Empirical Economics
https://doi.org/10.1007/s00181-018-1601-x

Growth cycle synchronization of the Visegrad Four and the European Union

Luboš Hanus[1] · **Lukáš Vácha**[1,2]

Received: 12 February 2016 / Accepted: 16 October 2018

Abstract
In this paper, we map the growth cycle synchronization across the European Union, specifically focusing on the position of the Visegrad Four countries. We study the synchronization using frequency and time–frequency domain. To accommodate for dynamic relationships among the countries, we propose a wavelet cohesion measure with time-varying weights. Analyzing quarterly data from 1995 to 2017, we show an increasing co-movement of the Visegrad Four countries with the European Union after the countries have accessed the European Union. We show that participation in a currency union increases the co-movement of the country adopting the Euro. Furthermore, we find a high degree of synchronization at business cycle frequencies of the Visegrad Four and countries of the European monetary union.

Keywords Growth cycles · Synchronization · Integration · Time–frequency · Wavelets · Co-movement

JEL classification E32 · F44 · C49

We gratefully acknowledge the financial support from the Czech Science Foundation under the GA16-14151S Project as well as the support from the Grant Agency of Charles University (GAUK), under Project No. 366015.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00181-018-1601-x) contains supplementary material, which is available to authorized users.

✉ Lukáš Vácha
vachal@utia.cas.cz

1 Institute of Economic Studies, Charles University, Opletalova 26, 110 00 Prague 1, Czech Republic

2 Institute of Information Theory and Automation, Academy of Sciences of the Czech Republic, Pod Vodarenskou Vezi 4, 182 00 Prague 8, Czech Republic

Published online: 27 November 2018

1 Introduction

It has been more than two decades since the breakup of the Eastern Bloc;[1] following its disintegration, those countries began their independent economic and political journeys. While undertaking their economic transformations during this time, the Czech Republic, Hungary, Poland, and Slovakia began discussing mutual cooperation—Visegrad Four (V4), established in 1991. Despite their initially different levels of economic maturity and development, historical and regional proximity connected them to achieve several goals to return from the East back to Europe. We take a closer look at their aim for faster convergence and integration into the European Union.[2]

In 2004, the Visegrad Four countries became members of the EU, which obliges them to adopt the Euro currency as part of the integration process. One of the concerns of successful integration into the European Economic and Monetary Union (EMU) is business cycle synchronization, which is motivated by the theory of Optimum Currency Area (OCA) (Mundell 1961). The common currency can be beneficial for both new and former countries in terms of trade transaction costs. A country joining the OCA needs to be well integrated at the level of macroeconomic variables to balance the costs and benefits of future unified monetary policies (De Haan et al. 2008). If the country is not integrated enough at the European level, then the policies of the European Central Bank that apply to all member states may be counter-cyclical for countries with low business cycle synchronization (Kolasa 2013). On the one hand, these policies may create difficulties for those countries. On the other hand, countries with low levels of synchronization may benefit from being members of the OCA ex-post, because the business cycle synchronization may appear as an endogenous criterion. This endogeneity of OCA means that forming a monetary union may make its members more synchronized (Frankel and Rose 1998).[3]

Assessing the degree of synchronization comes in hand with one of the most challenging tasks in economics—to identify, understand, and disentangle the factors and mechanisms that impact the dynamics of macroeconomic variables. Many quantitative econometric techniques have been developed to study the regular fluctuations of macroeconomic indicators and business cycles, e.g., Baxter and King (1999), Hodrick and Prescott (1981), Harding and Pagan (2002). Our work investigates the decomposition of business cycle into growth cycles over different time horizons. In order to disentangle the desired information, we apply wavelet methodology working in a time–frequency space. The analysis considers the case of the V4, both regarding the internal relationships among its constituent countries and regarding the relationships established within the framework of the European Union (EU).

We find different levels of co-movement between V4 countries and the EU during the 1995–2017 period. The V4 countries show strong co-movement concerning

[1] The Eastern Bloc was generally formed of the countries of the Warsaw Pact (as Central and Eastern European countries) and the Soviet Union.

[2] The Visegrad Four countries also joined the North Atlantic Treaty Organization in 1999 and applied for membership in the European Union in 1995–1996.

[3] The literature focusing on the evolution and determinants of business cycle synchronization between Central and Eastern European (CEE) countries and the EU is extensive, see, e.g., Darvas and Szapáry (2008), Artis et al. (2004), Backus et al. (1992).

cycles longer than 3 years. The pairwise synchronization of V4 countries with the EU appears to be significant even at longer cycles from 2004 onward. Studying common economic cycles shows that the V4 countries are well-synchronized for growth cycle with a periodicity of 2–8 years. Similarly, we observe higher synchronization for seven European core countries for business cycles of 3–8 years, and the relationship becomes even stronger after 2004. On the contrary, all countries together show no considerable relationship for cycles shorter than 1 year, which may reflect some short-term policy heterogeneity.

The contribution of this paper is twofold. We contribute to the literature with an empirical analysis of 23 years period studying the Visegrad Four within the framework of the European Union. Secondly, we propose the novel measure of cohesion with time-varying weights which better explains the relationship among countries.

The remainder of the paper is structured as follows. The following section reviews the relevant literature. Section 3 describes the methodology and introduces the cohesion measure with time-varying weights. Section 4 provides the data description. In Sect. 5, we provide the results. Finally, Sect. 6 concludes.

2 Literature review

Regarding the EU integration—and particularly the economic integration of the Central and Eastern European (CEE) countries—the literature has grown rapidly. Fidrmuc and Korhonen (2006) conduct a meta-analysis of 35 studies involving the synchronization of the EU and CEE countries and find a significant synchronization between new member states and the EU. However, only Hungary and Poland among the V4 countries reached a high level of synchronization. Artis et al. (2004) and Darvas and Szapáry (2008) obtained similar results studying correlations between the business cycles of the EU and Hungary and Poland. Results of Jagrič (2002) also imply that the economic co-movement of Hungary and Poland is high. Analogously, Bruzda (2011) shows that Poland's economic synchronization with the EU rises when intra-EU synchronization is stable. Recently, Aguiar-Conraria and Soares (2011a) study the business cycle synchronizations, using the industrial production index of Euro-12 countries,[4] taking into account the distances between regions. They show that countries that are closer to one another show higher synchronization. Moreover, Hungary and the Czech Republic exhibit a high level of business cycles co-movement with the EU after 2005. However, Slovakia, a member of the Euro area, has only minimal synchronization with the EU. Jiménez-Rodríguez et al. (2013) also find high correlations of CEE countries (except for the Czech Republic) with the EU business cycle, they show that together these countries exhibit a lower level of concordance when a factor model is employed. Crespo-Cuaresma and Fernández-Amador (2013) look at second moments of business cycles in the EU and they report a significant convergence since the 1990s. They show there is no decrease in the optimality of the currency area after the EU enlargements. Further, Bekiros et al. (2015) study business cycle of indus-

[4] These group consists of Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, and Spain. We analyze this group and the V4 countries.

trial production indexes at two sample periods: first only up to the crises (2007M12) and second including the crises. They use Germany as a proxy to the EU and show increased coherence during the crisis.

One of the most popular tools to assess the degree of synchronization is the Pearson correlation coefficient, which solely measures the degree of co-movement in a time domain. However, market-based economies are structured over different time horizons. For this reason, the interest in frequency domain techniques has grown. Christiano and Fitzgerald (2003) proposed a model based on a bandpass filter. Further, Croux et al. (2001) introduced a measure of co-movement, the dynamic correlation, based on a spectral analysis. This measure estimates correlation on a filtered time series. Nevertheless, both the time (static) Pearson correlation and the spectral domain dynamic correlation have several caveats. The first method loses time information, and the latter omits the co-movement dependence in time. Wavelet analysis overcomes these limitations since it combines both time and frequency domain. It also relaxes the assumption of covariance-stationarity; hence the analyzed time series can be locally stationary (Nason et al. 2000; Raihan et al. 2005).[5]

The literature acquaints with many studies that use wavelets. To name few compelling in economics, we refer to Crowley et al. (2006) who studied growth cycles of euro area core, Aguiar-Conraria et al. (2008) who analyzed the evolution of monetary policy in the US, Vacha and Barunik (2012) studying energy markets relationships, and Yogo (2008) who apply wavelet analysis to determine peaks and valleys of business cycles that correspond to the definition of the National Bureau of Economic Research. Further, Crowley and Hallett (2015) have used wavelet techniques to disentangle the relationship of the real gross domestic product (GDP) growth at different frequencies. Recently, Aguiar-Conraria et al. (2018) analyzed the cyclical behavior of the Taylor rule using the wavelet framework.

3 Methodology

To capture the co-movement of the growth cycles, we use wavelet measures. The wavelet transform has been developed to find a better balance between time and frequency dimensions and it also overcomes problems of stationarity.[6] The wavelet functions (filters) used for the decomposition are narrow or wide when we analyze high or low frequencies, respectively (Daubechies 1992). Thus, wavelet analysis is suitable for different types of stochastic processes using optimal time–frequency resolution (Crowley 2007; Cazelles et al. 2008).[7]

In the first part of our empirical study, we use the wavelet coherence (Torrence and Compo 1998; Grinsted et al. 2004) to quantify the pairwise co-movement of countries.

[5] Characteristics of locally stationary time series are close to the stationary ones at each point of time or shorter periods.

[6] This also overcomes the problem of short-time Fourier transform, or windowed Fourier transform (Gabor 1946).

[7] It is possible to use methods of evolutionary spectra of non-stationary time series developed by Priestley (1965). However, to study time-varying dynamics we need to give up some frequency resolution, which is not the case when using wavelet techniques.

For more details about the wavelet coherence see "Appendix A.1" in ESM. The rest of the study is focused on relationships among multiple countries. We begin with the frequency domain cohesion of Croux et al. (2001). Further, extending the work of Rua (2010) and Rua and Silva Lopes (2012) we propose wavelet cohesion estimator with time-varying weights.

3.1 Measurement of common cycles

Many time or frequency domain co-movement measures rely on the bivariate correlation. Based on the bivariate correlation, Croux et al. (2001) proposed a powerful tool for studying the relationship of multiple time series over the frequencies, coined cohesion. For the multiple time series $x_t = (x_{1t} \cdots x_{nt})$, $n \geq 2$, the cohesion in the frequency domain is defined as:

$$\text{coh}(\lambda) = \frac{\sum_{i \neq j} w_i w_j \rho_{x_i x_j}(\lambda)}{\sum_{i \neq j} w_i w_j}, \quad \text{coh}(\lambda) \in [-1, 1], \tag{1}$$

where λ is the frequency, $-\pi \leq \lambda \leq \pi$, w_i denotes a weight associated with time series x_{it}.

Following Croux et al. (2001), Rua and Silva Lopes (2012) extend the frequency measure to the time–frequency domain. Using wavelets they analogically define the wavelet cohesion as:

$$\text{coh}(\tau, s) = \frac{\sum_{i \neq j} \bar{\omega}_{ij} \rho_{x_i x_j}(\tau, s)}{\sum_{i \neq j} \bar{\omega}_{ij}}, \quad \text{coh}(\tau, s) \in [-1, 1], \tag{2}$$

where $\rho_{x_i x_j}(\tau, s)$ is a real wavelet-based measure of co-movement (Rua 2010), interpretable as a contemporaneous correlation coefficient around each point in the time–frequency plane, defined as:

$$\rho_{x_i x_j}(\tau, s) = \frac{\Re(W_{x_i x_j}(\tau, s))}{\sqrt{|W_{x_i}(\tau, s)|^2 |W_{x_j}(\tau, s)|^2}}, \quad \rho_{x_i, x_j}(\tau, s) \in [-1, 1], \tag{3}$$

where $\Re(W_{x_i x_j}(\tau, s))$ is the real part of the wavelet cross-spectrum, known as co-spectrum, of two time series. The co-spectrum is normalized by the squared roots of two wavelet power spectra. The measure captures both positive and negative co-movements of time series, which is inherited by the cohesion measure.[8] The wavelet cohesion, as shown in Eq. 2, is a weighted average of pairwise co-movement, where the weights, $\bar{\omega}_{ij}$, are attached to the pair of series, (i, j), i.e., a share of each pair among all time series. As a measure of co-movement of multiple time series, the cohesion uncovers their common cyclical behavior.

The wavelet cohesion (Eq. 2) employs fixed weights that represent constant shares of each pair. However, we see that weights (e.g., GDP, population size) often change

[8] In "Appendix" in ESM, we demonstrate the wavelet-based measure (Eq. 3) in two particular cases, as shown in Fig. A.2.

over time. This would reflect, for instance, that the developing or emerging countries have different speed of development. In our case, emerging countries show higher growth as they converge to the developed countries; hence, the weight of each pair significantly changes over time.

To reveal the dynamics and development of economies, we propose a new approach to map a multivariate relationship using the time-varying weights in the wavelet cohesion measure:

$$\mathrm{coh}^{TV}(\tau, s) = \frac{\sum_{i \neq j} \omega_{ij}(\tau)\rho_{x_i x_j}(\tau, s)}{\sum_{i \neq j} \omega_{ij}(\tau)}, \quad \mathrm{coh}^{TV}(\tau, s) \in [-1, 1], \tag{4}$$

where $\omega_{ij}(\tau)$ is the weight attached to the pair of time series (i, j) at given time τ. The wavelet cohesion with time-varying weights allows using different types of weights. For example, using GDP as a weight representing the size of an economy, a country with smaller or larger GDP can have smaller or larger effects on the co-movement than other countries. Additionally, as for the wavelet coherence, we test the statistical significance of wavelet cohesion estimates using Monte Carlo simulation methods (Ge 2008; Aguiar-Conraria and Soares 2014).[9]

Additionally, we support our wavelet cohesion using frequency domain cohesion of Croux et al. (2001), which we use for two time-invariant periods and it ideally complements the wavelet results.[10]

4 Data

To study the synchronization, we use the GDP from the database of OECD (2018).[11] We consider the GDP data as a measure of aggregated economic activity. We use both percentage changes from the previous period and the nominal value in EUR. We employ the nominal GDP in cohesion estimation as time-varying weights to measure the power of economies and their impact on the cycles. The dataset includes quarterly data, covering the period from 1995Q1 to 2017Q4.

The Visegrad region consists of the Czech Republic, Hungary, Poland and Slovakia, where only Slovakia is an EMU member. To study the co-movement of the Visegrad countries with the EU, we use the GDP data of EU-28.[12] Furthermore, we measure the common cycles of the V4 countries with the EU core group: Austria, Belgium, Germany, Finland, France, Luxembourg, and the Netherlands. In the literature, there is evidence of business cycles synchronization of EMU-12 during the 1990s, e.g.,

[9] Another possibility for testing the significance is area-wise test approach of Maraun et al. (2007).

[10] To obtain the confidence intervals of frequency cohesion, we follow the procedures of Franke and Hardle (1992) and Berkowitz and Diebold (1998), where instead of bootstrapping the cohesion measure we bootstrap each (cross-)spectrum. Schüler et al. (2017) used this approach in their power cohesion measure while studying financial cycles for G-7 countries.

[11] Data were obtained via OECD Database, May, 2018.

[12] The V4 countries are included in the EU-28; however, the contribution is minimal to change the EU GDP growth. For robustness check, we analyzed the co-movement of the V4 and the EA-19 GDPs, and these results are almost identical to those we report.

Crespo-Cuaresma and Fernández-Amador (2013). However, several countries form the EU core; it is always France and Germany, and additional countries on which studies are not consistent when specifying the EU core and periphery. We separate Greece, Ireland, Italy, Portugal, and Spain as five peripheral countries (Aguiar-Conraria and Soares 2011b; Ferreira-Lopes and Pina 2011; Grigoraş and Stanciu 2016). The EU core group is supposed to be the target for the V4 countries both economically and politically.

5 Results

5.1 Synchronization of the Visegrad Four countries

We begin our analysis of growth cycle synchronization within the group of V4 countries. The extent of synchronization and co-movement of gross domestic products is measured by the wavelet coherence. The wavelet coherence, depicted in Fig. 1, shows regions of co-movement localized in time–frequency; on x and y-axes we have time and corresponding cyclical component, respectively. The yellow color represents the strongest coherence, while the blue color indicates no coherence.

The beginning of the transition period in the 1990s presents weak synchronization at all cycles. This reflects the situation of the V4 countries which started their transition to market-based economies after the breakup of the Eastern Bloc. The low co-movement, except several regions around 1999 and 2000, may be caused by Slovakia's cold-shouldered participation in the political discussions during 1993–1997, which translated into the economic performance with a delay. Another possible reason is that even after a few years of formal and intensive cooperation the monetary and fiscal policies started to diverge. Many countries went through a financial crisis in the years around 1997. For instance, in the late 1990s, the Czech Republic had been through difficult years of stabilization (Antal et al. 2008). This divergence in economic environments might cause significant asynchrony in growth cycle behavior over both shorter and longer cycle periods. Related to policies of sovereign states, the low synchronization may also come from the low level of convergence of other macroeconomic variables (Kutan and Yigit 2004).

Nevertheless, this characteristic feature of a weak relationship for all pairs within the V4 countries lasts until 2004, with the exception of several regions of short periods of strong coherence.[13] We observe a high degree of synchronization of 1–5-year cycles beginning around 2004 for Hungary with Slovakia, the Czech Republic with both Hungary and Slovakia. These are the strongest coherences among the V4 countries. Furthermore, all V4 countries pairs co-move at cyclical component around 3–5 years beginning approximately in 2009. Interestingly, the overall relationship between Poland's and other V4 countries is notably weak, see the right column of Fig 1. Additionally, the coherence of the growth cycles up to 1 year is low during most of the sample period.

[13] Short periods of co-movement appear around and prior to 2000 at 1–2-year, and 2-year cycles, respectively, between Hungary and Slovakia, and Poland with the Czech Republic and Slovakia.

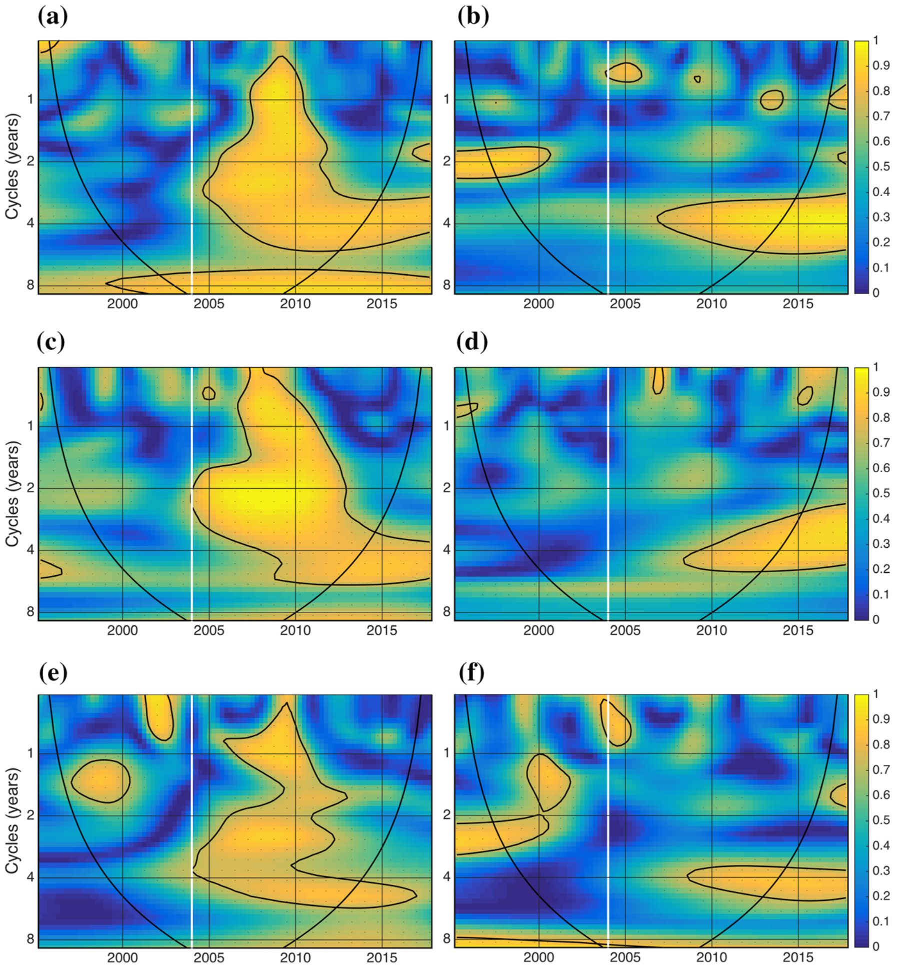

Fig. 1 Wavelet coherence within the Visegrad Four countries. The solid black line contours the significance level of 5% against the red noise. The area below the black curve is the cone of influence. The vertical solid white line indicates 2004—the year of the enlargement of the EU. **a** Czech Republic–Hungary, **b** Czech Republic–Poland, **c** Czech Republic–Slovakia, **d** Hungary–Poland, **e** Hungary–Slovakia, **f** Poland–Slovakia. (Color figure online)

5.2 Synchronization of V4 and the EU

In this section, we analyze the co-movement of the Visegrad Four countries and the European Union. We take the GDP growth of all 28 countries of the European Union. The reason is straightforward since once states are members of the EU they should support the economic aims of the EU and coordinate policies they make toward these aims.[14]

[14] We have additionally checked the co-movement of the V4 countries and the Euro area of 19 countries (EA-19) as a proxy of the EU. The results are almost indistinguishable.

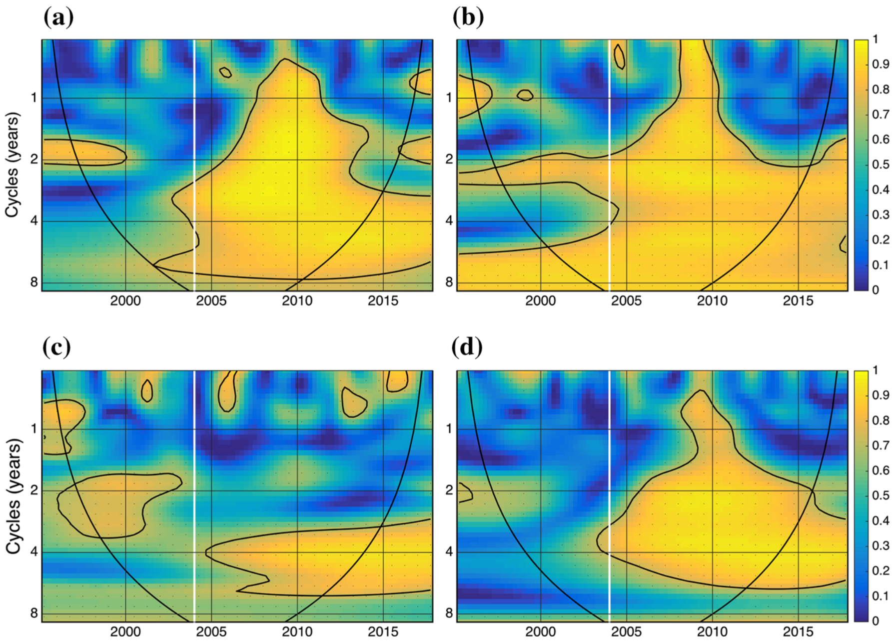

Fig. 2 Wavelet coherences of the Visegrad Four and EU-28. The solid black line contours the significance level of 5% against the red noise. The area below the black curve is the cone of influence. The vertical solid white line indicates 2004—the year of the enlargement of the EU. **a** Czech Republic–EU-28, **b** Hungary–EU-28, **c** Poland–EU-28, **d** Slovakia–EU-28. (Color figure online)

We observe a strong co-movement of the Czech Republic and Hungary with the EU starting around 2003 at 2–6-year cycles. In contrast, Slovakia and Poland are less synchronized with the EU. These findings are in line with the results of Aguiar-Conraria and Soares (2011a). A significant synchronization of Slovakia with the EU starts right after its accession to the EU. Synchronization increases gradually from 2004 and spreads from 2–4 to 1–6-year cycles around 2008 that is precisely at the time when Slovakia adopted the Euro, on January 1, 2009. Eventually, Slovakia may be considered as an example where the degree of synchronization increases after accession to the EU and EMU, which is consistent with the theory of endogeneity for optimum currency areas. Moreover, in comparison to the other 3 countries, Slovakia has not experienced any significant synchronization before 2004. On the other hand, the high synchronization around 2008 may also be a reaction to the global financial crisis hitting all countries. Nevertheless, this may be in line with the OCA theory when the crisis spills over all highly synchronized European countries even to those of V4 (Fig. 2).

Preparation of the Visegrad countries for the EU accession, which began shortly before 2000, is also one of the reasons for increased synchronization with EU. This is in line with findings of Kolasa (2013) who reports a substantial convergence with the Eastern enlargement of the EU. The high degree of synchronization of Hungary also supports the results of Fidrmuc and Korhonen (2006). For Poland, we do not see

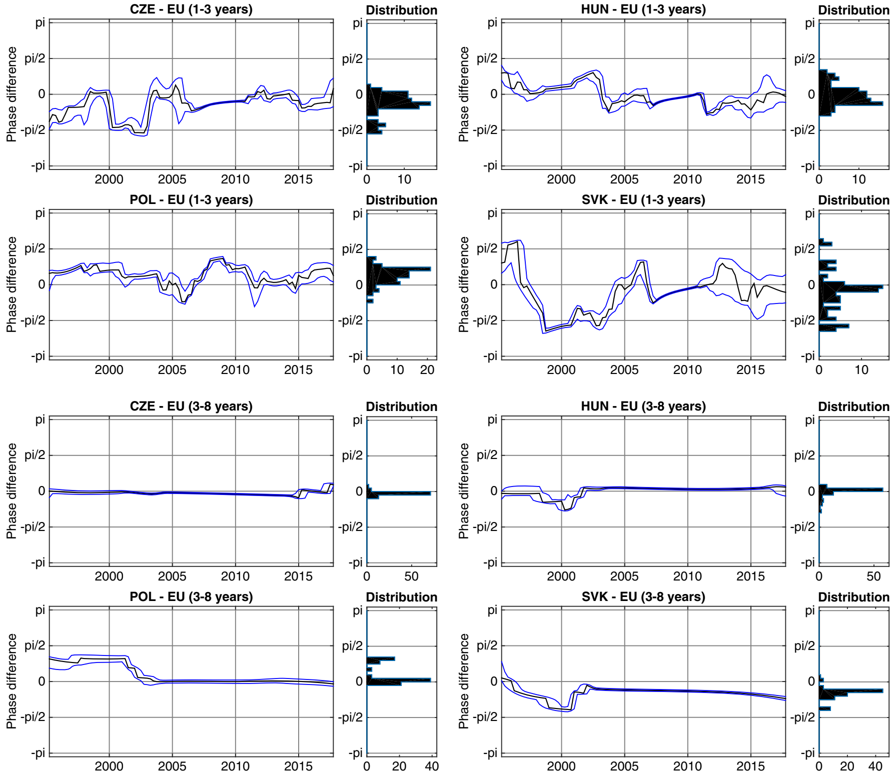

Fig. 3 Phase differences of short- and business cycle frequencies, 1–3 and 3–8 years, respectively. The solid black line is the true phase difference of two time series. The blue solid line is the 95% bootstrapped confidence interval. For each phase difference, its distribution is provided. (Color figure online)

a strong co-movement, we observe higher coherence only for a small region in comparison with other countries in the group, and it is around 4–6-year cycles beginning 2006. This low level of synchronization of most of Poland's and EU's growth cycles may be due to the different orientation structures of Poland's economy.[15]

Additionally, we provide the analysis of phase differences between each of V4 countries and the EU's GDP. The phase difference presents the information about the position of cycles of two economies, i.e., whether one leads the other. In Fig. 3, the phase differences show lead or lag position of the 1–3- and 3–8-year cycles between V4 countries and the EU.[16] There are many periods of time where phase differences are not significantly different from zero, indicating there is no country in the lead position, which also means the countries are in-phase.[17] Nevertheless, we observe periods with significant phase differences such as between 2006 and 2010. Which for

[15] Poland's economy share of agriculture in GDP is one of the higher.

[16] Two countries are in-phase if the phase difference belongs to $[-\pi/2, \pi/2]$; otherwise, they are in the anti-phase. Moreover, the first country leads the second, x_j, if the phase is in $[0, \pi/2]$ and $[-\pi, -\pi/2]$; when in $[-\pi/2, 0]$ and $[\pi/2, \pi]$, the second country is leading.

[17] Furthermore, the phase is more volatile when the coherence is low.

all V4 countries means following EU's growth cycles at 1–3 years frequency before and during the recession, except for Poland. When the phase difference belongs to the $[0, \pi/2]$ interval, the 1–3-year growth cycles of Hungary and Poland lead the EU cycles at these frequencies. This is most of the time for Poland and between 1998 and 2004 for Hungary. This lead/lag situation of the V4 region is puzzling, as the countries have been tightly connected to the EU economy and it happens only for Poland and Hungary at the beginning of the sample. One possible explanation for this counter-intuitive finding is that recessions or rebounds of the economies occur sooner compared to EU. For example, during the recession, the lead of V4 countries could be the negative growth lead since these countries are often at the beginning of the chain of outsourced production. In the time of crises, the cuts may start by subcontracted production. This may be the case with the debt crisis in 2013 where we see more volatile phase differences at 1–3-year cycles for all V4 countries. The Czech Republic was in-phase before 2013, then it follows in 2015, similarly for Hungary. On the other hand, in case of Slovakia, we have the significant leading position of the EU during 2004 and 2007–2010 for 1–3-year cycles and during whole sample period at 3–8-year cycles, which supports the concept of the endogeneity of OCA.

Observing the phase differences, the phase differences look more stable at business cycles horizons. This observation is due to high and significant coherences at these cycles.[18] Figure 3 shows that Slovakia follows the EU at cycles of 3–8-year period over the whole sample. Poland's 3–8-year growth cycles are in-phase and lead those of the EU from 1995 to 2003 then the phase is not significant from zero. Cycles of Hungary were lagging around 2000, but after 2001 Hungary is in-phase and leads the EU cycles. The business cycle growth component of the Czech Republic is lagging the EU after 2001 when it is significant, and their coherence is strong. At 3–8-year business cycles there are no directional changes of growth phase we may surely link to crisis periods.

5.3 Common economic cycle within Europe

In this part, we investigate the multivariate relationship of countries in the EU. As some of the countries experienced the very dynamic development of GDP, it is natural to construct a measure that takes these changes into account. We propose the wavelet cohesion with time-varying weights that precisely quantifies commonalities among cycles. In contrast to the coherence, the cohesion may be negative; it can capture a counter-cyclical co-movement of time series. For the weights, we use nominal GDP in EUR, which relate to the size of countries' economies and their wealth, respectively. For the measuring the synchronization, we continue using GDP growth data, and we analyze a period of 23 years spanning from 1995Q1 to 2017Q4.

[18] We should also carefully interpret the phase difference at 3–8-year cycles because of the cone of influence, which affects influences results at 8 years from both sides of the sample.

Table 1 Change of gross domestic products

1995 versus 2017	EU-28	EU-12	Germany	Czech Republic	Hungary	Poland	Slovakia
Δ GDP EUR (in %)	209	194	168	421	313	428	544

The values show how the GDPs of countries have grown between 1995 and 2017, 1995 = 100%

5.3.1 Does the size of economies affect economic cycle cohesion?

Let us now take a closer look at the GDP development of the V4 economies with respect to the European Union (EU-28), the Euro area (EU-12) and their close EU partner—Germany. We highlight Germany as well since its economic relationship with the V4 is strong. Germany's international trade with the V4 countries is larger than the trade of Germany and China. Since the transition period of the V4 countries, we have observed notable differences in GDP growth. Czech Republic's, Slovakia's, and Poland's GDP have grown to more than 400% of their 1995 level, the GDP of Hungary is approximately at its 313%, whereas Germany's and EU-28 GDP increases are only to their 168% and 209%, respectively, see Table 1.

Hence, considering the GDP differences, the adoption of weights is beneficial for our analysis. From the OCA's point of view, we are interested in the synchronization of economic cycles and the nominal GDP tells by how much power can each of the economies affect the whole system. The nominal GDP takes into account a gravitational attraction of the countries and their contribution to the common cycle.

5.3.2 Common cycles of the Visegrad Four and the EU

Despite many contributions, there is no general consensus to the question of EMU synchronization and the Euro adoption (De Haan et al. 2008; Aguiar-Conraria and Soares 2011b; Crespo-Cuaresma and Fernández-Amador 2013). Here, we proceed to study the strength of relationship of the V4 within the EU looking at growth cycle similarities. We focus on the common cycle of seven already integrated (EMU) countries, the EU core, and the V4 countries which are in the process of integration. Moreover, we also look at common cycles of both groups individually.

Using the wavelet cohesion with time-varying weights, we observe that V4 and EU core are significantly cohesive at cycles corresponding to cycles longer than 2 years from 2005. Surprisingly and contrary to the cohesive business cycles, we see very small common movements at the short-term cycles, 0.5–1 year over the whole sample. The strongest relationship appears during the period after 2002 at cycles of 3–8 years, see Fig. 4.[19] Knowing the case of Slovakia, which experienced a gradual increase of co-movement with EU after the Euro adoption, the high cohesion of V4 and EU core may signal a potential benefit from joining the EMU for the Czech Republic, Poland, and Hungary.

[19] The figures of wavelet cohesion, heatmaps, display the results the same way as those of the wavelet coherence, except that the scale of the cohesion may be negative. Hence, the blue color depicts the negative relationship between economies, which may also be strong.

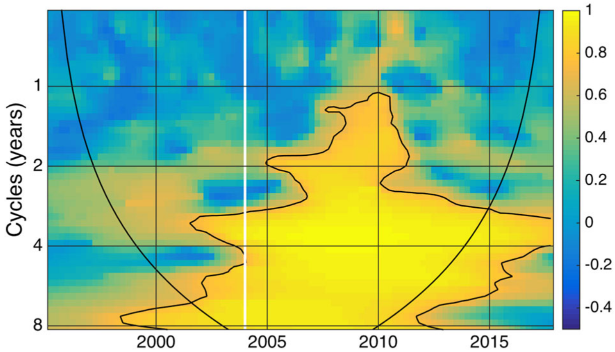

Fig. 4 Wavelet cohesion of the Visegrad Four and the EU core. The solid black line contours the significant cohesion (95%). The area below the black curve is the cone of influence. The vertical solid white line indicates 2004—the year of the enlargement of the EU. (Color figure online)

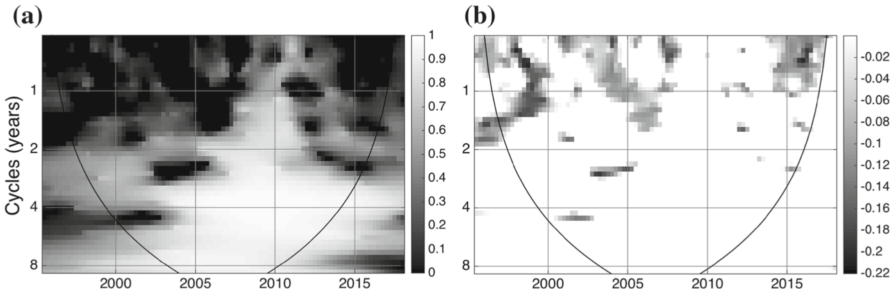

Fig. 5 Positive and negative cohesion of the Visegrad Four and EU core using time-varying weights in terms of Nominal GDP. The area below the black curve is the cone of influence. **a** Positive cohesion of V4 and EU core, **b** negative cohesion of V4 and EU core

To assess the common cycles of the V4 and EU core in a detailed perspective, we extract the cohesion (Fig. 4) into two parts: positive and negative. It indicates that the positive (pro-cyclical) cohesion dominates in this relationship and it is mostly for cycles longer than 2 years, as shown in Fig. 5a. On the contrary, when countries co-move counter-cyclically it is at cycles shorter than 2 years, as shown in Fig. 5b. Hence, the countries have common positive movements at business cycle frequencies, and in short periods they may go in the opposite direction.

Further, we support our findings with an analysis of common cycles of both subgroups separately. The degree of synchronization of the V4 is high and pro-cyclical at business cycle frequencies (3–8 year), especially from 2005 to 2015 for 3–6-year cycles, as shown in Fig. 6a. An area of high cohesion also appears at cycles around 2 years and begins in 2011. The short-term outlook provides some insights that Visegrad countries react weakly and counter-cyclically at cycles up to 2 years. Also an overall weak and negative synchronization covers the first part of the sample from 1995 to 2004.

Although we observe similar patterns of co-movement over the longer horizons, the overall synchronization of the EU core is much stronger than the one of the V4

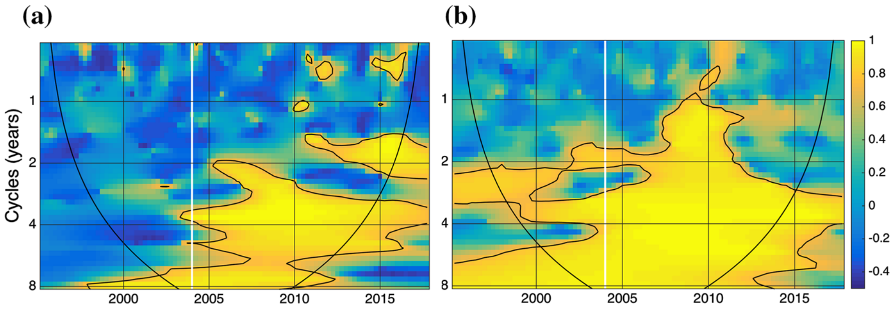

Fig. 6 Wavelet cohesion of Visegrad Four and EU core countries. The nominal GDP data used as time-varying weights. The solid black line contours the significance level of 5% against the red noise. The area below the black curve is the cone of influence. The vertical solid white line indicates 2004—the year of the enlargement of the EU. **a** Visegrad Four, **b** EU core. (Color figure online)

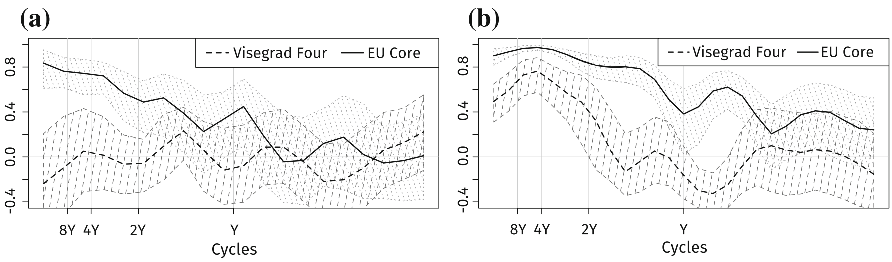

Fig. 7 Frequency cohesion of the Visegrad Four and EU core countries during two periods: **a** 1995–2004 and **b** 2005–2017. On the *x*-axis we depict cycle length and label four cyclical components of 1 year, 2 years, 4 years and 8 years using the gray vertical lines. The longest observed cycles are 10 and 13 years, for figures **a** and **b**, respectively. Dashed areas are 90% bootstrapped confidence intervals

countries, as shown in Fig. 6b. This result is in line with Rua and Silva Lopes (2012), who find a high cohesion of the business cycle dynamics of the EU countries. In the second half of the sample, for the EU core, the relationship slightly increases at the shorter cycles.[20]

Moreover, we complement the analysis with the frequency cohesion. Although it is time-invariant, it helps us depict the very low synchronization of all cyclical components of the V4 prior its accession to the EU. We find almost none existent common cycle among the V4 countries between 1994 and 2004, see Fig. 7a. On the contrary, the EU core countries significantly co-move at cycles longer than 1.5 years during that period. Looking at the period of 2005–2017, as shown in Fig. 7b, we see a different situation. The cohesion of V4 countries is greater for cycles longer than 2 years. The synchronization of the EU core during 2005–2016 is strong at almost all growth cycles. These findings are in line with our previous results from Sects. 5.1 and 5.2 of the pairwise coherence. The coherence of the V4 countries is low during 1995–2004 in both situations.

[20] In "Appendix Fig. A.1" in ESM, we provide complementary results showing cohesion of the EU-12 countries (a) and peripheral countries (b), where both show much lower synchronization than the EU core in Fig. 6.

6 Concluding remarks and policy implications

Growth cycle synchronization is a central question of economic integration, and thus it needs a rigorous examination. Adopting wavelet methodology, we have overcome the problems of traditional measures, such as operation in time or frequency domain only and of the necessity of time series stationarity. In this paper, we have proposed a measure of multivariate co-movement using the wavelet cohesion with time-varying weights that allows for precise localization of cyclical co-movement.

We have investigated the impact of V4 cooperation, which has one of its main aims to converge faster toward the EU. We have found very low levels of synchronization for the first years of their cooperation, which might be linked to the economic turbulence of the late 1990s. The coherence is low for each country paired with Poland, except cycles at 3–5-year period beginning around 2008. Nevertheless, the co-movement and cohesion of the V4 economies are strong, particularly after 2005.

Further, we have studied the growth cycle synchronization of the V4 with the EU. The results confirmed some already known interesting patterns. Slovakia's synchronization with the EU was poor before its accession to the EU. However, the relationship gets stronger after 2005, which supports the theory of the endogeneity of the OCA and the adoption of Euro. We have revealed that the highest coherence is between EU and both the Czech Republic and Hungary beginning in 2001. This might imply readiness of these countries for the Euro adoption considering one of the features—the coherence of growth cycles. By contrast, the degree of synchronization of the business cycles of Poland and EU is the lowest among V4.

Employing wavelet cohesion with time-varying weights, we have uncovered relationships in both time and frequency domains for multiple time series. Regarding the V4 its position within the EU, we have shown strong pro-cyclical behavior at cycles longer than 2 years. Concerning the EU core countries, we show that there is a weak synchronization of short-term dynamics. Conversely, we have demonstrated that the EU is highly cohesive at longer economic cycles, such as business cycle frequencies at 3–8 years. Finally, we have found high co-movement of the business cycle frequencies of the V4 and the EU core countries for the sample period when the V4 countries have been part of the EU. The similar growth cycles reactions to exogenous shocks of the V4 and the EU may be a relevant feature for further consideration of joining the monetary union. Higher the cohesion of the EU and its members, more efficient and coherent all policies might be.

Acknowledgements We are very thankful to the editor and referees for useful comments and suggestions. We would like to thank participants of two conferences for constructive discussions—the 2nd International Workshop on "Financial Markets and Nonlinear Dynamics" in Paris and Slovak Economic Association meeting in Košice.

References

Aguiar-Conraria L, Soares MJ (2011a) Business cycle synchronization and the Euro: a wavelet analysis. J Macroecon 33(3):477–489

Aguiar-Conraria L, Soares MJ (2011b) The continuous wavelet transform: a primer. Technical report NIPE-Universidade do Minho
Aguiar-Conraria L, Soares MJ (2014) The continuous wavelet transform: moving beyond uni- and bivariate analysis. J Econ Surv 28(2):344–375
Aguiar-Conraria L, Azevedo N, Soares MJ (2008) Using wavelets to decompose the time–frequency effects of monetary policy. Phys A Stat Mech Appl 387(12):2863–2878
Aguiar-Conraria L, Martins MM, Soares MJ (2018) Estimating the taylor rule in the time–frequency domain. J Macroecon 57:122–137
Antal J, Hlaváček M, Holub T (2008) Inflation target fulfillment in the Czech Republic in 1998–2007: some stylized facts. Czech J Econ Finance (Finance a uver) 58(09–10):406–424
Artis MJ, Marcellino M, Proietti T (2004) Characterizing the business cycle for accession countries. In: CEPR discussion papers 4457
Backus DK, Kehoe PJ, Kydland FE (1992) International real business cycles. J Polit Econ 100(4):745–775
Baxter M, King RG (1999) Measuring business cycles: approximate band-pass filters for economic time series. Rev Econ Stat 81(4):575–593
Bekiros S, Nguyen DK, Uddin GS, Sjö B (2015) Business cycle (de) synchronization in the aftermath of the global financial crisis: implications for the Euro area. Stud Nonlinear Dyn Econom 19(5):609–624
Berkowitz J, Diebold FX (1998) Bootstrapping multivariate spectra. Rev Econ Stat 80(4):664–666
Bruzda J (2011) Business cycle synchronization according to wavelets-the case of Poland and the Euro zone member countries. Bank i Kredyt 3:5–31
Cazelles B, Chavez M, Berteaux D, Ménard F, Vik JO, Jenouvrier S, Stenseth NC (2008) Wavelet analysis of ecological time series. Oecologia 156(2):287–304
Christiano LJ, Fitzgerald TJ (2003) The band pass filter. Int Econ Rev 44(2):435–465
Crespo-Cuaresma J, Fernández-Amador O (2013) Business cycle convergence in EMU: a first look at the second moment. J Macroecon 37:265–284
Croux C, Forni M, Reichlin L (2001) A measure of comovement for economic variables: theory and empirics. Rev Econ Stat 83(2):232–241
Crowley PM (2007) A guide to wavelets for economists. J Econ Surv 21(2):207–267
Crowley PM, Hallett AH (2015) Great moderation or "Will o' the Wisp"? A time–frequency decomposition of GDP for the US and UK. J Macroecon 44:82–97
Crowley PM, Maraun D, Mayes D (2006) How hard is the euro area core?: an evaluation of growth cycles using wavelet analysis. Bank of Finland Research Discussion Paper No. 18/2006. https://ssrn.com/abstract=3164195
Darvas Z, Szapáry G (2008) Business cycle synchronization in the enlarged EU. Open Econ Rev 19(1):1–19
Daubechies I (1992) Ten lectures on wavelets, vol 61. SIAM, Philadelphia
De Haan J, Inklaar R, Jong-A-Pin R (2008) Will business cycles in the euro area converge? A critical survey of empirical research. J Econ Surv 22(2):234–273
Ferreira-Lopes A, Pina ÁM (2011) Business cycles, core, and periphery in monetary unions: comparing Europe and North America. Open Econ Rev 22(4):565–592
Fidrmuc J, Korhonen I (2006) Meta-analysis of the business cycle correlation between the Euro area and the CEECs. J Comp Econ 34(3):518–537
Franke J, Hardle W (1992) On bootstrapping kernel spectral estimates. Ann Stat 20(1):121–145
Frankel JA, Rose AK (1998) The endogeneity of the optimum currency area criteria. Econ J 108(449):1009–25
Gabor D (1946) Theory of communication. Part 1: the analysis of information. J Inst Electr Eng Part III Radio Commun Eng 93(26):429–441
Ge Z (2008) Significance tests for the wavelet cross spectrum and wavelet linear coherence. Ann Geophys 26(12):3819–3829
Grigoraş V, Stanciu IE (2016) New evidence on the (de) synchronisation of business cycles: reshaping the European business cycle. Int Econ 147:27–52
Grinsted A, Moore JC, Jevrejeva S (2004) Application of the cross wavelet transform and wavelet coherence to geophysical time series. Nonlinear Process Geophys 11(5/6):561–566
Harding D, Pagan A (2002) Dissecting the cycle: a methodological investigation. J Monet Econ 49(2):365–381
Hodrick RJ, Prescott EC (1981) Post-war U.S. business cycles: an empirical investigation. In: Discussion papers 451. Northwestern University, Center for Mathematical Studies in Economics and Management Science

Jagrič T (2002) Measuring business cycles-a dynamic perspective. Banka Slovenije, Prikazi in analize X/1, Ljubljana

Jiménez-Rodríguez R, Morales-Zumaquero A, Égert B (2013) Business cycle synchronization between Euro area and Central and Eastern European countries. Rev Dev Econ 17(2):379–395

Kolasa M (2013) Business cycles in EU new member states: How and why are they different? J Macroecon 38(Part B):487–496

Kutan AM, Yigit TM (2004) Nominal and real stochastic convergence of transition economies. J Comp Econ 32(1):23–36

Maraun D, Kurths J, Holschneider M (2007) Nonstationary gaussian processes in wavelet domain: synthesis, estimation, and significance testing. Phys Rev E 75(1):016707

Mundell RA (1961) A theory of optimum currency areas. Am Econ Rev 51(4):657–665

Nason GP, Von Sachs R, Kroisandt G (2000) Wavelet processes and adaptive estimation of the evolutionary wavelet spectrum. J R Stat Soc Ser B (Stat Methodol) 62(2):271–292

OECD (2018) Quarterly GDP (indicator). https://doi.org/10.1787/b86d1fc8-en. Accessed 2 May 2018

Priestley MB (1965) Evolutionary spectra and non-stationary processes. J R Stat Soc Ser B (Methodol) 27(2):204–237

Raihan SM, Wen Y, Zeng B (2005) Wavelet: a new tool for business cycle analysis. In: Federal Reserve Bank of St Louis working paper series (2005-050)

Rua A (2010) Measuring comovement in the time–frequency space. J Macroecon 32(2):685–691

Rua A, Silva Lopes A (2012) Cohesion within the Euro area and the US: a wavelet-based view. In: Banco de Portugal, working paper (4)

Schüler YS, Hiebert P, Peltonen TA (2017) Coherent financial cycles for g-7 countries: why extending credit can be an asset. In: ESRB working papers series

Torrence C, Compo GP (1998) A practical guide to wavelet analysis. Bull Am Meteorol Soc 79(1):61–78

Vacha L, Barunik J (2012) Co-movement of energy commodities revisited: evidence from wavelet coherence analysis. Energy Econ 34(1):241–247

Yogo M (2008) Measuring business cycles: a wavelet analysis of economic time series. Econ Lett 100(2):208–212