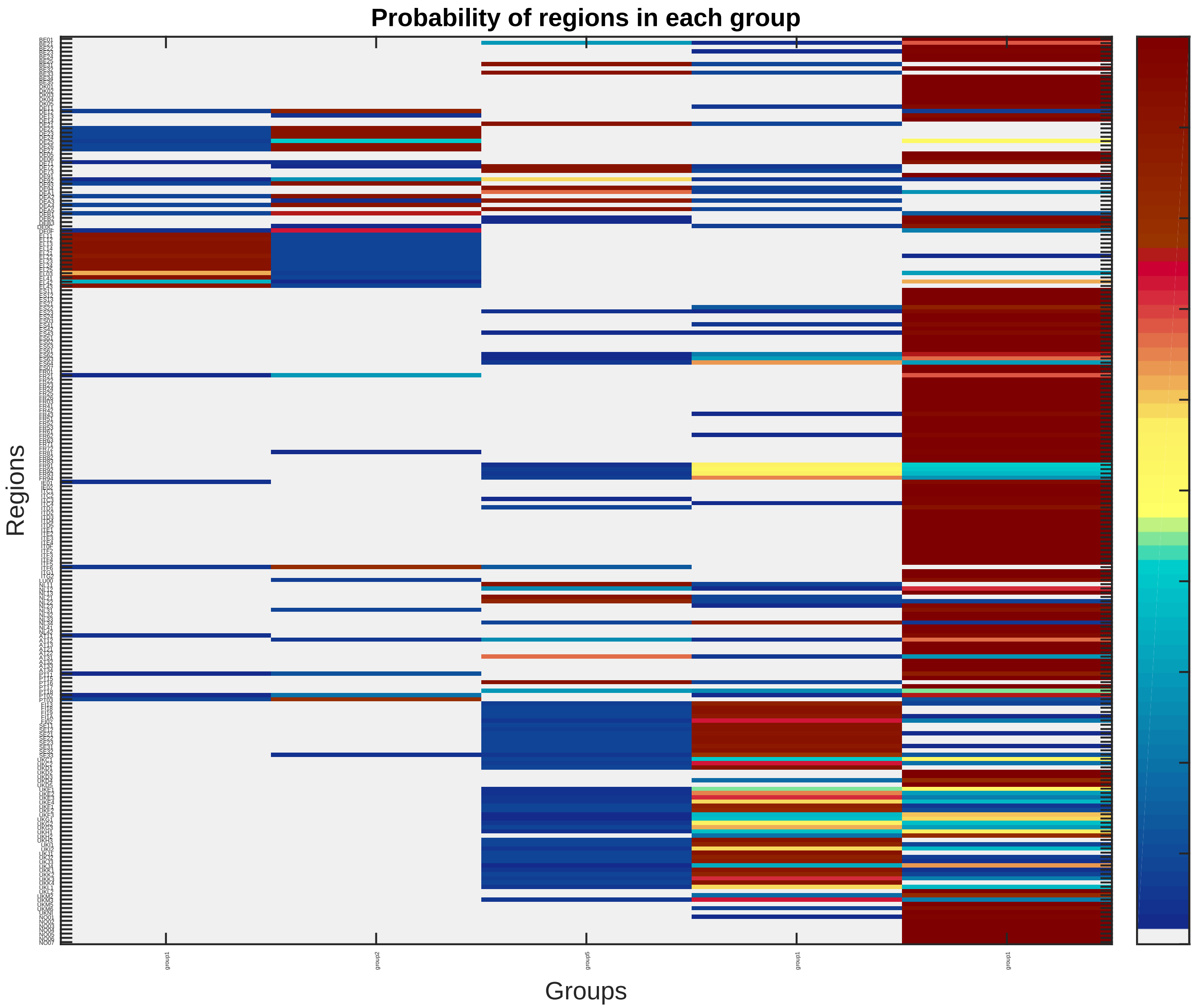

Figure 18: Probability by region of being in each group

Notes: This figure displays the probability of each region to belonging to each group. The lowest probability of being in a group is illustrated with blue colours, whereas the highest probability is represented in maroon.

	G1	G2	G3	G4	G5
BE01 RÉGION DE BRUXELLES-CAPITALE / BRUSSELS HOOFDSTEDELIJK GEWEST	0	0	0	0	1
BE21 Prov. Antwerpen	0	0	0.29	0.03	0.68
BE22 Prov. Limburg (B)	0	0	0	0	1
BE23 Prov. Oost-Vlaanderen	0	0	0	0.03	0.97
BE24 Prov. Vlaams-Brabant	0	0	0	0	1
BE25 Prov. West-Vlaanderen	0	0.01	0	0	0.99
BE31 Prov. Brabant Wallon	0	0	0.92	0.08	0
BE32 Prov. Hainaut	0	0	0	0	1
BE33 Prov. Liège	0	0	0.91	0.08	0.01
BE34 Prov. Luxembourg (B)	0	0	0	0	1
BE35 Prov. Namur	0	0	0	0	1
DK01 Hovedstaden	0	0.01	0	0	0.99
DK02 Sjælland	0	0	0	0.01	0.99
DK03 Syddanmark	0	0	0	0	1
DK04 Midtjylland	0	0	0	0	1
DK05 Nordjylland	0	0	0	0.01	0.99
DE11 Stuttgart	0	0	0	0.05	0.95
DE12 Karlsruhe	0.07	0.85	0.01	0	0.07
DE13 Freiburg	0	0.04	0	0.01	0.95
DE14 Tübingen	0	0.01	0	0	0.99
DE21 Oberbayern	0	0	0.92	0.08	0
DE22 Niederbayern	0.09	0.91	0	0	0
DE23 Oberpfalz	0.09	0.91	0	0	0
DE24 Oberfranken	0.09	0.91	0	0	0
DE25 Mittelfranken	0.07	0.42	0	0	0.51
DE26 Unterfranken	0.09	0.91	0	0	0
DE27 Schwaben	0.09	0.91	0	0	0
DE05 BREMEN	0	0	0	0	1
DE06 HAMBURG	0	0.01	0.01	0	0.98
DE71 Darmstadt	0.02	0.04	0.01	0.01	0.92
DE72 Gießen	0	0.02	0.92	0.06	0
DE73 Kassel	0	0	0.92	0.08	0
DE91 Braunschweig	0	0	0.01	0	0.99
DE92 Hannover	0.02	0.28	0.58	0.06	0.06
DE93 Lüneburg	0.09	0.91	0	0	0
DE94 Weser-Ems	0	0	0.92	0.08	0
DEA1 Düsseldorf	0	0	0.66	0.07	0.27
DEA2 Köln	0.09	0.91	0	0	0
DEA3 Münster	0	0.04	0.88	0.08	0
DEA4 Detmold	0.09	0.91	0	0	0
DEA5 Arnsberg	0	0	0.92	0.08	0
DEB1 Koblenz	0.09	0.76	0	0	0.15
DEB2 Trier	0	0	0.03	0.01	0.96
DEB3 Rheinhessen-Pfalz	0	0	0.02	0.01	0.97
DE0C SAARLAND	0	0.02	0.01	0.07	0.9
DE0F SCHLESWIG-HOLSTEIN	0.04	0.72	0.01	0	0.23
EL11 Anatoliki Makedonia, Thraki	0.91	0.09	0	0	0
EL12 Kentriki Makedonia	0.9	0.09	0	0	0.01
EL13 Dytiki Makedonia	0.91	0.09	0	0	0
EL14 Thessalia	0.91	0.09	0	0	0
EL21 Ipeiros	0.91	0.09	0	0	0
EL22 Ionia Nisia	0.89	0.08	0	0	0.03
EL23 Dytiki Ellada	0.91	0.09	0	0	0
EL24 Sterea Ellada	0.91	0.09	0	0	0
EL25 Peloponnisos	0.91	0.09	0	0	0
EL03 ATTIKI	0.62	0.07	0	0	0.31
EL41 Voreio Aigaio	0.91	0.09	0	0	0
EL42 Notio Aigaio	0.35	0.03	0	0.01	0.61
EL43 Kriti	0.91	0.09	0	0	0

Figure 19: Probability by region of being in each group

		G1	G2	G3	G4	G5
ES11	Galicia	0	0	0	0	1
ES12	Principado de Asturias	0	0	0	0	1
ES13	Cantabria	0	0	0	0.01	0.99
ES21	País Vasco	0	0	0	0	1
ES22	Comunidad Foral de Navarra	0	0	0.01	0.14	0.85
ES23	La Rioja	0	0	0.04	0.02	0.94
ES24	Aragón	0	0	0	0	1
ES03	COMUNIDAD DE MADRID	0	0	0	0	1
ES41	Castilla y León	0	0	0	0.05	0.95
ES42	Castilla-La Mancha	0	0	0	0.01	0.99
ES43	Extremadura	0	0	0.03	0.02	0.95
ES51	Cataluña	0	0	0	0	1
ES52	Comunidad Valenciana	0	0	0	0	1
ES53	Illes Balears	0	0	0	0	1
ES61	Andalucía	0	0	0	0	1
ES62	Región de Murcia	0	0	0.02	0.22	0.76
ES63	Ciudad Autónoma de Ceuta	0	0.01	0.02	0.31	0.66
ES64	Ciudad Autónoma de Melilla	0	0	0.06	0.63	0.31
ES07	CANARIAS	0	0	0	0	1
FR01	ÎLE DE FRANCE	0	0	0	0	1
FR21	Champagne-Ardenne	0.03	0.29	0	0	0.68
FR22	Picardie	0	0	0	0	1
FR23	Haute-Normandie	0	0	0	0	1
FR24	Centre	0	0	0	0	1
FR25	Basse-Normandie	0	0	0	0	1
FR26	Bourgogne	0	0	0	0	1
FR03	NORD - PAS-DE-CALAIS	0	0	0	0	1
FR41	Lorraine	0	0	0	0	1
FR42	Alsace	0	0	0	0	1
FR43	Franche-Comté	0	0.01	0.01	0.03	0.95
FR51	Pays de la Loire	0	0	0	0	1
FR52	Bretagne	0	0	0	0	1
FR53	Poitou-Charentes	0	0	0	0	1
FR61	Aquitaine	0	0	0	0	1
FR62	Midi-Pyrénées	0	0.01	0	0.03	0.96
FR63	Limousin	0	0	0	0	1
FR71	Rhône-Alpes	0	0	0	0	1
FR72	Auvergne	0	0	0	0	1
FR81	Languedoc-Roussillon	0	0.02	0	0	0.98
FR82	Provence-Alpes-Côte d'Azur	0	0.01	0	0	0.99
FR83	Corse	0	0	0	0	1
FR91	Guadeloupe	0	0	0.04	0.55	0.41
FR92	Martinique	0	0	0.07	0.53	0.4
FR93	Guyane	0.01	0	0.05	0.57	0.37
FR94	Réunion	0	0	0.07	0.65	0.28
IE01	Border, Midland and Western	0.04	0.01	0	0	0.95
IE02	Southern and Eastern	0	0.01	0	0	0.99

Figure 19 (Cont.): Probability by region of being in each group

		G1	G2	G3	G4	G5
ITC1	Piemonte	0	0	0	0.01	0.99
ITC2	Valle d'Aosta/Vallée d'Aoste	0	0	0	0.01	0.99
ITC3	Liguria	0	0	0.02	0	0.98
ITC4	Lombardia	0	0	0	0.02	0.98
ITD1	Provincia Autonoma Bolzano/Bozen	0	0	0.08	0	0.92
ITD2	Provincia Autonoma Trento	0	0	0	0	1
ITD3	Veneto	0	0	0	0	1
ITD4	Friuli-Venezia Giulia	0	0	0	0.01	0.99
ITD5	Emilia-Romagna	0	0	0	0	1
ITE1	Toscana	0	0	0	0	1
ITE2	Umbria	0	0	0	0	1
ITE3	Marche	0	0	0	0.01	0.99
ITE4	Lazio	0	0	0	0	1
IT0F	SUD	0	0	0	0	1
ITF2	Molise	0	0	0	0.01	0.99
ITF3	Campania	0	0	0	0	1
ITF4	Puglia	0	0	0	0.01	0.99
ITF5	Basilicata	0	0	0	0.01	0.99
ITF6	Calabria	0.06	0.8	0.14	0	0
ITG1	Sicilia	0	0	0	0	1
ITG2	Sardegna	0	0	0	0	1
LU00	LUXEMBOURG (GRAND-DUCHÉ)	0	0.07	0	0	0.93
NL11	Groningen	0	0	0.92	0.08	0
NL12	Friesland (NL)	0	0	0.26	0.03	0.71
NL13	Drenthe	0	0	0	0	1
NL21	Overijssel	0	0	0.92	0.08	0
NL22	Gelderland	0	0	0.84	0.08	0.08
NL23	Flevoland	0.01	0	0	0.03	0.96
NL31	Utrecht	0	0.08	0	0	0.92
NL32	Noord-Holland	0	0	0	0	1
NL33	Zuid-Holland	0	0	0	0	1
NL34	Zeeland	0	0	0.08	0.86	0.06
NL41	Noord-Brabant	0	0	0	0	1
NL42	Limburg (NL)	0	0	0	0.01	0.99
AT11	Burgenland (A)	0.04	0.01	0	0	0.95
AT12	Niederösterreich	0	0.05	0.25	0.04	0.66
AT13	Wien	0	0	0	0	1
AT21	Kärnten	0	0	0	0	1
AT22	Steiermark	0	0	0	0	1
AT31	Oberösterreich	0	0	0.66	0.05	0.29
AT32	Salzburg	0	0	0	0	1
AT33	Tirol	0	0	0	0	1
AT34	Vorarlberg	0	0	0	0	1
PT11	Norte	0.02	0.12	0	0	0.86
PT15	Algarve	0	0	0	0.01	0.99
PT16	Centro (P)	0	0	0.91	0.08	0.01
PT17	Lisboa	0	0	0	0.01	0.99
PT18	Alentejo	0	0.01	0.29	0.26	0.44
PT02	Região Autónoma dos AÇORES	0.03	0.19	0	0.02	0.76
PT03	Região Autónoma da MADEIRA	0.09	0.79	0	0.01	0.11
FI13	Itä-Suomi	0	0	0.07	0.85	0.08
FI18	Etelä-Suomi	0	0	0.08	0.92	0
FI19	Länsi-Suomi	0	0	0.08	0.92	0
FI1A	Pohjois-Suomi	0	0	0.08	0.89	0.03
FI02	ÅLAND	0.01	0	0.05	0.73	0.21

Figure 19 (Cont.): Probability by region of being in each group

	G1	G2	G3	G4	G5
SE11 Stockholm	0	0	0.08	0.91	0.01
SE12 Östra Mellansverige	0	0	0.07	0.92	0.01
SE21 Småland med öarna	0	0	0.08	0.9	0.02
SE22 Sydsverige	0	0	0.08	0.92	0
SE23 Västsverige	0	0	0.08	0.92	0
SE31 Norra Mellansverige	0	0	0.08	0.89	0.03
SE32 Mellersta Norrland	0	0.01	0.08	0.91	0
SE33 Övre Norrland	0	0.04	0.05	0.78	0.13
UKC1 Tees Valley and Durham	0	0	0.08	0.41	0.51
UKC2 Northumberland and Tyne and Wear	0	0	0.07	0.73	0.2
UKD1 Cumbria	0	0	0.08	0.92	0
UKD2 Cheshire	0	0	0	0	1
UKD3 Greater Manchester	0	0	0	0	1
UKD4 Lancashire	0	0	0.01	0.18	0.81
UKD5 Merseyside	0	0	0	0	1
UKE1 East Yorkshire and Northern Lincolnshire	0	0	0.04	0.44	0.52
UKE2 North Yorkshire	0	0	0.04	0.65	0.31
UKE3 South Yorkshire	0	0	0.06	0.71	0.23
UKE4 West Yorkshire	0	0	0.05	0.59	0.36
UKF1 Derbyshire and Nottinghamshire	0	0.01	0.08	0.85	0.06
UKF2 Leicestershire, Rutland and Northamptonshire	0	0	0.08	0.82	0.1
UKF3 Lincolnshire	0	0	0.03	0.37	0.6
UKG1 Herefordshire, Worcestershire and Warwickshire	0	0	0.03	0.39	0.58
UKG2 Shropshire and Staffordshire	0	0	0.06	0.56	0.38
UKG3 West Midlands	0	0	0.08	0.61	0.31
UKH1 East Anglia	0	0	0.04	0.39	0.57
UKH2 Bedfordshire and Hertfordshire	0	0	0	0.2	0.8
UKH3 Essex	0	0	0.08	0.92	0
UKI1 Inner London	0	0	0.08	0.84	0.08
UKI2 Outer London	0	0	0.05	0.59	0.36
UKJ1 Berkshire, Buckinghamshire and Oxfordshire	0	0	0.08	0.91	0.01
UKJ2 Surrey, East and West Sussex	0	0	0.08	0.85	0.07
UKJ3 Hampshire and Isle of Wight	0	0	0.08	0.88	0.04
UKJ4 Kent	0	0	0.03	0.34	0.63
UKK1 Gloucestershire, Wiltshire and Bristol/Bath area	0	0	0.06	0.9	0.04
UKK2 Dorset and Somerset	0	0	0.08	0.84	0.08
UKK3 Cornwall and Isles of Scilly	0	0	0.07	0.71	0.22
UKK4 Devon	0	0	0.08	0.91	0.01
UKL1 West Wales and The Valleys	0	0	0.06	0.58	0.36
UKL2 East Wales	0	0	0	0	1
UKM2 Eastern Scotland	0	0	0.01	0.18	0.81
UKM3 South Western Scotland	0	0	0.05	0.72	0.23
UKM5 North Eastern Scotland	0	0	0.01	0	0.99
UKM6 Highlands and Islands	0	0	0	0.07	0.93
UKNI NORTHERN IRELAND	0	0	0	0	1

Figure 19 (Cont.): Probability by region of being in each group

	G1	G2	G3	G4	G5
NO01 Oslo og Akershus	0	0	0	0.02	0.98
NO02 Hedmark og Oppland	0	0	0	0	1
NO03 Sør-Østlandet	0	0	0	0	1
NO04 Agder og Rogaland	0	0	0	0	1
NO05 Vestlandet	0	0	0	0	1
NO06 Trøndelag	0	0	0	0	1
NO07 Nord-Norge	0	0	0	0	1

Figure 19 (Cont.): Probability by region of being in each group

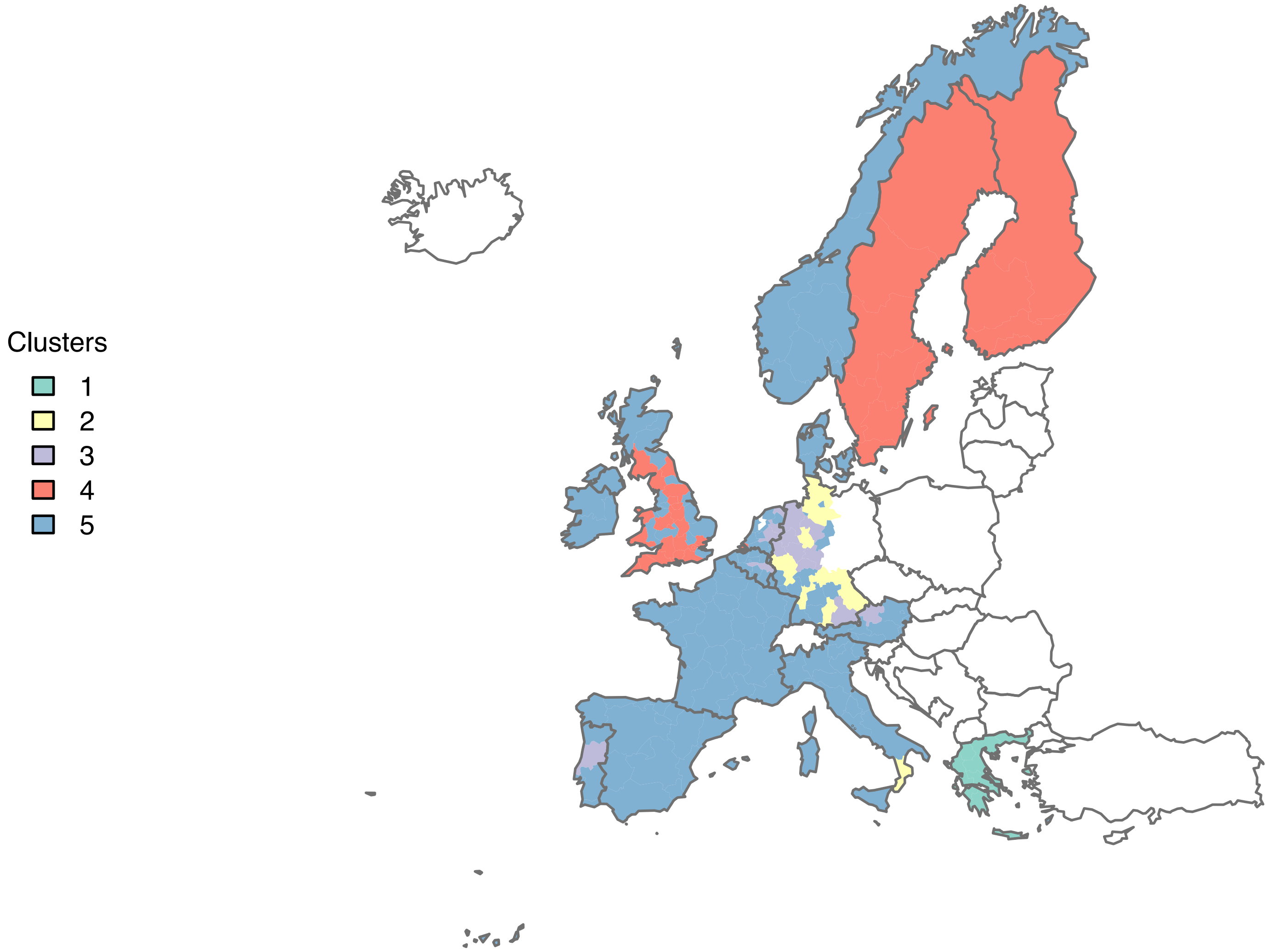

Figure 20: Geographical distribution of regional business cycles into different groups

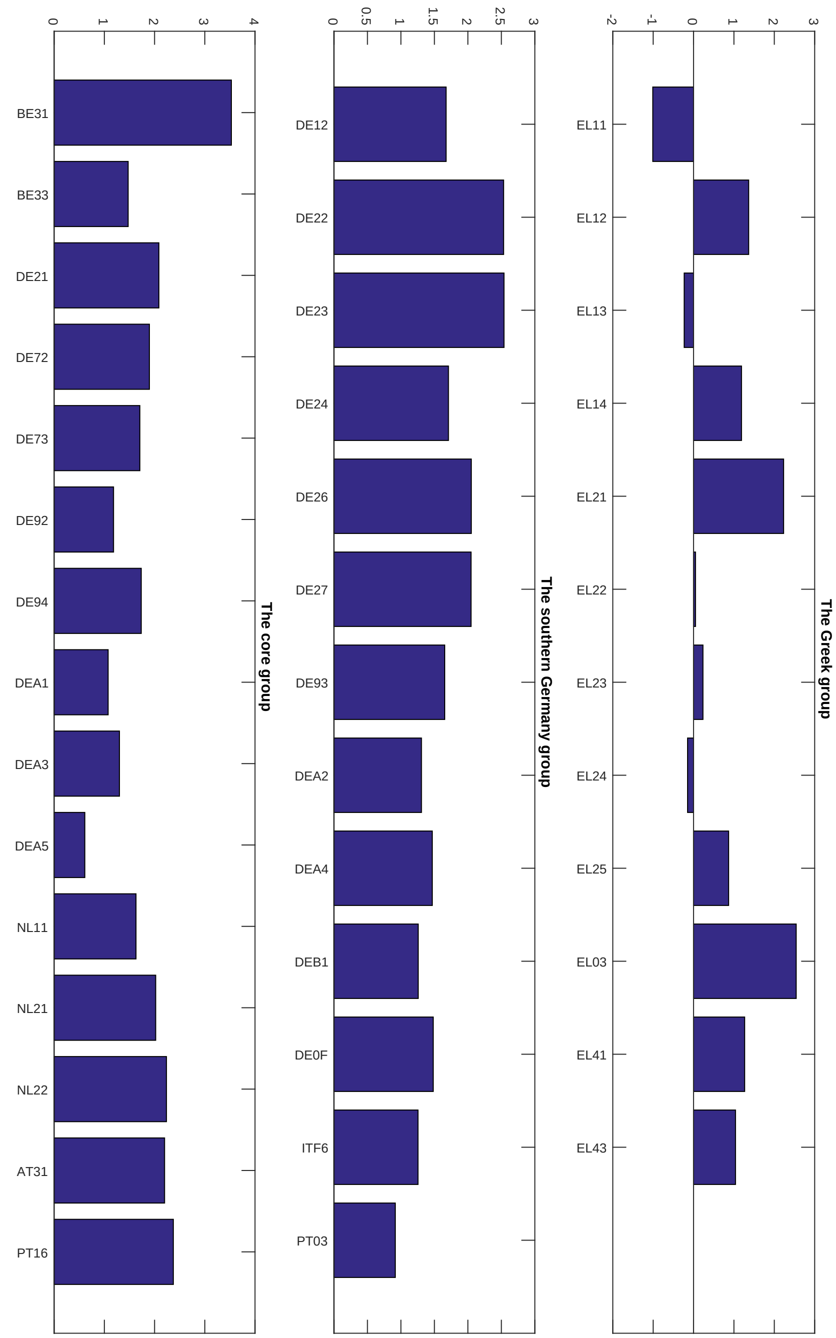

Figure 21: Real GDP growth by region in each group

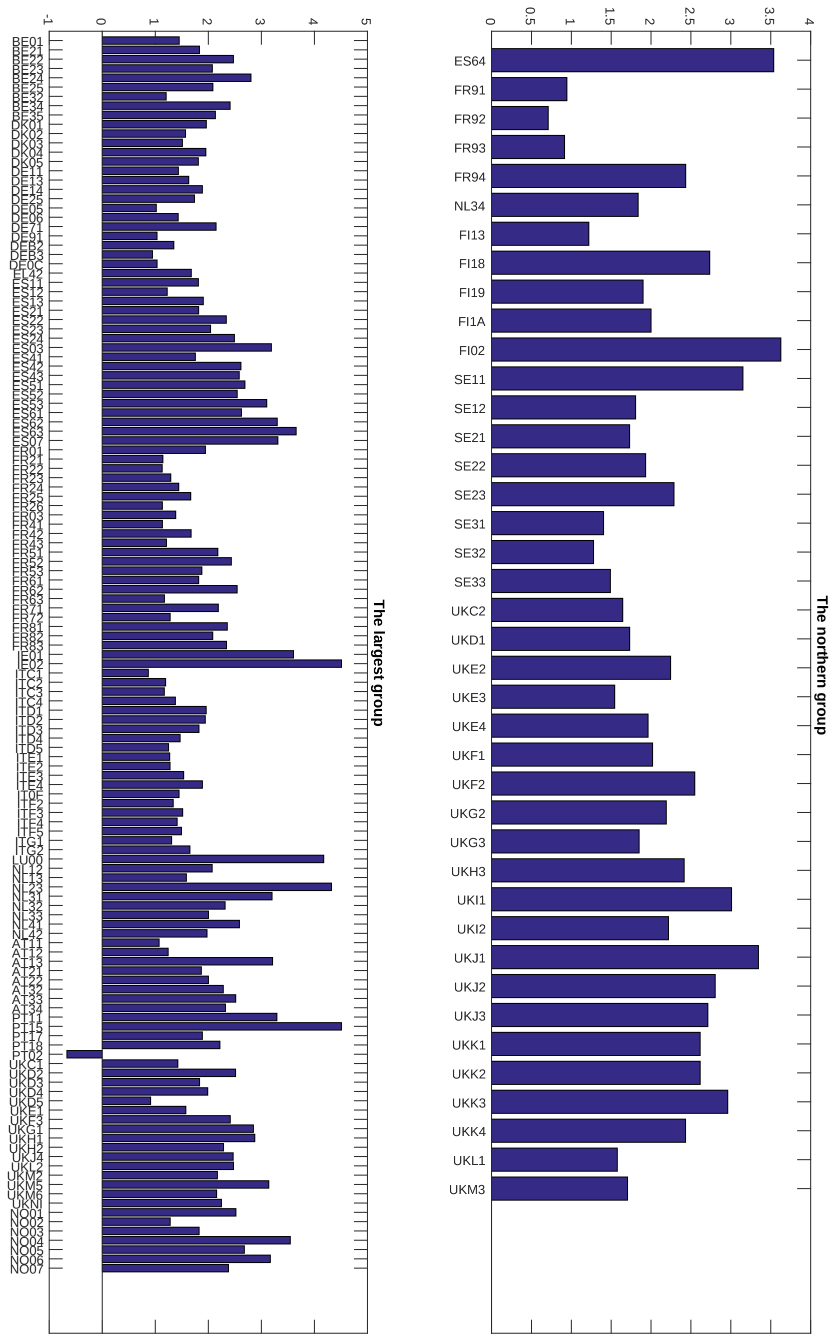

Figure 21 (Cont.): Real GDP growth by region in each group

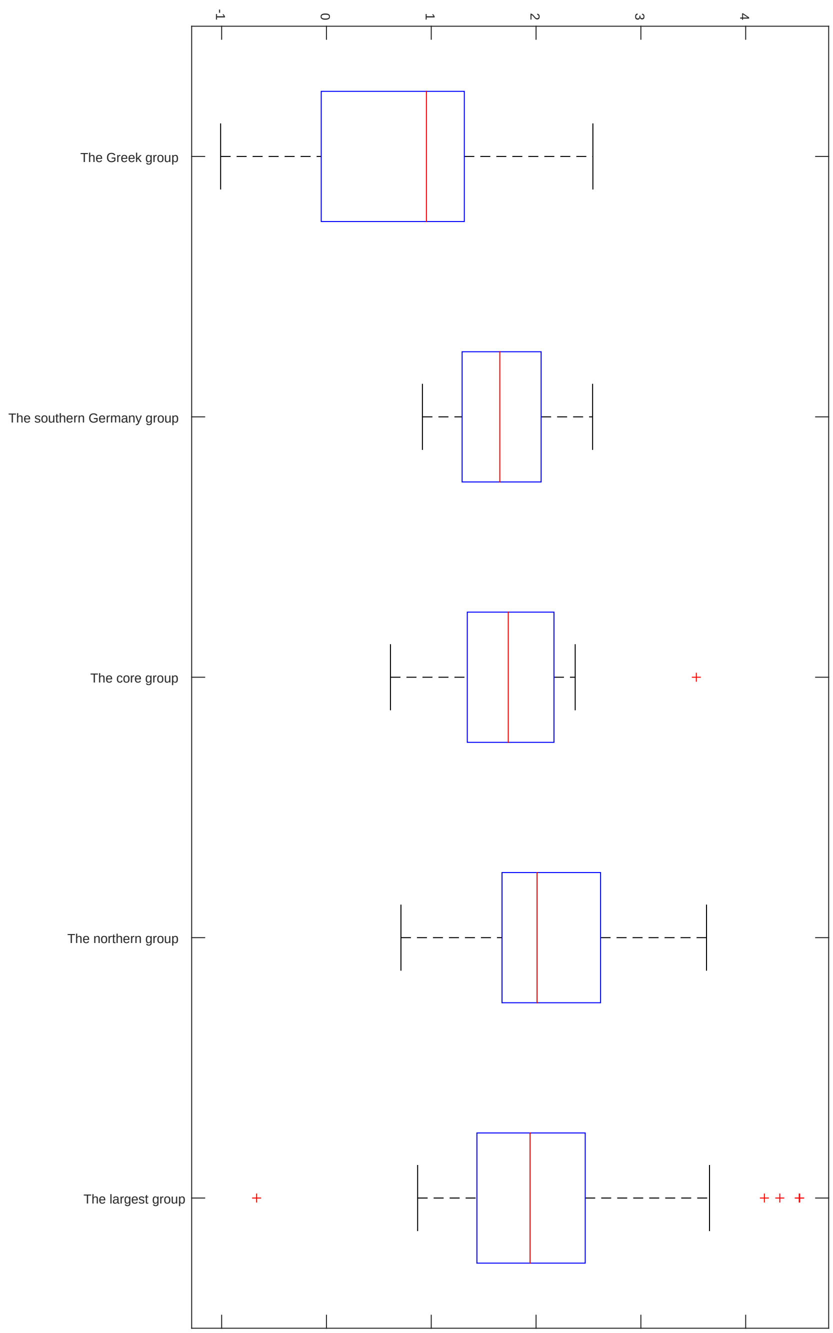

Figure 22: Boxplot of the real GDP growth by group

Notes: The body of the boxplot is represented by a blue box, which goes from the first quartile (25% of the data below this value) to the third quartile (25% of the data above this value) and the red line inside the box represents the median (50% of the data is greater than that value, that is, it is the middle of the dataset). Two horizontal lines, in dotted lines, named whiskers, extend from the upper side and the lower side of the

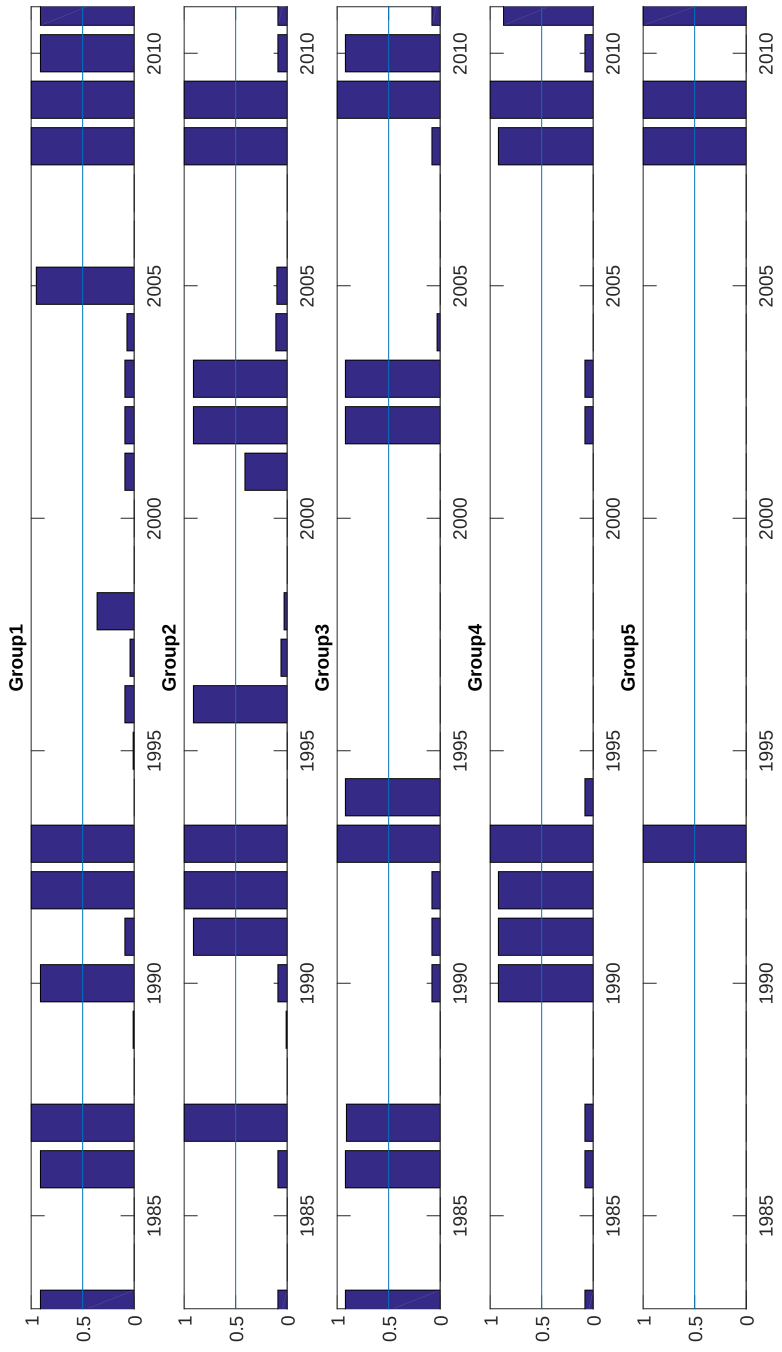

Figure 23: Probability of recession by group $I_t = 0$

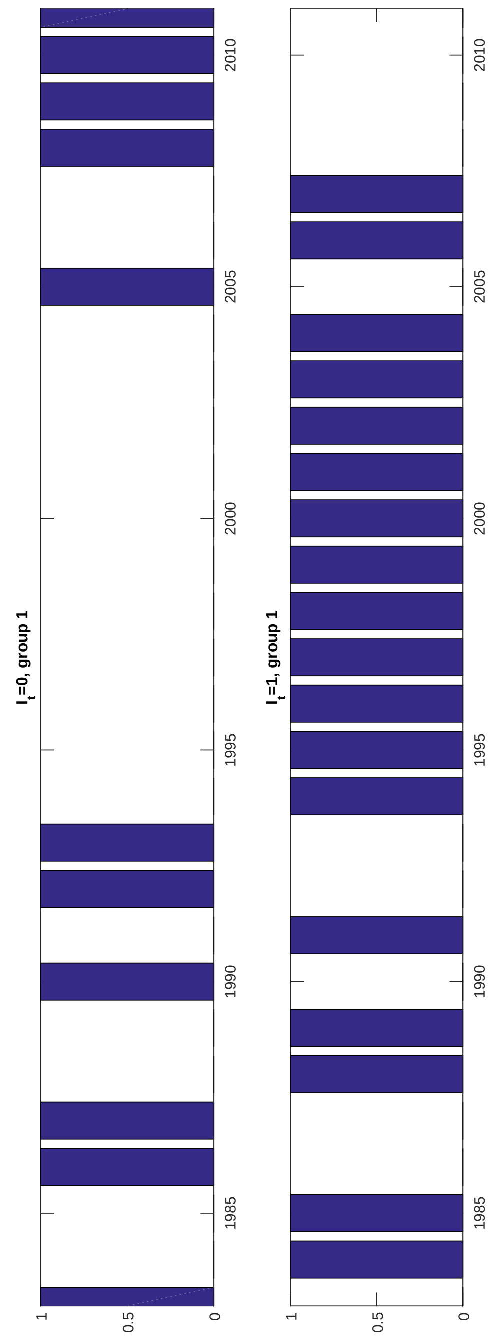

Figure 24: Business cycle Group one

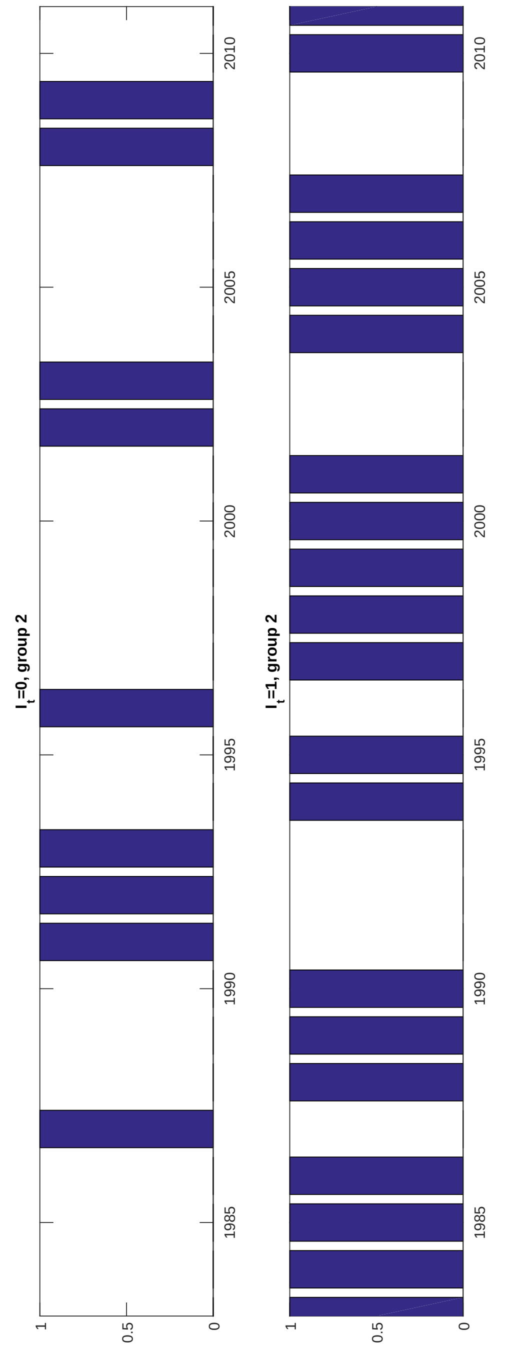

Figure 25: Business cycle Group two

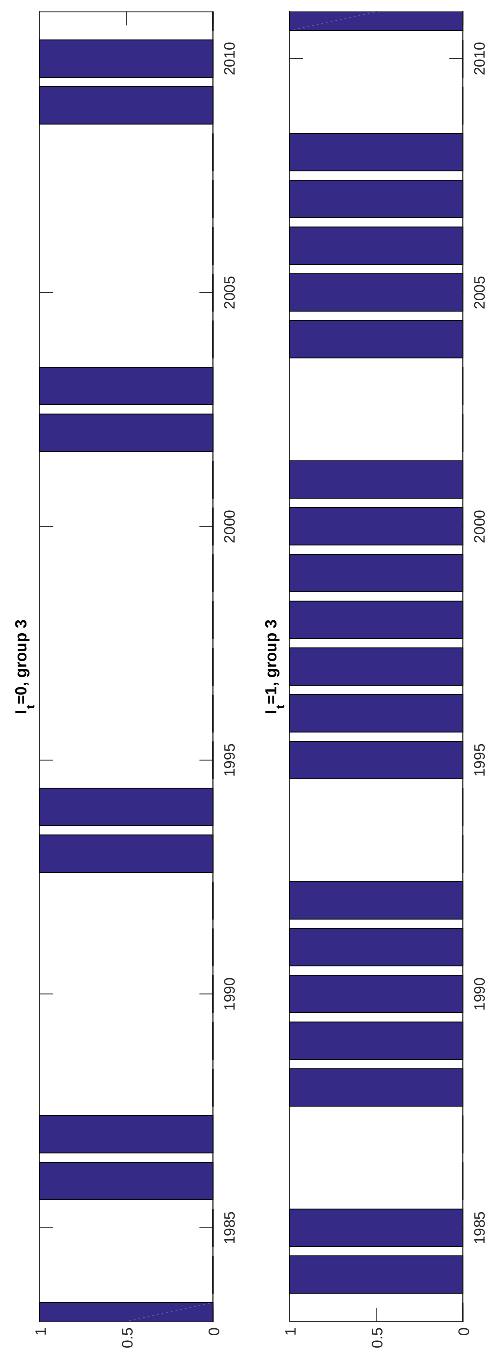

Figure 26: Business cycle Group three

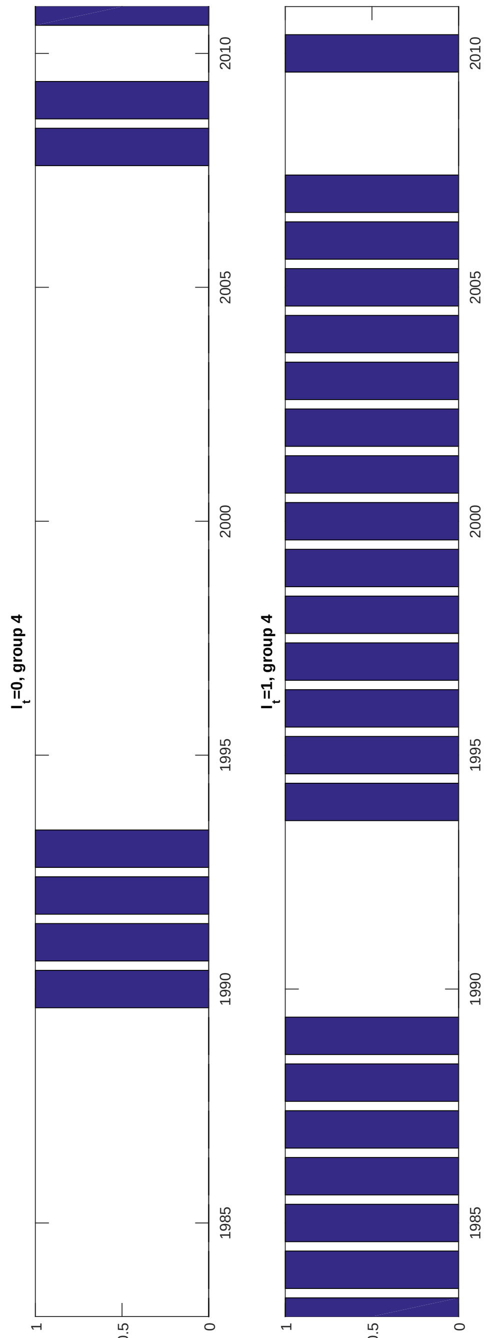

Figure 27: Business cycle Group four

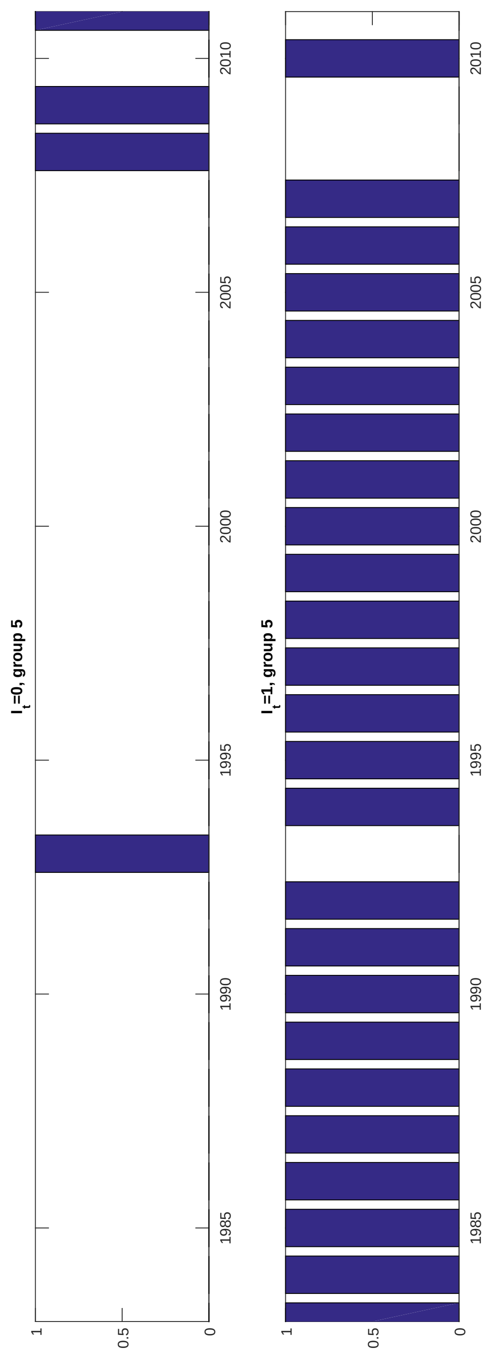

Figure 28: Business cycle Group five

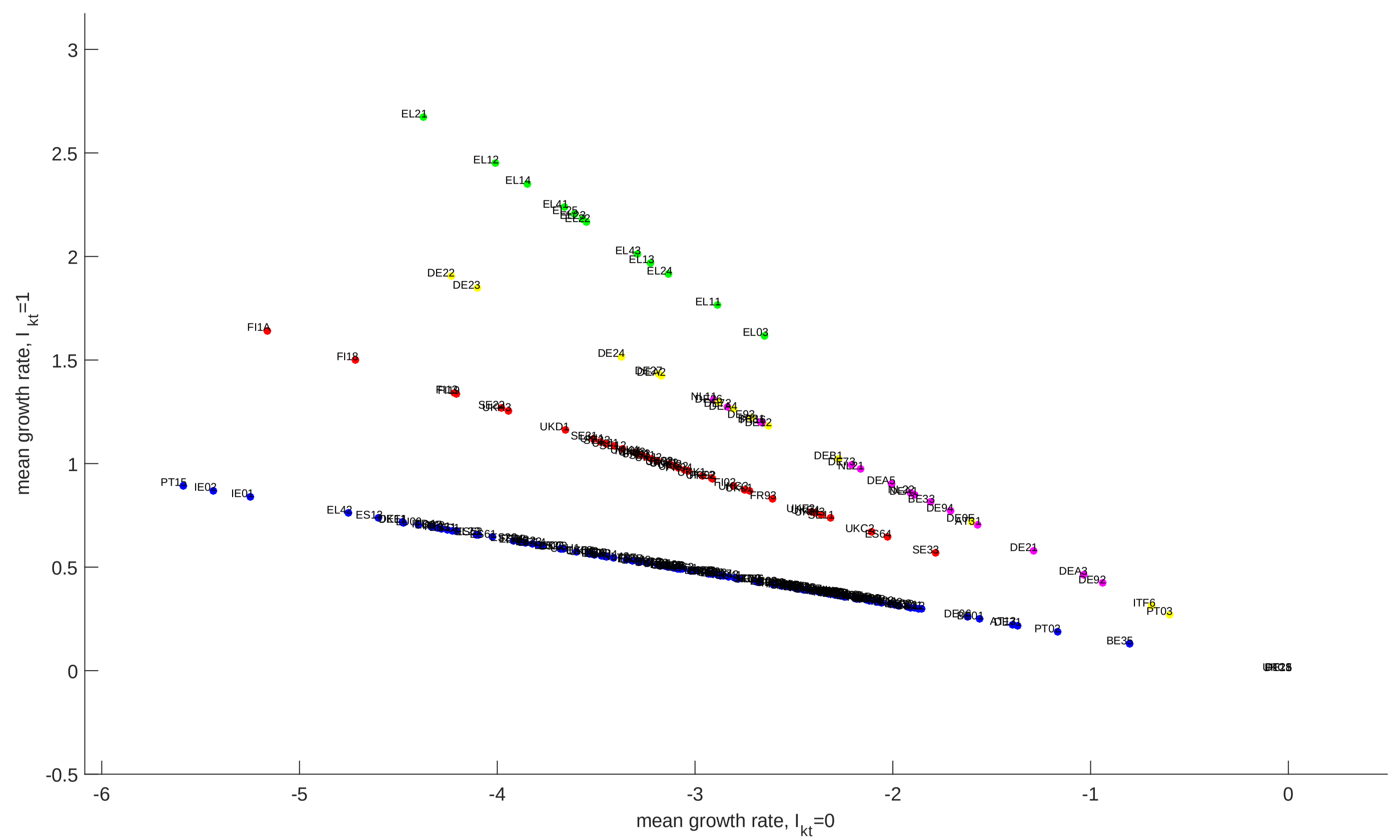

Figure 29: Distribution of regions (by groups) according to their mean growth rate during expansion and recession

Notes: The numbers represent the average of the demeaned real GDP growth rates in each cyclical phase and region.
Group one in green, group two in yellow, group three in purple, group four in red and group five in blue.
Note that demeaning growth rates in each region yields linear correlations between high and low growth rate averages.

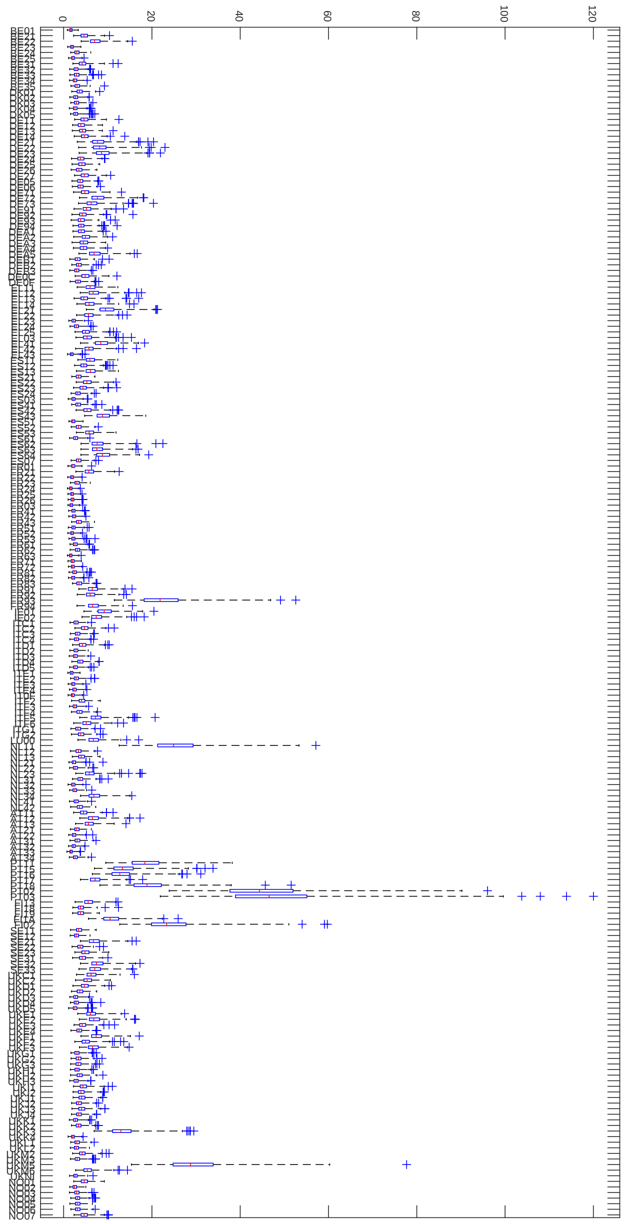

Figure 30: Boxplot of unit specific variances

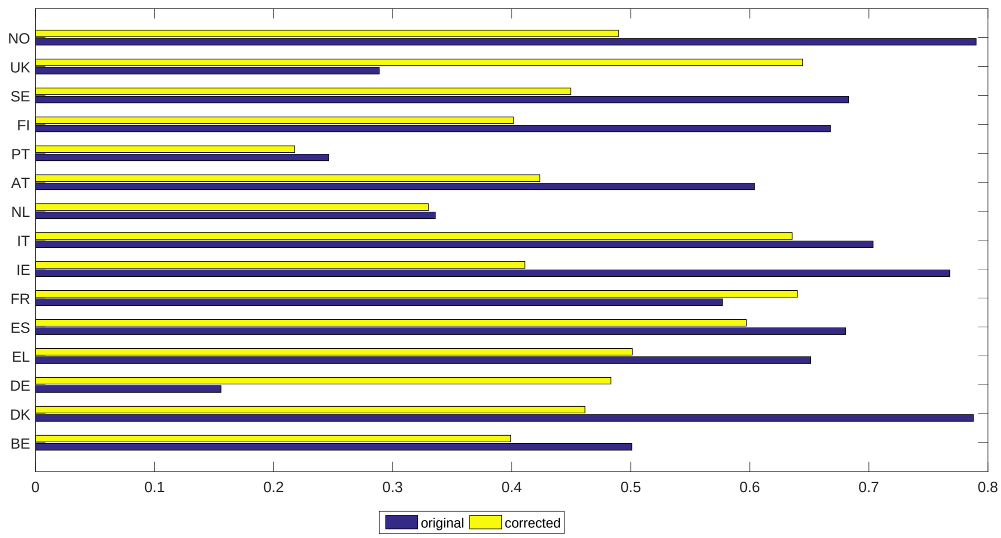

Figure 31: Indexes of intra-country regional synchronization

Note: LU has been removed from the Figure as it is a one-region country.

Appendix: List of NUTS-2 regions and codes

This appendix summarizes the list of regions (NUTS-2), countries and corresponding codes used for the empirical analysis. The nomenclature of territorial units for statistics (NUTS) provides a single, uniform breakdown of the economic territory of the European Union. Indeed, NUTS is the geographical breakdown used in compiling regional accounts. We use the NUTS 2013 classification, which is valid as from 1 January 2015.[56]

[56] For details, see `http://ec.europa.eu/eurostat/web/nuts/overview`.

NUTS2 CODE	GEOGRAPHICAL UNIT
BE	BELGIQUE-BELGIË
BE1	RÉGION DE BRUXELLES-CAPITALE / BRUSSELS HOOFDSTEDELIJK GEWEST
BE21	Prov. Antwerpen
BE22	Prov. Limburg (B)
BE23	Prov. Oost-Vlaanderen
BE24	Prov. Vlaams-Brabant
BE25	Prov. West-Vlaanderen
BE31	Prov. Brabant Wallon
BE32	Prov. Hainaut
BE33	Prov. Liège
BE34	Prov. Luxembourg (B)
BE35	Prov. Namur
DK	DANMARK
DK01	Hovedstaden
DK02	Sjælland
DK03	Syddanmark
DK04	Midtjylland
DK05	Nordjylland
DE	GERMANY
DE11	Stuttgart
DE12	Karlsruhe
DE13	Freiburg
DE14	Tübingen
DE21	Oberbayern
DE22	Niederbayern
DE23	Oberpfalz
DE24	Oberfranken
DE25	Mittelfranken
DE26	Unterfranken
DE27	Schwaben
DE3	BERLIN
DE41	Brandenburg - Nordost
DE42	Brandenburg - Südwest
DE5	BREMEN
DE6	HAMBURG
DE71	Darmstadt
DE72	Gießen
DE73	Kassel
DE8	MECKLENBURG-VORPOMMERN
DE91	Braunschweig
DE92	Hannover
DE93	Lüneburg
DE94	Weser-Ems
DEA1	Düsseldorf
DEA2	Köln
DEA3	Münster
DEA4	Detmold
DEA5	Arnsberg
DEB1	Koblenz
DEB2	Trier
DEB3	Rheinhessen-Pfalz
DEC	SAARLAND
DED1	Chemnitz
DED2	Dresden
DED3	Leipzig
DEE	SACHSEN-ANHALT
DEF	SCHLESWIG-HOLSTEIN
DEG	THÜRINGEN

NUTS2 CODE	GEOGRAPHICAL UNIT
EL	GREECE
EL11	Anatoliki Makedonia, Thraki
EL12	Kentriki Makedonia
EL13	Dytiki Makedonia
EL14	Thessalia
EL21	Ipeiros
EL22	Ionia Nisia
EL23	Dytiki Ellada
EL24	Sterea Ellada
EL25	Peloponnisos
EL3	ATTIKI
EL41	Voreio Aigaio
EL42	Notio Aigaio
EL43	Kriti
ES	ESPAÑA
ES11	Galicia
ES12	Principado de Asturias
ES13	Cantabria
ES21	País Vasco
ES22	Comunidad Foral de Navarra
ES23	La Rioja
ES24	Aragón
ES3	COMUNIDAD DE MADRID
ES41	Castilla y León
ES42	Castilla-La Mancha
ES43	Extremadura
ES51	Cataluña
ES52	Comunidad Valenciana
ES53	Illes Balears
ES61	Andalucía
ES62	Región de Murcia
ES63	Ciudad Autónoma de Ceuta
ES64	Ciudad Autónoma de Melilla
ES7	CANARIAS
FR	FRANCE
FR1	ÎLE DE FRANCE
FR21	Champagne-Ardenne
FR22	Picardie
FR23	Haute-Normandie
FR24	Centre
FR25	Basse-Normandie
FR26	Bourgogne
FR3	NORD - PAS-DE-CALAIS
FR41	Lorraine
FR42	Alsace
FR43	Franche-Comté
FR51	Pays de la Loire
FR52	Bretagne
FR53	Poitou-Charentes
FR61	Aquitaine
FR62	Midi-Pyrénées
FR63	Limousin
FR71	Rhône-Alpes
FR72	Auvergne
FR81	Languedoc-Roussillon
FR82	Provence-Alpes-Côte d'Azur
FR83	Corse
FR91	Guadeloupe
FR92	Martinique
FR93	Guyane
FR94	Réunion

NUTS2 CODE	GEOGRAPHICAL UNIT
IE	IRELAND
IE01	Border, Midland and Western
IE02	Southern and Eastern
IT	ITALIA
ITC1	Piemonte
ITC2	Valle d'Aosta/Vallée d'Aoste
ITC3	Liguria
ITC4	Lombardia
ITD1	Provincia Autonoma Bolzano/Bozen
ITD2	Provincia Autonoma Trento
ITD3	Veneto
ITD4	Friuli-Venezia Giulia
ITD5	Emilia-Romagna
ITE1	Toscana
ITE2	Umbria
ITE3	Marche
ITE4	Lazio
ITF	SUD
ITF2	Molise
ITF3	Campania
ITF4	Puglia
ITF5	Basilicata
ITF6	Calabria
ITG1	Sicilia
ITG2	Sardegna
LU	LUXEMBOURG (GRAND-DUCHÉ)
NL	NEDERLAND
NL11	Groningen
NL12	Friesland (NL)
NL13	Drenthe
NL21	Overijssel
NL22	Gelderland
NL23	Flevoland
NL31	Utrecht
NL32	Noord-Holland
NL33	Zuid-Holland
NL34	Zeeland
NL41	Noord-Brabant
NL42	Limburg (NL)
AT	AUSTRIA
AT11	Burgenland (A)
AT12	Niederösterreich
AT13	Wien
AT21	Kärnten
AT22	Steiermark
AT31	Oberösterreich
AT32	Salzburg
AT33	Tirol
AT34	Vorarlberg
PT	PORTUGAL
PT11	Norte
PT15	Algarve
PT16	Centro (P)
PT17	Lisboa
PT18	Alentejo
PT2	Região Autónoma dos AÇORES
PT3	Região Autónoma da MADEIRA

NUTS2 CODE	GEOGRAPHICAL UNIT
FI	FINLAND
FI13	Itä-Suomi
FI18	Etelä-Suomi
FI19	Länsi-Suomi
FI1A	Pohjois-Suomi
FI2	ÅLAND
SE	SWEDEN
SE11	Stockholm
SE12	Östra Mellansverige
SE21	Småland med öarna
SE22	Sydsverige
SE23	Västsverige
SE31	Norra Mellansverige
SE32	Mellersta Norrland
SE33	Övre Norrland
UK	UNITED KINGDOM
UKC1	Tees Valley and Durham
UKC2	Northumberland and Tyne and Wear
UKD1	Cumbria
UKD2	Cheshire
UKD3	Greater Manchester
UKD4	Lancashire
UKD5	Merseyside
UKE1	East Yorkshire and Northern Lincolnshire
UKE2	North Yorkshire
UKE3	South Yorkshire
UKE4	West Yorkshire
UKF1	Derbyshire and Nottinghamshire
UKF2	Leicestershire, Rutland and Northamptonshire
UKF3	Lincolnshire
UKG1	Herefordshire, Worcestershire and Warwickshire
UKG2	Shropshire and Staffordshire
UKG3	West Midlands
UKH1	East Anglia
UKH2	Bedfordshire and Hertfordshire
UKH3	Essex
UKI1	Inner London
UKI2	Outer London
UKJ1	Berkshire, Buckinghamshire and Oxfordshire
UKJ2	Surrey, East and West Sussex
UKJ3	Hampshire and Isle of Wight
UKJ4	Kent
UKK1	Gloucestershire, Wiltshire and Bristol/Bath area
UKK2	Dorset and Somerset
UKK3	Cornwall and Isles of Scilly
UKK4	Devon
UKL1	West Wales and The Valleys
UKL2	East Wales
UKM2	Eastern Scotland
UKM3	South Western Scotland
UKM5	North Eastern Scotland
UKM6	Highlands and Islands
UKN	NORTHERN IRELAND
NO	NORWAY
NO01	Oslo og Akershus
NO02	Hedmark og Oppland
NO03	Sør-Østlandet
NO04	Agder og Rogaland
NO05	Vestlandet
NO06	Trøndelag
NO07	Nord-Norge