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Cohesion within the euro area and the US: A wavelet-based view

by
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The analysis of synchronisation 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 synchronisation to assess cohesion across countries or regions by resorting to wavelet analysis. This wavelet-based measure of cohesion allows one to study how synchronisation has evolved over time and across frequencies simultaneously. In particular, we investigate the cohesion among euro area countries and within the US, 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*

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1. Introduction

The assessment of comovement among different countries or regions has long been a topic of interest in economics. In fact, the degree of synchronisation of macroeconomic fluctuations across countries or regions plays a key role in 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 [see, for example, de Haan et al. (2008) for a literature survey regarding business cycle synchronisation in the euro area]. 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 synchronised business cycles. However, it has also been pointed out that economic integration itself can affect the synchronisation of macroeconomic fluctuations. For instance, Frankel and Rose (1998) claim that the removal of trade barriers induces 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 specialisation and less synchronised business cycles. See, for example, Kalemli-Ozcan et al. (2001) for an overview of the effects of economic integration on output fluctuations symmetry.

Several measures have been used in the literature to assess synchronisation but the Pearson correlation coefficient remains the most popular because it summarises the degree of comovement through time in a single value. Alternatively, one can resort to spectral analysis, to obtain insights about the relationship at the frequency level. 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 [which has been used by Tripier (2002), Rua and Nunes (2005) and Camacho et al. (2006), among others]. However, while the Pearson correlation coefficient completely disregards the relationship at the frequency level, with the dynamic correlation proposed by Croux et al. (2001) all the information about the time dependence of comovement is lost.

To overcome such caveats, Rua (2010) has proposed a wavelet-based measure of comovement to assess simultaneously how two variables are contemporaneously related at different frequencies and how such relationship has evolved over time. 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. 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, 2012), and Rua (2011, 2012) [see Crowley (2007) for a survey].

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. As cohesion draws on the dynamic correlation measure, the phase shifts are disregarded and the focus is on the contemporaneous comovement among the series. 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 been applied by Croux et al. (2001) to assess the synchronisation of output fluctuations between European countries and across the US states and regions, by Carlino and DeFina (2004) to study the comovement in employment across the US states and sectors, by Crone (2005) to evaluate the business cycle cohesion within US regions, and *inter alia*, by Eickmeier and Breitung (2006) for assessing output growth and inflation cohesion between European countries.

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. Note that it can provide information about the strength of the relationship at a given frequency and time but it cannot uncover the lead-lag relation between the variables since, by definition, the phase differences are discarded. Although the lead-lag relation may be important by itself, one can interpret synchronisation precisely as the degree of comovement when one disregards phase shifts, that is, one is interested in the contemporaneous relationship between the series.

Focusing on output growth, we investigate the cohesion among euro area countries and within the US, at both the regional and state levels, over the last decades. We find that cohesion within the euro area has been higher at low frequencies, which is in line with Crowley and Mayes (2008) who also found a higher synchronisation of output growth for longer cycles than for shorter ones for the main euro area countries. We also find that cohesion in the euro area has increased for most frequencies, being very high since the end of the 1990s. In this respect, Eickmeier and Breitung (2006) also found that cohesion increases significantly across frequencies when the time span includes the period after the introduction of the euro. Moreover, 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. Likewise in the euro area case, we find that output growth cohesion within US is positive at both the regional and state levels (Carlino and DeFina, 2004, found similar evidence with US employment data). It is also found that US cohesion is higher at the regional level than at the state level, both across frequencies and over time. This is in line with the findings of Croux et al. (2001) and Carlino and DeFina (2004) who argue that aggregation results in a higher comovement. In the US case, we find that cohesion is higher at the typical business cycle frequency range but it declined during the 1980s. However, this has been reverted with cohesion attaining a high level during the most recent economic and financial crisis episode. 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 US regions and states, we find a noteworthy heterogeneity in the results at the sectoral level.

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 application is carried out for both the euro area and the US. 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-localisation 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,[1] that is,

$$\psi_{\tau,s}(t) = \frac{1}{\sqrt{s}}\psi\left(\frac{t-\tau}{s}\right) \quad [1]$$

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:

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

where * denotes the complex conjugate.

The most commonly used mother wavelet for the continuous wavelet transform is the Morlet wavelet [see, for example, Aguiar-Conraria and Soares (2013) and references therein], which can be simply defined as:

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

One can observe that the Morlet wavelet is a complex sine wave within a Gaussian envelope whereas ω_0 is the wavenumber. By increasing (decreasing) the wavenumber one achieves better (poorer) frequency localisation but poorer (better) time localisation. In practice, ω_0 is set to 6 as it provides a good balance between time and frequency localisation [see, for example, Adisson (2002) for further details]. Since the wavelength for the Morlet wavelet is given by $\frac{4\pi s}{\omega_0+\sqrt{2+\omega_0^2}}$ (see Torrence and Compo, 1998), then for $\omega_0 = 6$, the wavelet scale s is almost equal to the Fourier period, which eases the interpretation of wavelet analysis.

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:

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

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:

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

where ϖ_{ij} is the weight attached to the pair of series (i, j)s 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 possible with the cohesion measure suggested in Croux et al. (2001), which focus on the frequency level only. This is of particular importance as there is by now evidence that comovement can vary across frequencies as well as over time [see Crowley and Mayes (2008), Rua and Nunes (2009), Rua (2010) among others]. 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 US Department of Commerce.[2] Annual real GDP by region and state is available from 1977 up to 2011. However, as nominal data is available from 1963, in order to cover a longer time span we resorted to the US 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 the US corresponding deflator, so as to obtain volume series since 1963 and up to 2011. In order to ease the comparison between the US 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; and 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*.[3] 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).[4] As this data ranges from 1970 up to 2007, we updated it up to 2011 resorting to the *AMECO Database*.

The weights used in Equation [5] correspond to the share of output of the pair (i, j) in the year 2005.[5] As usual, all series are taken in logs and first differenced. By considering growth rates, it is possible to assess how output synchronisation differs across frequencies, allowing to assess both at the business cycle frequency range as well as at other frequencies. If one had used, for example, a band-pass filter the latter information would be lost.

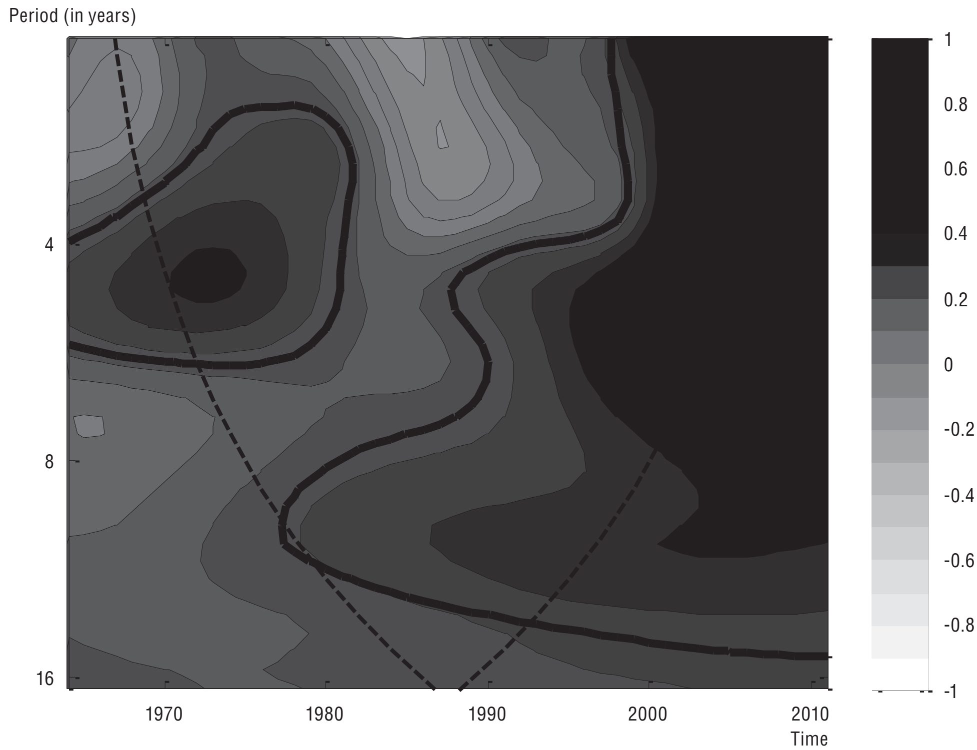
4. Cohesion within euro area and US

4.1. Spatial cohesion

In this section, we proceed to compute the suggested measure so as to assess the cohesion among euro area countries and the cohesion within the US 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. As the continuous wavelet transform at a given point in time uses information of neighbouring data points, the values of the wavelet transform are generally less accurate as the wavelet approaches the edges of the time-series (this region is known as the cone of influence (see Torrence and Compo, 1998). With finite length time-series, edge effects occur at the beginning and end of the sample period, as the Fourier transform assumes data to be periodic. The region affected increases with the temporal support (or width) of the wavelet and to limit the wraparound effects one usually resorts to zero padding (see, for example, Aguiar-Conraria and Soares, 2013). Hence, the results should be read carefully close to the beginning or the end of the time series. The dashed line delimits the cone of influence. Note that we restricted the figures to periods up to around sixteen years which corresponds to the lowest frequency where there is at least some part outside the cone of influence. Concerning the statistical significance of cohesion, as the distribution is not known, the critical values for a 5% significance level were determined through a Monte Carlo simulation exercise.[6] The bold line delimits the area where cohesion is statistically different from zero with a 95% confidence level.

In Figure 1, we present the wavelet-based measure of cohesion among euro area countries in terms of GDP growth. Several findings emerge. Firstly, one can observe that cohesion has been typically higher at low frequencies, i.e., long-run dynamics, than at the remaining frequencies. In this respect, Crowley and Mayes (2008) also found a higher synchronisation of output growth for longer cycles than for shorter ones when considering the three major euro area countries (Germany, France and Italy). Moreover, at low frequencies, cohesion has increased throughout time becoming statistically significant since the beginning of the 1980s. At the standard business cycle frequency range, that is fluctuations between two and eight years, cohesion was particularly high at the beginning of the 1970s, during the oil crisis, while decreasing during the 1980s. This lends support to Inklaar and de Haan's (2001) finding that correlations of euro area countries business cycle are higher in the period 1971-79 than 1979-87. However, cohesion within euro area has increased again since the mid-1990s which is in line with the results of Massmann and Mitchell (2004) obtained by computing pairwise correlations with rolling windows. Similarly, Altavilla (2004) presents evidence that synchronisation of several euro countries has increased after 1991, while Darvas and Szapáry (2008) also find evidence in support of more business cycle comovement in the euro area since 1993, the start of the run-up to the

Figure 1. **Cohesion within euro area**



European Monetary Union. Finally, one should note that cohesion has been very high for most frequencies since the beginning of the euro area (see also Rua, 2010).

Regarding the US, we compute the cohesion at both the regional and state levels (see Figures 2 and 3, respectively). Likewise in the euro area case, cohesion is positive within the US at both the regional and state levels [Carlino and DeFina (2004) report similar evidence with US employment data]. Comparing Figures 2 and 3, one can observe that the US cohesion at the regional level is higher than at the state level, whatever the frequency and 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 (see also Tootell, 1990, and Carlino and DeFina, 2004). The frequency range where cohesion is higher and statistically significant is at the business cycle frequency band. 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 US there seems to be evidence of a decrease in cohesion since the 80s. In this respect, Wyne and Koo (2000) found that the synchronisation between the 12 US Federal Reserve districts was higher in the run-up to the first oil shock and decreased during the 1980s. However, one should note that cohesion has increased again and attained a high level during the most recent economic and financial crisis episode.

To shed some more light on the above mentioned results, in Section 4.2 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 US. To complement and provide further insights about the previous results, we

Figure 2. **Cohesion within US (at the regional level)**

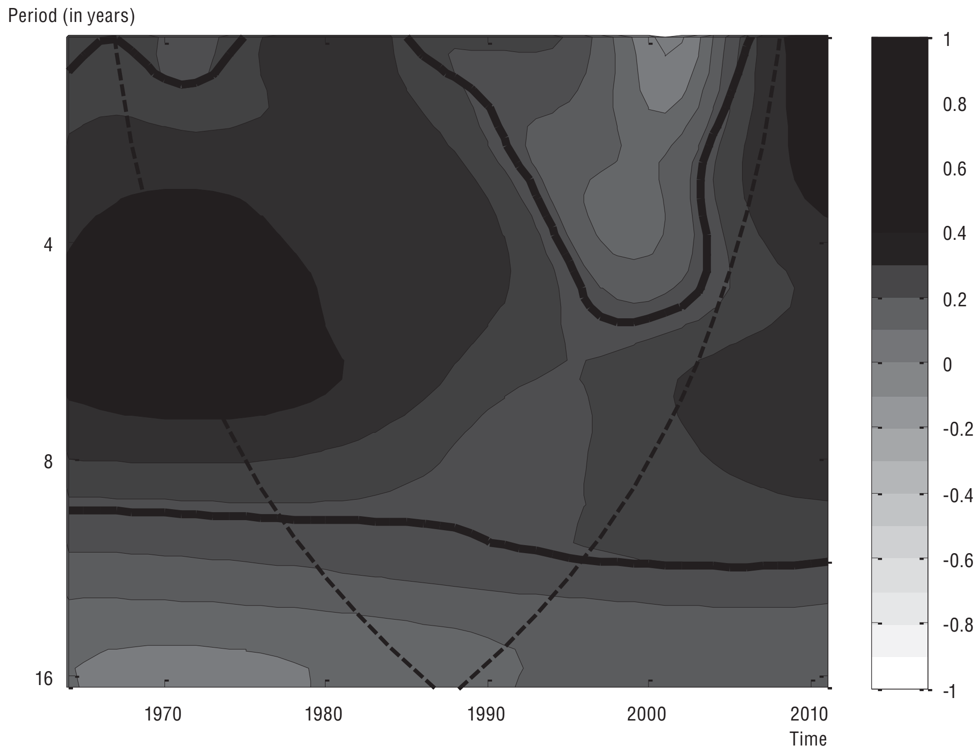
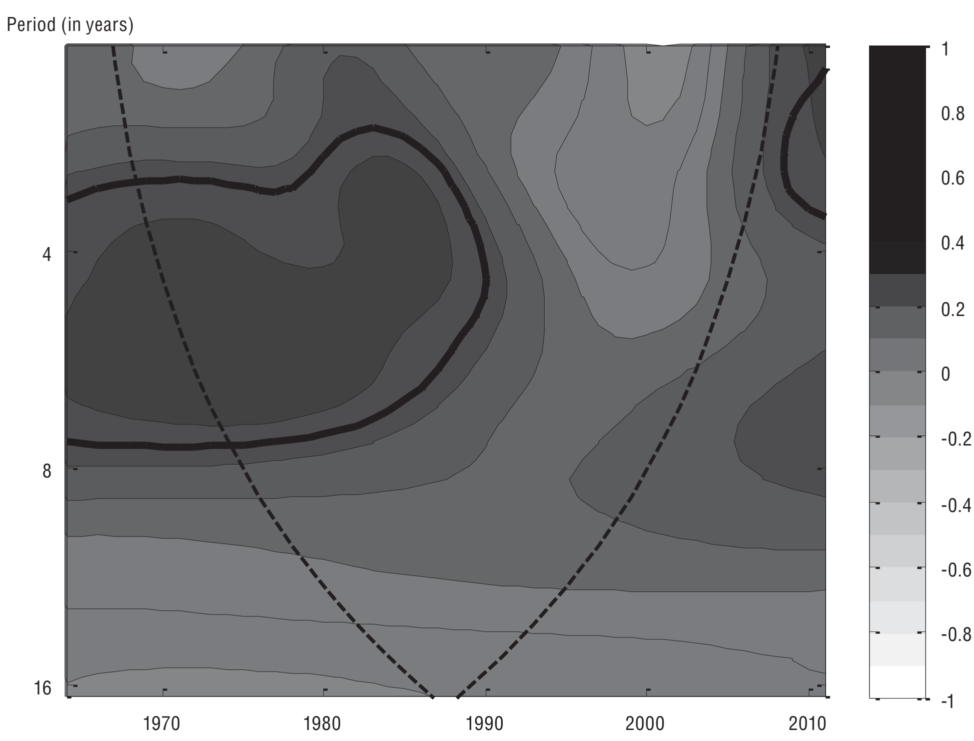


Figure 3. **Cohesion within US (at the state level)**



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.

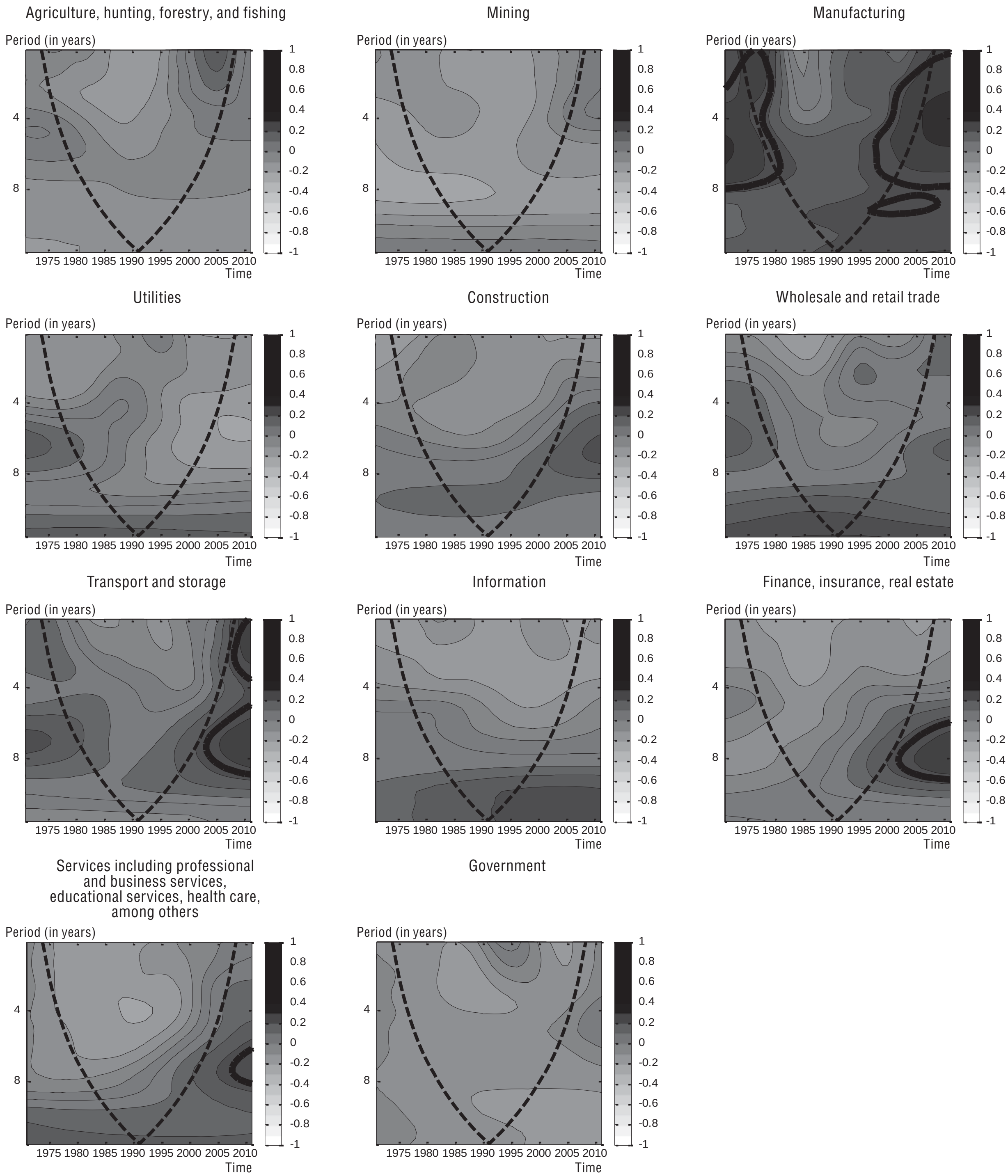
The results at the sectoral level for the euro area are reported in Figure 4. Each plot presents the cohesion among the euro area countries for a given sector. In general, sectors like Agriculture, Mining, Government and to a lesser extent, Utilities and Construction present relatively weak cohesion across frequencies and over time. In contrast, Manufacturing is the sector that presents the highest cohesion. Darvas and Szapáry (2008) also found higher synchronisation for industry than for services in the euro area. Sectors such as Manufacturing, Wholesale and retail trade, and Information denote a relatively high cohesion at low frequencies, which has increased throughout time, and seem to be responsible for the above mentioned time-varying behaviour of cohesion within the euro area at low frequencies. At the business cycle frequency range, one should note that in the case of Manufacturing, after presenting a high cohesion up to the 1980s, it recorded a decrease in the subsequent period. However, it increased again since the 1990s. Such increase was also observed in the sector related to Finance, insurance and real estate reflecting the financial integration that has been taking place in the euro area. Other sectors that have also recorded an increase in the more recent period are Transport and storage and Services including professional and business services and others.

We now turn to the US results (see Figures 5 and 6). As pointed out in Section 4.1, 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 results suggest a noteworthy heterogeneity in terms of cohesion across sectors. In this respect, Carlino and DeFina (2004) also found considerable variation in the degree of cohesion across sectors using employment data at the state level. Overall, the sectors that present the lowest cohesion are Mining, Finance, insurance and real estate, and Government whereas the highest cohesion is recorded by Manufacturing, Wholesale and retail trade, and Transport and storage. This is also broadly in line with the results of Carlino and DeFina (2004). In the sectors where cohesion has been higher, it is more marked at the business cycle frequency range. The exception is the Information sector where cohesion has been higher at low frequencies, namely in the first half of the sample period. At the latter part of the sample, cohesion in the Information sector has been statistically significant only at higher frequencies. In sectors like Construction and Agriculture, cohesion was high only during the 1970s and 1980s, whereas in the Utilities sector it was more pronounced during the last decade. In the cases of Manufacturing, Wholesale and retail trade, Transport and storage and Services including professional and business services and others cohesion was high up to the 1980s and then decreased progressively. These sectors appear to be behind the overall decrease of cohesion within the US at the business cycle frequency range which has been mentioned earlier. However, all these sectors present a noteworthy increase in the latter part of the sample period driving up again the cohesion within the US.

5. Conclusions

The assessment of output synchronisation 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, we propose a wavelet-based

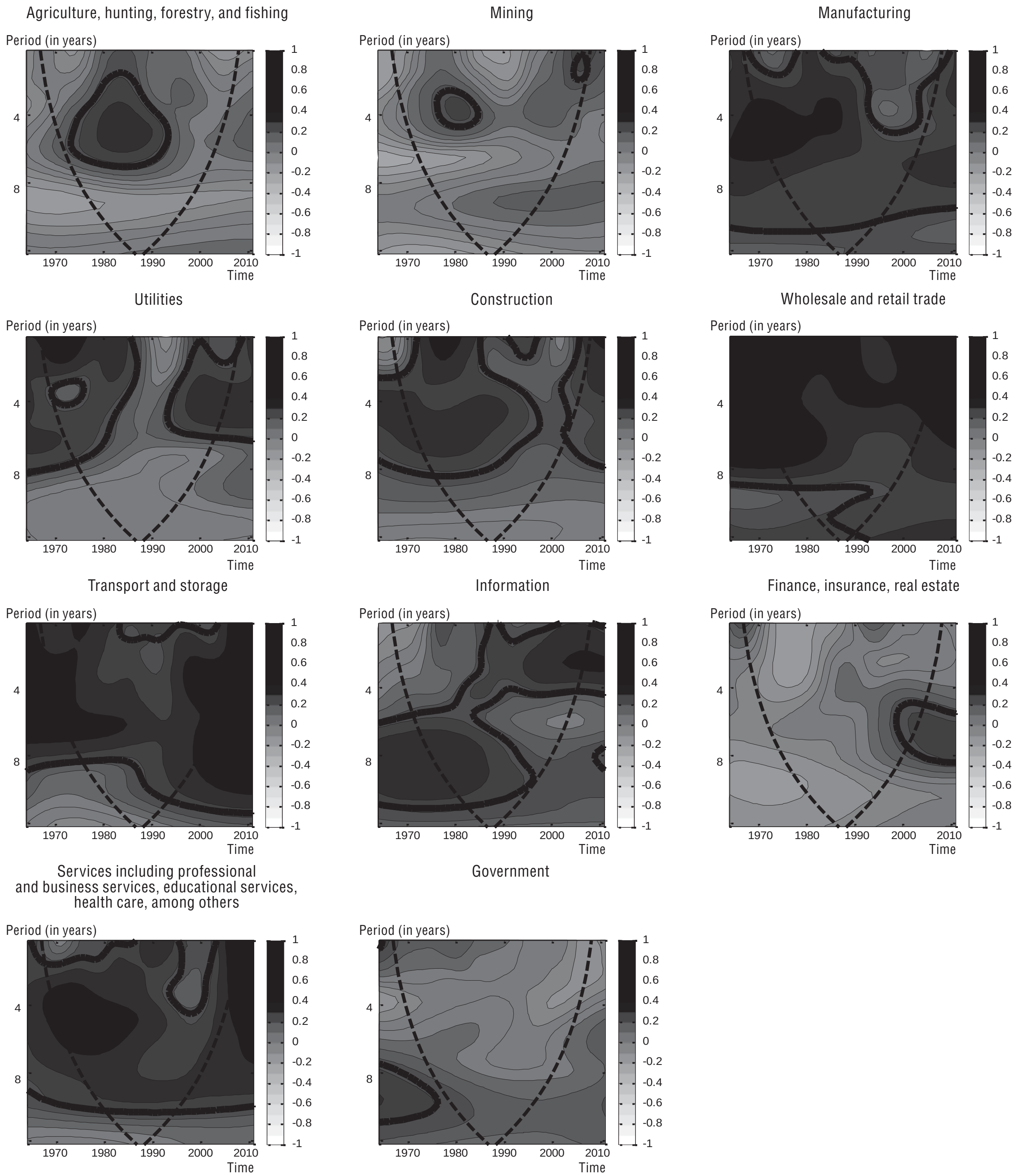
Figure 4. **Cohesion across euro area countries by sector**



measure of cohesion which allows one to assess how synchronisation has evolved over time and across frequencies simultaneously, within a set of countries or regions.

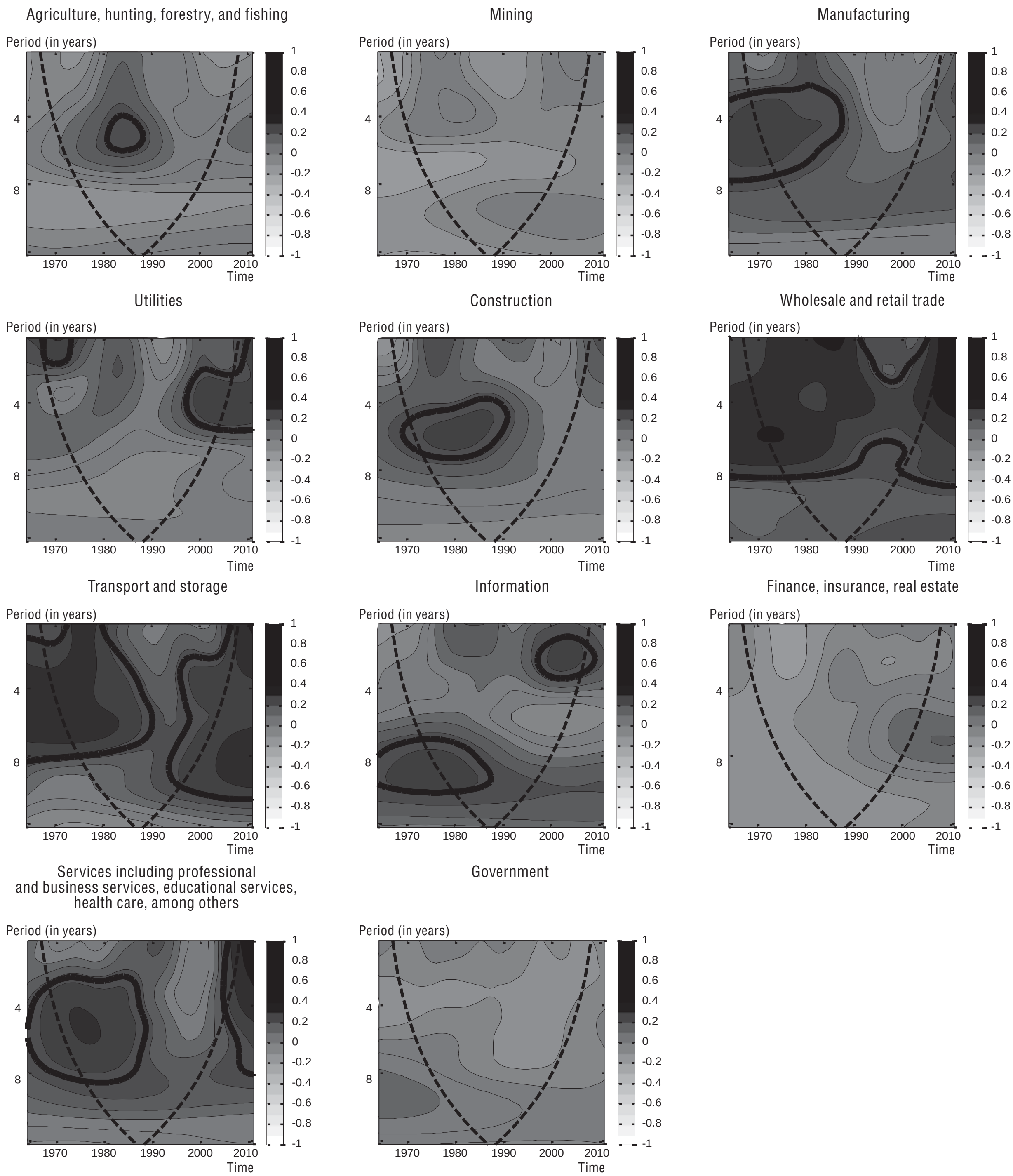
To illustrate its empirical application we focus on the output growth synchronisation within the euro area and the US. We study cohesion among the euro area countries and within the US, both at the regional and state levels over the last decades. The results obtained

Figure 5. **Cohesion across US regions by sector**



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 low frequencies and that it has increased for most frequencies, being very high since the introduction of the euro. In the case of the US, cohesion has been higher at the business cycle frequency range. Despite the decrease observed during the 1980s, there was a

Figure 6. **Cohesion across US states by sector**



noteworthy increase during the most recent economic and financial crisis episode. These findings for the US hold both at the regional and state levels. Furthermore, we find that the US 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.

Notes

1. For a general discussion about the relationship between scale and frequency, see, for example, Aguiar-Conraria and Soares (2013).
2. The eight 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 *www.bea.gov/regional*.
3. See *http://ec.europa.eu/economy_finance/db_indicators/ameco*.
4. See *www.euklems.net*.
5. One should note that the results are not sensitive to the chosen year.
6. In particular, the critical values are obtained by considering 10 000 sets of autoregressive processes based on the series under analysis (see, for example, Torrence and Compo, 1998). In fact, we found that for most series the AR(1) model is the preferred one. All computations are done using Matlab and the codes are available from the authors upon request.

References

Adisson, P. (2002), *The Illustrated Wavelet Transform Handbook*, The Institute of Physics, London.

Aguiar-Conraria, L. and M.J. Soares (2013), "The Continuous Wavelet Transform: Moving Beyond Uni- and Bi-variate Analysis", *Journal of Economic Surveys*, Vol. 28, Iss. 2, 344-375, Doi: *http://dx.doi.org/10.1111/joes.12012*.

Altavilla, C. (2004), "Do EMU Members Share the Same Business Cycle?", *Journal of Common Market Studies*, Vol. 42, No. 5, 869-896.

Camacho, M., G. Perez-Quiros and L. Saiz (2006), "Are European Business Cycles Close Enough to Be Just One?", *Journal of Economic Dynamics and Control*, 30, 1687-1706.

Carlino, G. and R. DeFina (2004), "How Strong Is Co-Movement in Employment Over the Business Cycle? Evidence from State/Sector Data", *Journal of Urban Economics*, 55, 298–315.

Crone, T. (2005), "An Alternative Definition of Economic Regions in the United States Based on Similarities in State Business Cycles", *Review of Economics and Statistics*, 87, 617-626.

Croux, C., M. Forni and L. Reichlin (2001), "A Measure of Comovement for Economic Variables: Theory and Empirics", *Review of Economics and Statistics*, 83, 232-241.

Crowley, P. (2007), "A Guide to Wavelets for Economists", *Journal of Economic Surveys*, 21, 207-264.

Crowley, P. and D. Mayes (2008), "How Fused Is the Euro Area Core? An Evaluation of Growth Cycle Co-Movement and Synchronization Using Wavelet Analysis", *Journal of Business Cycle Measurement and Analysis*, Vol. 2008, No. 1, 63-95, Doi: *http://dx.doi.org/10.1787/jbcma-v2008-1-en*.

Darvas, Z. and G. Szapáry (2008), "Business Cycle Synchronization in the Enlarged EU", *Open Economies Review*, Vol. 19, No. 1, 1-19.

Eickmeier, S. and J. Breitung (2006), "How Synchronized Are New EU Member States with the Euro Area? Evidence from a Structural Factor Model", *Journal of Comparative Economics*, 34, 538-563.

Frankel, J. and A. Rose (1998), "The Endogeneity of the Optimum Currency Area Criterion", *Economic Journal*, 108, 1009-1025.

Gallegati, M. and M. Gallegati (2007), "Wavelet Variance Analysis of Output in G7 Countries", *Studies in Nonlinear Dynamics and Econometrics*, Vol. 11, No. 3, Art. 6.

Gallegati, M., A. Palestrini and M. Petrini (2008), "Cyclical Behavior of Prices in the G7 Countries Through Wavelet Analysis", *Advances in Complex Systems*, Vol. 11, 1, 119-130.

Haan, J. (de), R. Inklaar and R. Jong-A-Pin (2008), "Will Business Cycles in the Euro Area Converge: A Critical Survey of Empirical Research", *Journal of Economic Surveys*, Vol. 22, No. 2, 234-273.

Inklaar, R. and J. de Haan (2001), "Is There Really a European Business Cycle? A Comment", *Oxford Economic Papers*, 53, 215-220.

Kalemli-Ozcan, S., B. Sorensen and O. Yosha (2001), "Economic Integration, Industrial Specialization and the Asymmetry of Macroeconomic Fluctuations", *Journal of International Economics*, 55, 107-137.

Krugman, P. (1993), "Lesson of Massachusetts for EMU", in F. Giavazzi and F. Torres (eds), *The Transition to Economic and Monetary Union in Europe*, Cambridge University Press, 241-261.

Massmann, M. and J. Mitchell (2004), "Reconsidering the Evidence: Are Eurozone Business Cycles Converging?", *Journal of Business Cycle Measurement and Analysis*, Vol. 1, No. 3, 275-308, Doi: *http://dx.doi.org/10.1787/jbcma-v2004-3-en*.

Mundell, R. (1961), "A Theory of Optimum Currency Areas", *American Economic Review*, 51, 657-665.

Percival, D. and A. Walden (2000), *Wavelet Methods for Time Series Analysis*, Cambridge University Press.

Priestley, M.B. (1981), *Spectral Analysis and Time Series*, Vol. I and II, Academic Press, London.

Rose, A. (2000), "One Money, One Market: Estimating the Effect of Common Currencies on Trade", *Economic Policy*, 30, 9-45.

Rua, A. (2010), "Measuring Comovement in the Time-frequency Space", *Journal of Macroeconomics*, 32, 685-691.

Rua, A. (2011), "A Wavelet Approach for Factor-Augmented Forecasting", *Journal of Forecasting*, 30, 666-678.

Rua, A. (2012), "Money Growth and Inflation in the Euro Area: A Time-Frequency View", *Oxford Bulletin of Economics and Statistics*, 74, 875-885.

Rua, A. and L.C. Nunes (2005), "Coincident and Leading Indicators for the Euro Area: A Frequency Band Approach", *International Journal of Forecasting*, 21, 503-523.

Rua, A. and L.C. Nunes (2009), "International Comovement of Stock Market Returns: A Wavelet Analysis", *Journal of Empirical Finance,* 16, 632-639.

Rua, A. and L.C. Nunes (2012), "A Wavelet-Based Assessment of Market Risk: The Emerging Markets Case", *Quarterly Review of Economics and Finance*, Vol. 52, 84-92.

Tootell, G. (1990), "Central Bank Flexibility and the Drawbacks to Currency Unification", *New England Economic Review*, May/June, 3-17.

Torrence, C. and G. Compo (1998), "A Practical Guide to Wavelet Analysis", *Bulletin of the American Meteorological Society*, Vol. 79, No. 1, 61-78.

Tripier, F. (2002), "The Dynamic Correlation Between Growth and Unemployment", *Economics Bulletin*, Vol. 5, No. 4, 1-9.

Wyne, M.A. and J. Koo (2000), "Business Cycles Under Monetary Union: A Comparison of the EU and US", *Economica*, 67, 347-374.

Yogo, M. (2008), "Measuring Business Cycles: A Wavelet Analysis of Economic Time Series", *Economics Letters*, 100, 208-212.

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