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COHESION WITHIN THE EURO AREA AND THE U. S.: A WAVELET-BASED VIEW

António Rua

Artur Silva Lopes

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Please address correspondence to
António Rua
Banco de Portugal, Economics and Research Department
Av. Almirante Reis 71, 1150-012 Lisboa, Portugal;
Tel.: 351 21 313 0841, email: arua@bportugal.pt

Banco de Portugal
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BANCO DE PORTUGAL

Av. Almirante Reis, 71

1150-012 Lisboa

www.bportugal.pt

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Cohesion within the euro area and the U. S.: a wavelet-based view

António Rua* Artur Silva Lopes†

Abstract

The assessment of synchronization of macroeconomic fluctuations across countries or regions has been crucial, for example, for the debate on economic integration. In this paper, we propose a multivariate measure of synchronization to assess cohesion across countries or regions by resorting to wavelet analysis. This wavelet-based measure of cohesion allows one to assess how synchronization has evolved over time and across frequencies simultaneously. In particular, we investigate the cohesion among euro area countries and the cohesion within the U.S. both at the regional and state levels over the last decades. In addition, an analysis at the sectoral level is also conducted. The results obtained unveil a noteworthy heterogeneity and highlight the usefulness of a wavelet-based measure of cohesion.

Keywords: Cohesion; Wavelets; Time-frequency; Output growth.

JEL classification: C40, E32.

*Banco de Portugal and ISEG–Technical University of Lisbon. Address: Economic Research Department, Banco de Portugal, Av. Almirante Reis no 71, 1150-012 Lisboa, Portugal. Email: antonio.rua@bportugal.pt

†CEMAPRE & ISEG–Technical University of Lisbon.

1 Introduction

The analysis of business cycle comovement has long been a topic of interest in economics. Several measures have been used in the literature to assess the synchronization of business cycles but the Pearson correlation coefficient remained the most popular because it summarizes the degree of comovement through time in a single value. However, due to its synthetic nature it can be rather limited describing the relationship between the variables. Alternatively, one can resort to spectral analysis, to obtain further insights about the relationship at the frequency level (see, for example, A'Hearn and Woitek (2001), Pakko (2004) and Breitung and Candelon (2006)). Croux *et al.* (2001) have suggested a spectral-based measure, the dynamic correlation, which is conceptually similar to the contemporaneous correlation but allows to measure comovement at the frequency level (empirical work drawing on this measure includes, for example, Tripier (2002), Rua and Nunes (2005) and Camacho *et al.* (2006)). However, while the Pearson correlation coefficient disregards completely the relationship at the frequency level, with the dynamic correlation proposed by Croux *et al.* (2001) all the information on time dependence of comovement is lost.

To overcome such caveats, Rua (2010) has proposed a measure of comovement by resorting to wavelet analysis. Wavelet analysis constitutes a very promising tool as it represents a refinement in terms of analysis, in the sense that both time and frequency domains are taken into account. Although wavelets have been more popular in fields such as signal and image processing, meteorology, and physics, such analysis can also provide fruitful insights about several economic phenomena (see, for example, the pioneer work of Ramsey and Zhang (1996, 1997) and Ramsey and Lampart (1998a,b)). Recent applications of wavelets in economics can be found, for instance, in Gallegati and Gallegati (2007), Gallegati *et al.* (2008), Yogo (2008), Crowley and Mayes (2008), Rua and Nunes (2009) and Rua (2011, 2012) (see Crowley (2007) for a survey). In particular, the wavelet-based measure of comovement suggested by Rua (2010) allows one to assess simultaneously how variables are related at different frequencies and how such relationship has evolved over time. Therefore, it is possible to capture both time and frequency varying features within an unified framework.

In order to take on board more than two series when assessing comovement, Croux *et al.* (2001) have extended the dynamic correlation to the multivariate case and named this generalised measure as cohesion. Cohesion is based on the dynamic correlations between all possible pairs of series within a group of variables and has been used by Croux *et al.* (2001) to assess the comovement of output fluctuations between European countries and across the U.S. states and regions. As stressed by de Haan *et al.* (2008), this measure provides a useful summary statistic on the degree of comovement across countries or regions while avoiding the problem of choosing a base country or region. Cohesion has also been applied by Carlino and DeFina (2004) to study the comovement in employment across the U.S. states and sectors, by Crone (2005) to evaluate the business cycle cohesion within U.S. regions, and *inter alia*, by Eickmeier and Breitung (2006) for assessing output growth and inflation cohesion between European countries.

The assessment of comovement among different countries or regions now involves a huge literature. In fact, the degree of synchronization of macroeconomic fluctuations across countries or regions plays a key role on the discussion about the attractiveness of economic integration. In this respect, the debate about the European monetary union has dominated the literature over the past decade.[1] In particular, building on the work of Mundell (1961) on Optimum Currency Areas, it has been argued that the cost of joining a monetary union will be low if countries have highly synchronized business cycles. However, it has also been pointed out that economic integration itself can affect the synchronization of macroeconomic fluctuations.[2]

[1] See, for example, de Haan *et al.* (2008) for a literature survey regarding business cycle synchronization in the euro area.

[2] For instance, Frankel and Rose (1998) claim that the removal of trade barriers induces

Hence, besides the frequency level perspective of comovement, capturing its time-varying dimension is also a worthwhile purpose.

Following Croux *et al.* (2001), we extend the bivariate measure proposed in Rua (2010) to the more general case in order to obtain a measure of cohesion in the wavelet domain. The resulting measure allows one to assess how cohesion has evolved over time and across frequencies simultaneously. Therefore, it can provide a detailed and rich picture, with additional insights in the time dimension. Focusing on output growth, we investigate the cohesion between euro area countries and the cohesion within the U.S. at both the regional and state levels over the last decades.

We find that cohesion within the euro area has been higher at the long-run and business cycle frequencies and that it has increased since the mid-90s across all frequencies. For the U.S. we find that cohesion is higher at the typical business cycle frequency range but seems to have decreased since the beginning of the 90's, and we note that this finding holds at both the regional and state levels. Moreover, we also find that U.S. cohesion is higher at the regional level than at the state level, both across frequencies and over time. In addition, besides taking into account the spatial perspective when assessing cohesion, we also conduct an analysis at the sectoral level. Resorting to disaggregated data by eleven sectors for the euro area countries and U.S. regions and states, we find a noteworthy heterogeneity in the results at the sectoral level. This analysis allows us also to unveil the sectors underlying the previously mentioned overall results.

The paper is organised as follows. In section 2 the main building blocks are discussed and the wavelet-based measure of cohesion is presented. In section 3 a data description is provided, while in section 4 the empirical

a higher symmetry of output fluctuations, while Rose (2000) provides evidence that a common currency results in more trade. In contrast, Krugman (1993) argues that a higher level of trade can lead to a higher economic specialization and less synchronized business cycles. See, for example, Kalemli-Ozcan *et al.* (2001) for an overview of the effects of economic integration on output fluctuations symmetry.

application is carried out for both the euro area and the U.S.. Finally, section 5 concludes.

2 Measuring cohesion in the wavelet domain

While the well-known Fourier transform decomposes the time series into infinite length sines and cosines (see, for example, Priestley (1981)), discarding all time-localization information, the wavelet transform uses local base functions that can be stretched and translated with a flexible resolution in both frequency and time. In particular, the wavelet transform decomposes a time series in terms of some elementary functions, the daughter wavelets or simply wavelets $\psi_{\tau,s}(t)$. These wavelets result from a mother wavelet $\psi(t)$, that can be expressed as function of the time position τ (translation parameter) and the scale s (dilation parameter), which is related with the frequency, that is,

$$\psi_{\tau,s}(t) = \frac{1}{\sqrt{s}}\psi\left(\frac{t-\tau}{s}\right). \tag{1}$$

To be a mother wavelet $\psi(t)$ must fulfil several conditions (see, for example, Percival and Walden (2000) for further discussion). The continuous wavelet transform of a time series $x(t)$ with respect to $\psi(t)$ is given by the following convolution

$$W_x(\tau, s) = \int_{-\infty}^{+\infty} x(t)\psi^*_{\tau,s}(t)dt = \frac{1}{\sqrt{s}}\int_{-\infty}^{+\infty} x(t)\psi^*\left(\frac{t-\tau}{s}\right)dt, \tag{2}$$

where * denotes the complex conjugate.

The most commonly used mother wavelet is the Morlet wavelet, which can be simply defined as

$$\psi(t) = \pi^{-\frac{1}{4}}e^{i\omega_0 t}e^{\frac{-t^2}{2}}. \tag{3}$$

One can observe that the Morlet wavelet is a complex sine wave within a Gaussian envelope whereas ω_0 is the wavenumber. In practice, ω_0 is set to 6 as it provides a good balance between time and frequency localization (see, for example, Adisson (2002) for further details on the Morlet wavelet).

Given two time series $x_i(t)$ and $x_j(t)$, with wavelet transforms $W_{x_i}(\tau, s)$ and $W_{x_j}(\tau, s)$, one can define the cross-wavelet spectrum as $W_{x_i x_j}(\tau, s) = W_{x_i}(\tau, s) W_{x_j}^*(\tau, s)$. As the mother wavelet is in general complex, the cross-wavelet spectrum is also complex valued and it can be decomposed into real and imaginary parts. The measure proposed in Rua (2010) is given by

$$\rho_{x_i x_j}(\tau, s) = \frac{\Re\left(W_{x_i x_j}(\tau, s)\right)}{\sqrt{\left|W_{x_i}(\tau, s)\right|^2 \left|W_{x_j}(\tau, s)\right|^2}}, \tag{4}$$

where $\Re$ denotes the real part of the cross-wavelet spectrum. This wavelet-based measure $\rho_{x_i x_j}(\tau, s)$ allows one to evaluate the degree of comovement in the time-frequency space and assess over which periods of time and over which frequencies is the comovement higher. Basically, it plays a role as a contemporaneous correlation coefficient around each moment in time and for each frequency. Since it provides information about the comovement not only at the frequency level but also over time, it can be seen as a generalisation of the dynamic correlation measure suggested by Croux *et al.* (2001).

In a similar fashion to Croux *et al.* (2001), who extended the dynamic correlation measure to the multivariate case, providing a measure of cohesion in the frequency domain, we extend the bivariate measure proposed by Rua (2010) to the more general case in order to obtain a measure of cohesion in the wavelet domain. In particular, cohesion is defined as the weighted average of the wavelet-based measure $\rho_{x_i x_j}(\tau, s)$ between all possible pairs of series:

$$coh(\tau, s) = \frac{\sum_{i \neq j} \varpi_{ij} \rho_{x_i x_j}(\tau, s)}{\sum_{i \neq j} \varpi_{ij}}, \tag{5}$$

where ϖ_{ij} is the weight attached to the pair of series (i, j). As the $\rho_{x_i x_j}(\tau, s)$ range between -1 and 1, the wavelet-based cohesion also varies between -1 and 1. This measure allows one to quantify the extent of cohesion among several series at different frequencies and investigate if such global relationship has changed over time. Hence, it enables a richer analysis than the one which is possible with the cohesion measure suggested in Croux *et al.* (2001), which focus only at the frequency level. This is of particular importance as there is by now evidence that comovement can vary across frequencies as well as over time. Moreover, the suggested wavelet-based cohesion allows to capture both features within an unified framework.

3 Data

Regarding the United States, we considered data at the regional and state levels provided by the Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce.[3] Annual real GDP by region and state is available from 1977 up to 2008. However, as nominal data is available from 1963, in order to cover a longer time span we resorted to the U.S. GDP deflator prior to 1977. The disaggregation of regional and state output by sectors is also provided by the BEA for the same sample periods, and again we used

[3]The 8 BEA regions are: New England, Mideast, Great Lakes, Plains, Southeast, Southwest, Rocky Mountain, Far West. The 51 BEA states are: Alabama, Alaska, Arizona, Arkansas, California, Colorado, Connecticut, Delaware, District of Columbia, Florida, Georgia, Hawaii, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New Hampshire, New Jersey, New Mexico, New York, North Carolina, North Dakota, Ohio, Oklahoma, Oregon, Pennsylvania, Rhode Island, South Carolina, South Dakota, Tennessee, Texas, Utah, Vermont, Virginia, Washington, West Virginia, Wisconsin, Wyoming. See http://www.bea.gov/regional .

the U.S. corresponding deflator, so as to obtain volume series since 1963 and up to 2008. In order to ease the comparison between the U.S. and the euro area, we considered eleven sectors, namely: (1) Agriculture, hunting, forestry, and fishing; (2) Mining; (3) Manufacturing; (4) Utilities; (5) Construction; (6) Wholesale and retail trade; (7) Transport and storage; (8) Information; (9) Finance, insurance, real estate and rental and leasing; (10) Services including professional and business services, educational services, health care, social assistance, arts, entertainment, recreation, accommodation and food services and other services; (11) Government.

Concerning the euro area, we considered all the member countries as of 1 January 2001, namely, Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal and Spain. Data regarding annual real GDP has been collected from the European Commission AMECO database.[4] Concerning sectoral data for the euro area countries, we used the EU KLEMS database provided by the Groningen Growth and Development Centre (GGDC, which is financially supported by the European Commission).[5] As this data ranges from 1970 up to 2007, we updated it with the year 2008 resorting to the AMECO database.

The weights used in (5) correspond to the share of output of the pair (i, j) in the year 2000.[6] As usual, all series are taken in logs and first differenced.

4 Cohesion within euro area and the U.S.

4.1 Spatial cohesion

In this section we proceed into the computation of the suggested measure to assess the cohesion among euro area countries and the cohesion within

[4] See http://ec.europa.eu/economy_finance/db_indicators/ameco .

[5] See http://www.euklems.net .

[6] As both the euro area and the U.S. data are released with 2000 as the base year, this year was selected to compute the weights. Nevertheless, the results are not sensitive to the chosen year.

the U.S. at both the regional and state levels. As three dimensions are involved, the wavelet-based cohesion is presented through a contour plot. The horizontal axis refers to time while the vertical axis refers to frequency. To ease interpretation, the frequency is converted to time units (years). The gray scale is for the wavelet-based cohesion, where increasing darkness corresponds to an increasing value and mimics the height in a surface plot. Hence, through the inspection of the graph one can identify both frequency bands (in the vertical axis) and time intervals (in the horizontal axis) where cohesion is larger and whether it has changed over time.[7]

In Figure 1 we present the wavelet-based measure of cohesion among euro area countries in terms of GDP growth. Several findings seem to be particularly relevant. First, one can observe that cohesion is typically larger at low frequencies, *i.e.*, for long-run dynamics, than in the remaining frequencies. Moreover, at low frequencies cohesion has increased in the late 70's and early 80's and has kept high thereafter. Concerning the standard business cycle frequency range — that is, fluctuations between two and eight years —, although cohesion has been lower than at low frequencies, it has also increased since the mid-90s. At high frequencies, that is, for the very short-run fluctuations, cohesion has always been weak with the exception of the latter part of the sample. Hence, cohesion within the euro area has been larger for the long-term and business cycle dynamics and it has increased for several frequencies since the mid-90s.[8]

Regarding the U.S., we compute the cohesion at both the regional and state levels (see Figures 2 and 3, respectively). Likewise as in the euro area case, cohesion is positive within the U.S. at both the regional and state levels (see also Carlino and DeFina (2004)). Comparing Figures 2 and 3, one can observe that the U.S. cohesion at the regional level is higher than

[7] All computations are done using Matlab and the codes are available from the authors upon request.

[8] All these findings are broadly in line with the results of Rua (2010), who considers only the major euro area countries and assesses all possible country pairs individually.

at the state level, whatever the frequency and/or the time period. This is in line with the results of Croux *et al.* (2001), who argue that this is due to the fact that by aggregating the states the idiosyncratic sources of variations are diminished. In contrast with the euro area, the frequency range where cohesion is higher in the US is at the business cycle frequency range. A noteworthy and distinct finding is that, while in the euro area cohesion seems to have increased, reflecting most probably the deepening of the process of European economic integration, in the U.S. there seems to be evidence of a decrease in cohesion since the beginning of the 90's. This holds both at the regional and state levels.

To shed more light on this latter issue as well as on all the previous results, in the next section we conduct a cohesion analysis at the sectoral level.

4.2 Cohesion at the sectoral level

Up to now the focus has been on assessing the spatial cohesion within the euro area and the U.S.. To complement and provide further insights about the previous results, we also investigate cohesion at the sectoral level. This analysis allows us to identify whether the above findings are broadly based or if they are being driven by any particular sector.

The results at the sectoral level for the euro area are reported in Figure 4. Each plot presents the cohesion among the euro area countries for a given sector. In general, sectors like Agriculture, Mining, Government and to a lesser extent, Utilities, Construction, Transport and storage present relatively weak cohesion across frequencies and over time. Contrasting with these, sectors such as Manufacturing, Wholesale and retail trade, and Information denote a relatively high cohesion at low frequencies, one which has increased throughout time. These sectors seem to be responsible for the time-varying behaviour discussed earlier of cohesion within the euro area at low frequencies. It is also interesting to note that the sector where cohesion has been increasing over the last decade and across all frequencies is the sector related to Finance, insurance and real estate. This clearly reflects the financial integration that has been taking place in the euro area.

We now turn to the U.S. results (see Figures 5 and 6). As pointed out in the previous section, cohesion at the regional level is higher than at the state level and this finding seems to hold for all the sectors across all the frequencies and over time. Since the results at the regional and state levels are qualitatively similar, henceforth we focus on the results obtained at the state level. The sectors that present lower cohesion are Agriculture, Mining, Finance, insurance and real estate and Government. In sectors like Construction, Transport and storage and, to a lesser extent, Utilities, cohesion seems to be higher at business cycle frequencies, whereas in the Information sector cohesion is more marked at low frequencies. On the other hand, in Manufacturing, Wholesale and retail trade, and Services including professional and business services and others, where cohesion has been high at the business cycle frequency range, have recorded a decrease in the last years. Hence, these appear to be the main sectors behind the recent deterioration of cohesion within the U.S..

5 Conclusions

The assessment of output synchronization across countries or regions has been of key importance in several strands of the literature as, for example, in the discussion of economic integration. Though comovement is traditionally measured in the time domain resorting to the well-known Pearson correlation coefficient, there has been an increasing focus on frequency domain analysis. However, while the former approach ignores the relationship at the frequency level, the latter disregards the fact that comovement can change over time. To overcome such shortcomings one can resort to wavelet analysis. In particular, in this paper we propose a wavelet-based measure of cohesion which allows one to assess how synchronization has evolved over time and across frequencies simultaneously, within a set of countries or regions.

To illustrate its empirical application we focus on the output growth synchronization within the euro area and the U.S.. We study cohesion among the euro area countries and within the U.S., both at the regional and state levels over the last decades. The results obtained highlight the usefulness of a wavelet-based measure of cohesion so as to uncover both frequency and time-varying features. We find that cohesion within the euro area has been higher at the long-run frequencies and that it has increased since the mid-90s across all frequencies. In contrast, cohesion within the U.S. is higher at the typical business cycle frequency range but seems to have decreased since the beginning of the 90's. These findings for the U.S. hold both at the regional and state levels. Furthermore, we find that the U.S. cohesion at the regional level is higher than at the state level across all frequencies and over the whole sample period. Additionally, we find a noteworthy heterogeneity in the results at the sectoral level. The sectors that seem to lie behind the overall results are identified.

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Figure 1 - Cohesion within euro area

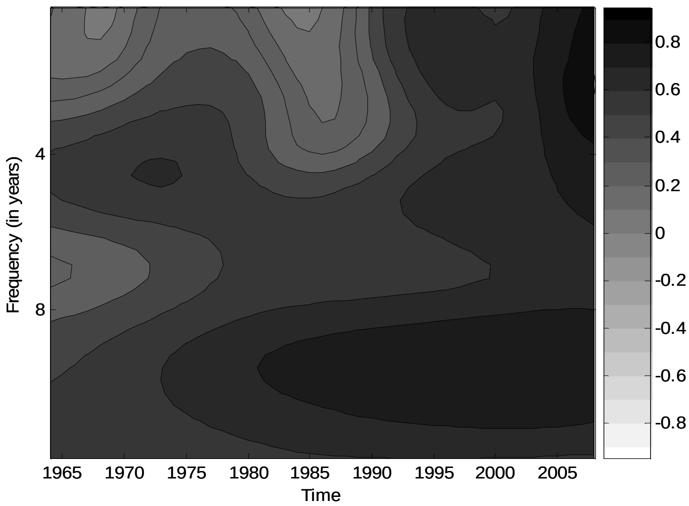


Figure 2 - Cohesion within US (at the regional level)

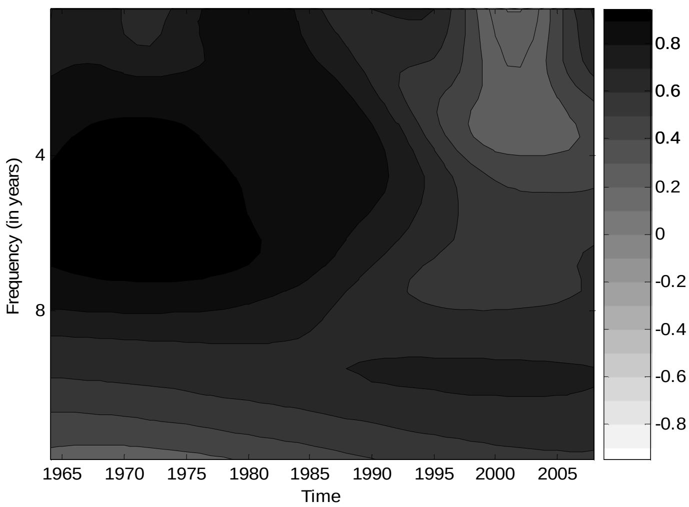


Figure 3 - Cohesion within US (at the state level)

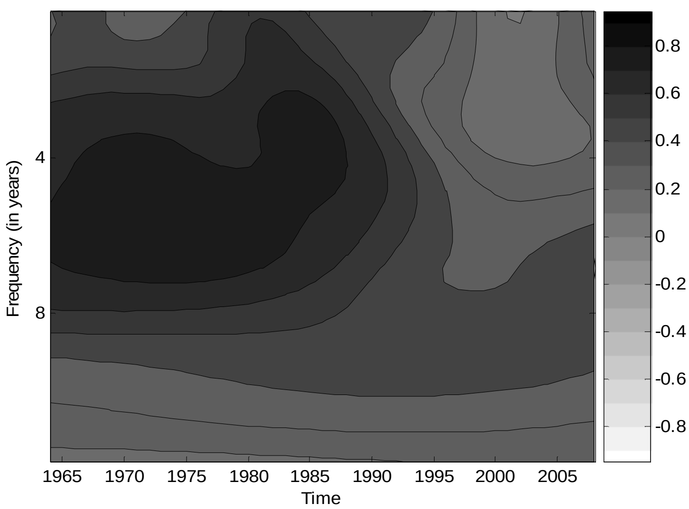


Figure 4 - Cohesion across euro area countries by sector

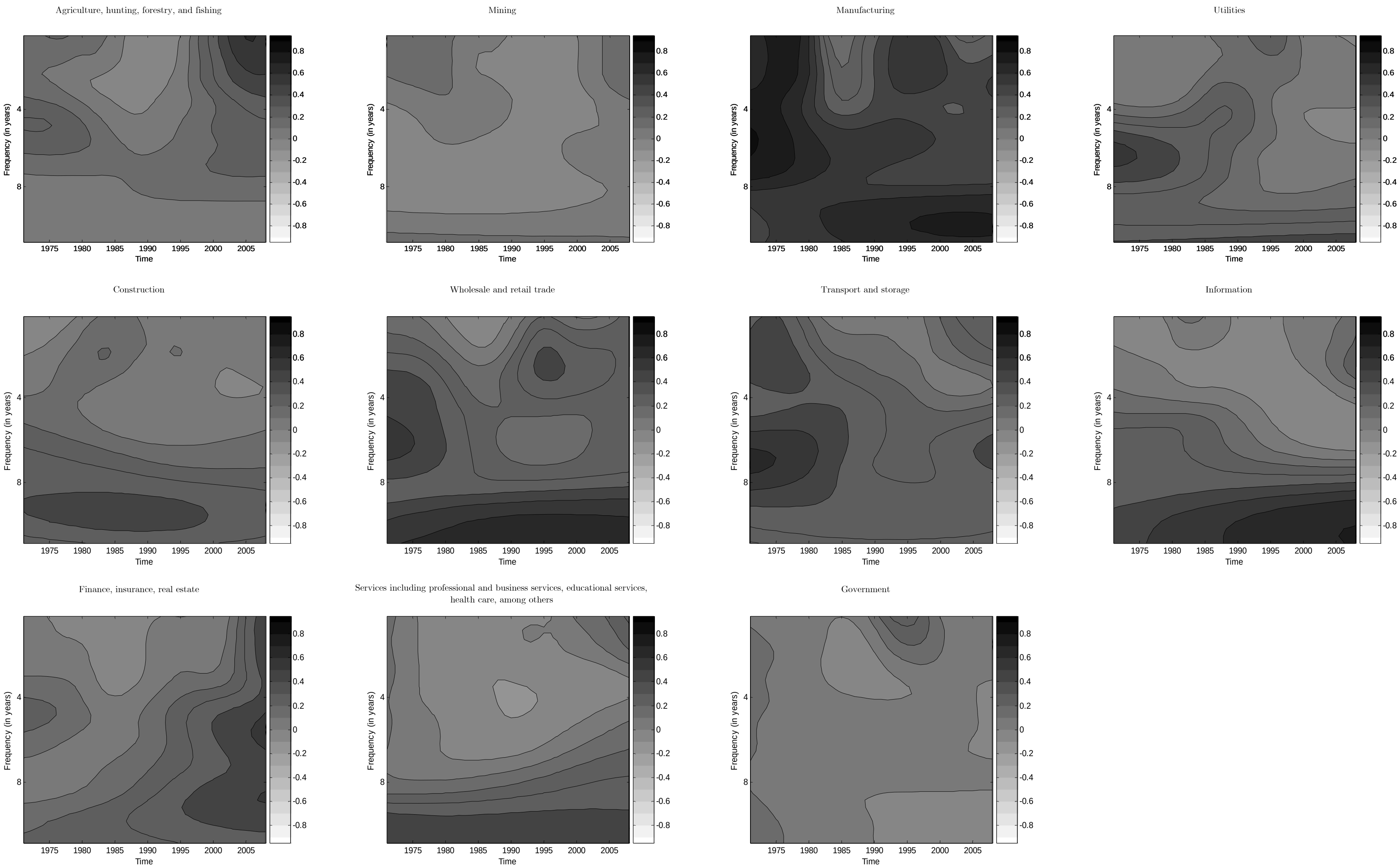


Figure 5 - Cohesion across US regions by sector

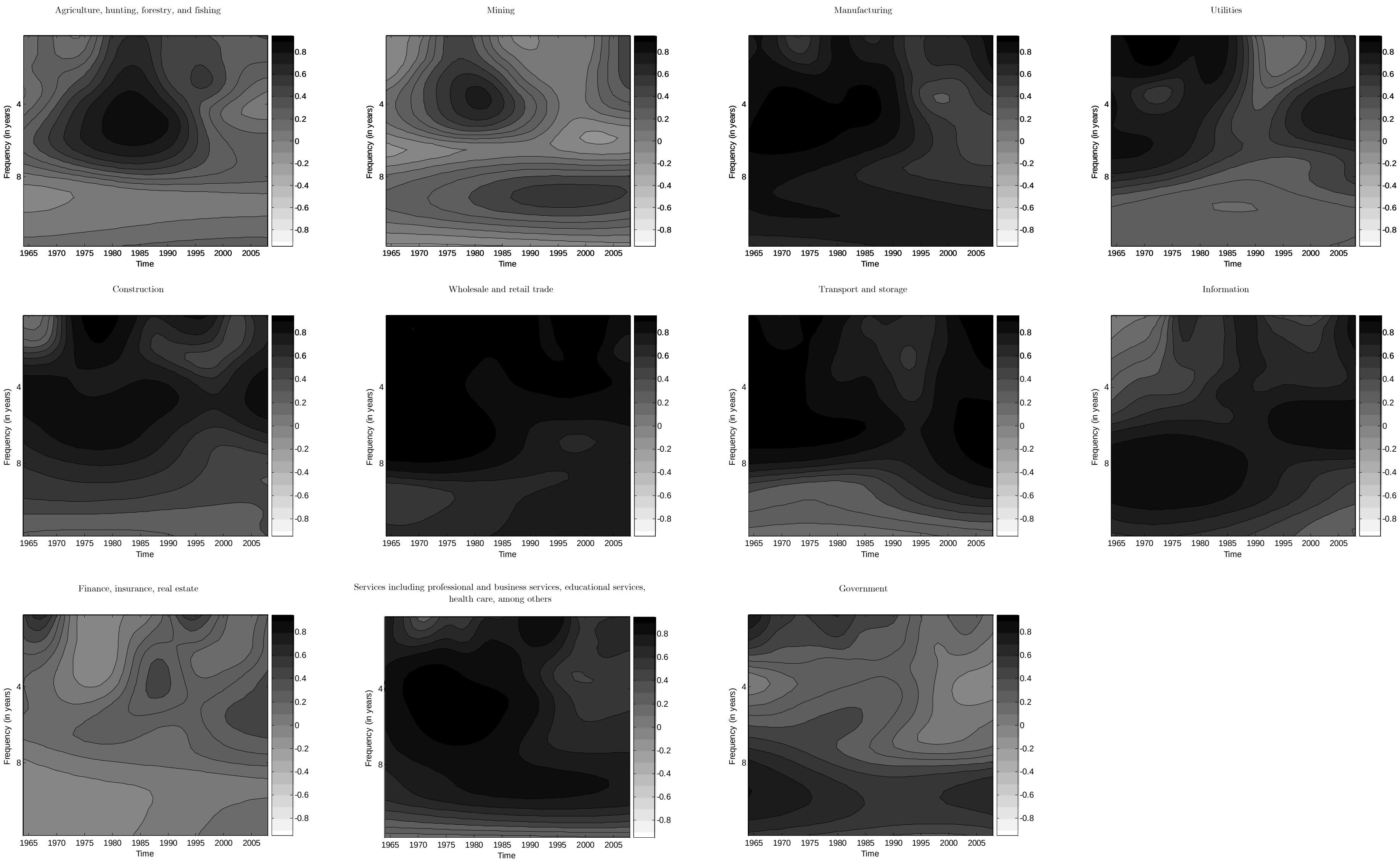
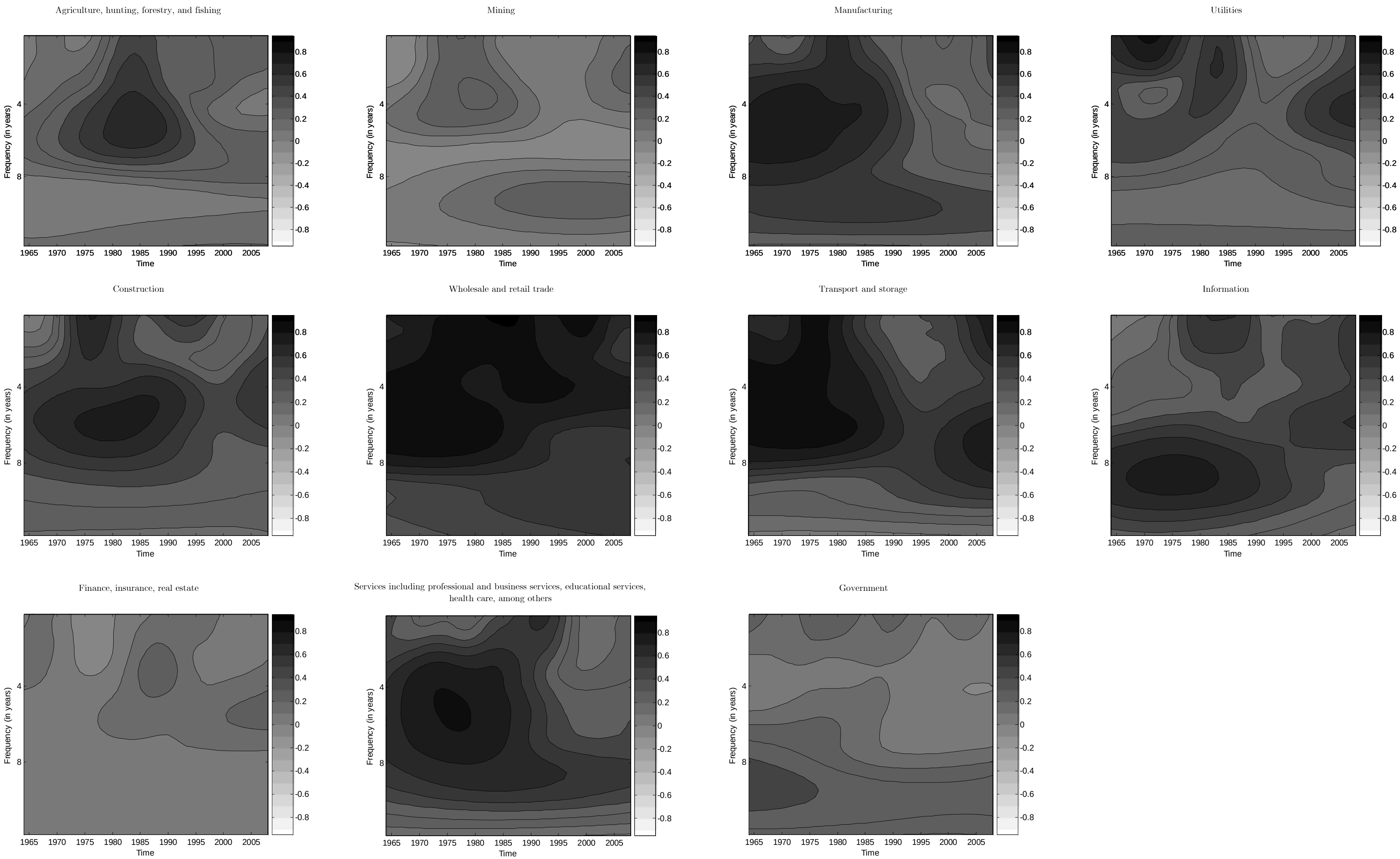


Figure 6 - Cohesion across US states by sector



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