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Abstract

Using the measures proposed by Mink et al. (2012), we reexamine the coherence of business cycles in the euro area using a long sample period. We also analyze the impact of the COVID-19 pandemic on business cycle coherence and examine whether our measures for business cycle coherence indicate a core versus periphery within EMU. Our results suggest that business cycle coherence did not increase monotonically. The COVID-19 pandemic made that the signs of the output gaps of euro area countries became more similar, but we find large differences in the amplitude of the output gaps across countries.

JEL-Codes: E320, F020, F420.

Keywords: Covid-19 crisis, business cycle coherence, synchronization, output gaps, euro area.

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1 Introduction

With the creation of the European Economic and Monetary Union (EMU), member states gave up domestic monetary and exchange rate policies which they could use to respond to idiosyncratic shocks. Whereas common shocks hit all member states (although their transmission may be asymmetric as the COVID-19 pandemic has illustrated), idiosyncratic shocks are asymmetric in nature. In other words, not all member states of the monetary union are affected by those shocks. Under normal circumstances, common shocks in the euro area can be countered by the monetary policy of the European Central Bank (ECB), while national fiscal policy could be used to stabilize idiosyncratic shocks and the asymmetric effects of common shocks.

Before the start of EMU, many academics questioned the viability of a monetary union comprised of many countries. In their seminal paper, Bayoumi and Eichengreen (1993) show that before the start of EMU there was a core of countries where economic shocks were highly synchronized, and a periphery where synchronization was significantly lower. In their update of the Bayoumi-Eichengreen study, Campos and Macciarelli (2016) reach more optimistic conclusions. Using a similar estimation methodology and the same sample of countries and time period, these authors study the 1989-2015 period and conclude that the core-periphery pattern has weakened. Updating their previous study, Bayoumi and Eichengreen (2017) even report that Portugal, Ireland, Italy, Spain and Greece belong to the core of the euro area, where the core is defined as countries whose aggregate supply and demand shocks are relatively highly correlated with those of Germany. Rathke et al. (2020) estimate common euro area shocks and calculate impulse

responses to these shocks at the country-sector level. They report varying degrees of heterogeneity across member countries' responses to common shocks. The level of heterogeneity was most pronounced during the financial crisis. Finally, Campos and Macchiarelli (2021) use a new dynamic framework to study convergence dynamics and find that Ireland, Portugal, and Finland are persistently classified as periphery countries. Spain is moving towards the core, while Greece moves away from the core.

A more direct way to examine whether the common monetary policy is equally optimal for all countries in the euro area is to analyze the coherence (or, as it is often called, the synchronization) of business cycles. Business cycles reflect shocks, amplification channels, and channels of adjustments.[1] The more business cycles differ, the less the ECB's policies will benefit all countries equally. For instance, whereas countries with a negative output gap would prefer an expansionary monetary policy, countries with a positive output gap would prefer a more restrictive policy stance. Still, even if output gaps would have the same sign, cross-country differences in the amplitude of the output gap can hamper the implementation of a common monetary policy as well. Countries with large swings in their output gaps would prefer larger interest rate steps than countries with moderate output gap amplitudes.[2]

There is a large literature examining (the drivers of) business cycle coherence (see de Haan et al., 2008 and Gaechter and Riedl, 2014 for reviews). Most of this

[1] Furceri et al. (2021) compare adjustment channels in the US and EMU. Their evidence suggests that labor mobility plays a key role in the US, but less so in EMU. In turn, price flexibility is more important as a shock absorber in EMU than in the US.

[2] At the same time, joining the monetary union has been argued to increase business cycle coherence. Introducing a common currency will increase trade, and more trade will increase business cycle coherence of the countries in the monetary union (cf. Frankel and Rose, 1998); see de Haan et al. (2008) for a further discussion and Azcona (2021) for a recent contribution.

literature uses the correlation of output gaps to measure business cycle coherence. However, as shown by Mink et al. (2012), the correlation coefficient of output gaps does not properly take into account that output gaps can have a different sign and/or have a different amplitude. For instance, two output gap series may have very different amplitudes while the correlation between both series equals one. These authors propose two simple measures to analyze output gap coherence that can be used as an alternative for the correlation coefficient. These measures examine whether countries' output gaps have the same sign (output gap synchronicity), and whether these output gaps have the same amplitude (which is taken into account by their measure of output gap similarity).[3] Mink et al. (2012) show that output gaps in the US are less coherent than output gaps in the euro area, even though the US has been a monetary union for much longer and is generally believed to be more integrated than the euro area.

This paper employs the methodology of Mink et al. (2012) in order to examine business cycle coherence in the euro area. Several alternative methods have been used to analyze business cycle coherence, such as network analysis (cf. Matesanz Gomez et al., 2017) or fuzzy clustering (cf. Alhborn and Wortmann, 2018). One of the advantages of the method used in this paper is that it provides measures for businesses cycle coherence for each time period in the sample, so that we can zoom in on differences between the period before the COVID-19 crisis hit Europe and the COVID-19 crisis period. Another advantage of this method is that it takes differences between the amplitudes of business cycles into account. This is important, as Belke et al. (2017) report that there are large differences in the

[3]The method has been used in various other studies. See, for instance, Miles and Vijverberg (2014) ; Communale (2017); Miles (2017); and Samarina et al. (2017).

amplitudes of national business cycles in the euro area.

Our paper contributes to the literature as follows. First, we reexamine coherence of business cycles in the euro area using a long sample period. Although it has received a lot of attention in the past, recent research on this issue is scant. Second, we analyze the impact of the COVID-19 pandemic on business cycle coherence in the euro area. Although the COVID-19 pandemic was a common shock, it seems that not all countries in the euro area were equally affected. Previous research suggests that the financial crisis had a major impact on business cycle coherence (cf. Gaechter et al., 2012). For instance, Belke et al. (2017) report that the output co-movement between core and peripheral countries in the euro area decreased markedly in the wake of the financial crisis. Interestingly, they also report that core countries saw rising coherence of output during both the financial crisis and the subsequent sovereign debt crisis. Third, we examine whether our measures for business cycle coherence suggest a core versus periphery within EMU and whether COVID-19 has lead to changes.

The rest of the paper is structured as follows. Section 2 outlines the method. Section 3 describes the data, while Section 4 offers the results. Section 5 presents a robustness analysis. The final section concludes.

2 Method

As explained in the previous section, we focus on output gaps, i.e., deviations of real GDP from its trend value.[4] Such output gaps play a central role in the monetary policy maker's reaction function, either because the policy maker ex-

[4]This section heavily draws on Mink et al. (2012).

plicitly aims at stabilizing output fluctuations, or because the output gap is used as an indicator of future inflationary pressures.

2.1 Computation of output gaps

Our real GDP data suffer from structural breaks towards the end of the sample due to the COVID-19 shock. This makes the computation of output gaps more difficult. We cannot use the band-pass filter of Baxter-King (1999) because it implies dropping observations at both the beginning and end of the sample. The Christiano-Fitzgerald (2003) filter can also not be used, because it generates symmetric cycles in the middle of the sample but asymmetric cycles towards both ends of the sample.

An alternative would have been the often-used Hodrick-Prescott (1997) filter, which minimizes the sum of the squared cyclical components c_t^2 and a slowly evolving squared trend component τ_t in a times series $y_t,\ t = 1, \ldots T$

$$\left(\sum_{t=1}^{T} c_t^2 + \lambda \sum_{t=2}^{T-1} \left[(\tau_{t+1} - \tau_t) - (\tau_t - \tau_{t-1}) \right]^2 \right),$$

where λ is equal to the variance between the trend component τ_t and cyclical component $c_t (\equiv y_t - \tau_t)$. For quarterly observations λ is usually taken equal to 1600.

Hamilton (2018) heavily criticises the HP filter for several reasons. Therefore, we adopt his alternative: a regression of real output at date $t + h$ on the four most recent values as of date t.

2.2 Synchronicity

Our first coherence measure, which we call output gap synchronicity, captures for a region of n countries whether positive and negative output gaps coincide, regardless of their amplitudes. Denoting the output gap of country i at time t by $g_i(t)$ and the reference output gap for the region at time t by $g_r(t)$, we calculate synchronicity between an individual country i and the reference in period t as

$$\phi_{it} = \frac{g_i(t)g_r(t)}{|g_i(t)g_r(t)|}. \tag{1}$$

For now, we assume the reference is the output gap of one country r out of the n countries in the region, but below we propose an alternative way to define the region's reference output gap. The synchronicity measure is defined on a $[-1, 1]$ scale, where a value of 1 indicates that output gap i has the same sign as the reference, while a value of -1 indicates that both output gaps have opposite signs.

The synchronicity measure can be used to evaluate overall synchronicity of the n countries in the region with the reference output gap. To this end we calculate

$$\phi_{it} = \frac{1}{n}\sum_{i=1}^{n} \frac{g_i(t)g_r(t)}{|g_i(t)g_r(t)|}, \tag{2}$$

where $g_i(t)$ is the output gap of country i at time t and $g_r(t)$ is the reference output gap for the region at time t. It is defined on a $[-1 + 2/n, 1]$ scale, where a value of 1 indicates that the output gaps of all countries have the same sign as the reference. When all output gaps (other than the reference) have a different sign than the reference output gap, it follows that the measure equals $-1 + 2/n$, which for large n is about equal to -1.

2.3 Similarity

While output gap correlations do not accurately reflect to what extent output gaps have the same sign, they also do not consider whether output gaps have the same amplitude. The correlation between two series can be equal to one even when both series have different standard deviations. Perfect correlation between the output gaps of countries forming a currency union thus does not mean that the common monetary policy suits all these countries equally well.

To take amplitude differences between output gaps for a region of n countries into account, we measure output gap similarity between country i and the reference output gap r as

$$\phi_{it} = 1 - \frac{|g_i(t) - g_r(t)|}{\sum_{i=1}^{n} |g_i(t)|/n} \tag{3}$$

Similarity thus subtracts the absolute difference between both output gaps as a share of the average of all output gaps in the region from one. Through scaling by the average absolute output gap, the similarity measure becomes scale invariant. Similarity is defined on a $[1-n, 1]$ scale, where a value of one indicates that both output gaps are perfectly synchronous and have identical amplitudes. A value of $1-n$ occurs when i and r have opposite signs and all other output gaps are equal to zero.

Overall similarity of the n countries with the reference is calculated by averaging the measure in (3) over all countries, which yields

$$\phi_{it} = 1 - \frac{\sum_{i=1}^{n} |g_i(t) - g_r(t)|}{\sum_{i=1}^{n} |g_i(t)|}. \tag{4}$$

This measure is defined on a $[2-n, 1]$ scale; similarity equals one when all output gaps are identical.

2.4 Reference output gap

Having defined our output gap synchronicity and similarity measures, we need to specify the region's reference output gap. We adopt a statistical approach here and select the reference that maximizes synchronicity in (2) and similarity in (4) simultaneously. This implies that the reference gap $g_r(t)$ should be set to the median of the output gaps of all individual countries observed at time t. This minimizes the numerator of (2) and thus maximizes output gap similarity in the sample of countries (see Joag-Dev, 1989), while it simultaneously maximizes overall synchronicity, since the median output gap has by definition the same sign as the majority of the observed output gaps.

This reference gap time series maximizes synchronicity and similarity not only for the full sample period for which it is calculated, but also for all possible sub-samples. This property reflects the fact that the reference output gap and the synchronicity and similarity measures are calculated on a per-observation basis without being affected by output gaps observed at earlier or later dates.

Defining the reference as the median output gap rather than as the output gap of a particular country (or as the weighted output gap of a group of countries as we do in the robustness analysis) implies that the minimum values that synchronicity and similarity in the region as a whole can attain are now equal to zero. The synchronicity measure equals zero if half of the countries have a positive output gap and half have a negative output gap. The similarity measure equals zero if the

reference output gap is equal to zero. For all other values of the reference output gap, the measure is larger than zero. This result follows from the fact that the sum of the difference between output gaps and their median, i.e., the numerator of (4), is always smaller than the sum of the difference between these output gaps and zero, i.e., the denominator of the equation. Similarity only attains its minimum (maximum) value when synchronicity is at its minimum (maximum) value as well.

3 Data

To analyze the coherence of output gaps, we estimate the synchronicity and similarity of the output gap for all countries that have been part of the euro area for a long time (except for Luxembourg). More specifically, our country set consists of Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, and Spain. Countries that joined the euro area later have not been included as the time series for their output gaps are rather short. Our data set contains time series for quarterly real GDP (with reference year 2010) for each country. The data source is the IMF's International Financial Statistics. Furthermore, the period 2000 Q1 until 2021 Q1 is used in the analysis and thus, the Global Financial Crisis and the COVID-19 crisis are included. Figure A.1 in Appendix A presents the data used.

4 Results

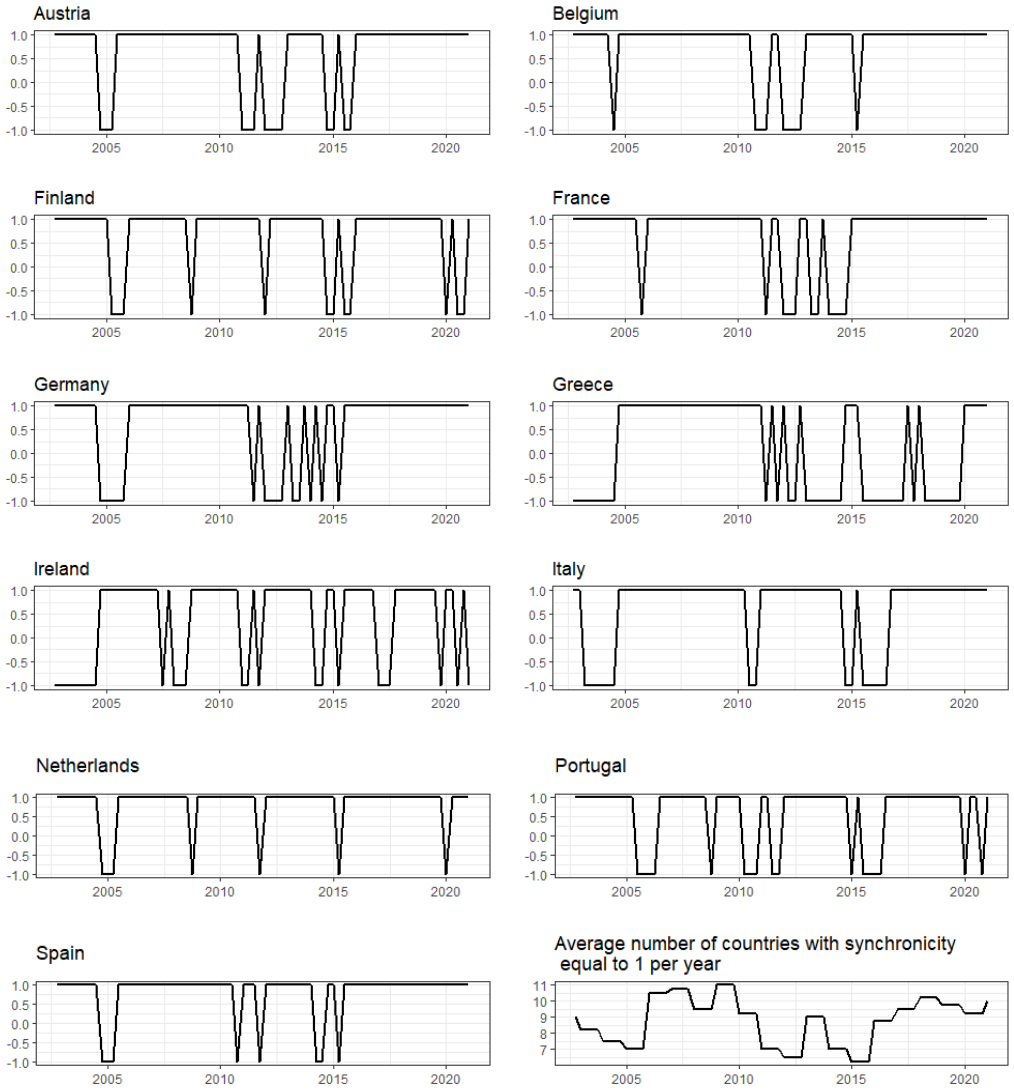
4.1 Synchronicity and similarity: full sample

Figure 1 shows the synchronicity measures for each country in our sample. The graph in the bottom right panel in this figure summarizes the outcomes by showing for each year the number of countries having a synchronicity measure of one. During the Global Financial Crisis in 2007-2009 and the COVID-19 crisis in 2021, the average number of countries with a synchronicity equal to 1 is higher than in other years. Figure 2 shows the similarity measure for individual euro area countries. The graph in the bottom right panel in Figure 2 shows for each year the median value of the synchronicity measure and the loes curve.[5] The blue line represents the loess curve.

Both synchronicity and similarity fluctuate over time and differ across countries; especially Greece and Ireland deviate from the rest. The graphs suggest that business cycle coherence in the euro area follows a non-linear pattern. Notably during crises, business cycle coherence seems to increase.

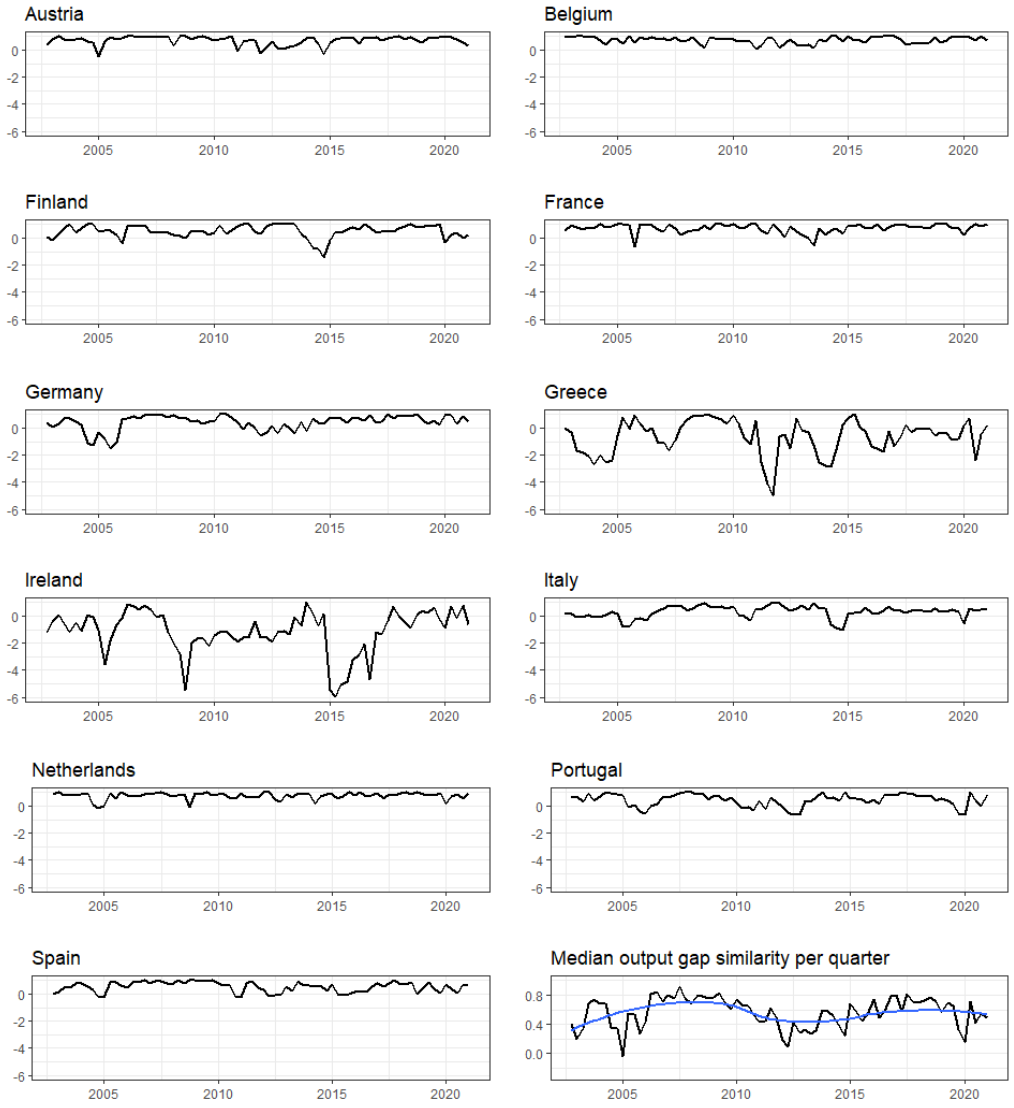
[5]The loess (locally estimated scatter plot smoothing) curve is a non-parametric technique that uses a local weighted regression to fit a smooth curve through a time plot or scatter plot.

Figure 1: Output gap synchronicity for each country based on output gaps obtained by the Hamilton (2018) filter



Note: The graph in the bottom right panel in this figure summarizes the outcomes by showing for each year the number of countries having a synchronicity measure of one.

Figure 2: Output gap similarity for each country based on output gaps obtained by the Hamilton (2018) filter



Note: The graph in the bottom right panel in Figure 2 shows for each year the median value of the synchronicity measure and the loes curve.

Since we also want to examine the impact of the (common) COVID-19 shock on the coherence of output gaps in the euro area, the period 2019 Q2 until 2021 Q1 is singled out. This period covers the four quarters before the COVID-19 crisis, and the first four quarters of the crisis. Table 1 shows the average synchronicity and similarity measures during the last four quarters before the COVID-19 crisis and the four quarters of the COVID-19 crisis. The second and third column of the table show that overall synchronicity increased from 0.68 before the crisis to 0.77 during the crisis. However, for several countries synchronicity did not increase. The most notable increases occurred in Greece and the Netherlands, while synchronicity decreased in Finland and Ireland. Although the COVID-19 pandemic was a common shock, the sign of the output gap in some countries (Finland, Ireland, and Portugal) deviates from that of the reference. This is also shown in the time series of the original GDP data and the output gap based on the Hamilton filter, as shown in Figures A.1 and A.2 in Appendix A, respectively.

Table 1: Mean output gap synchronicity and similarity before and during COVID-19 shock

	Synchronicity		*Similarity*	
Period	2019Q2 - 2020Q1	2020Q2 - 2021Q1	2019Q2 - 2020Q1	2020Q2 - 2021Q1
Austria	1	1	0.91	0.63
Belgium	1	1	0.91	0.84
Finland	0.5	0	0.6	0.21
France	1	1	0.69	0.89
Germany	1	1	0.5	0.66
Greece	−0.5	1	−0.47	−0.47
Ireland	0.5	0	−0.05	0.16
Italy	1	1	0.15	0.5
Netherlands	0.5	1	0.68	0.76
Portugal	0.5	0.5	−0.17	0.57
Spain	1	1	0.51	0.45
Overall	0.68	0.77	0.39	0.47

Note: Numbers shown refer to four quarters before the COVID-19 pandemic and four quarters during the COVID-19 pandemic. The last column the mean of all 11 countries per period.

The two right-hand side columns of Table 1 show average similarity just before and during the COVID-19 crisis. Average similarity also increased, from 0.39 just before the crisis to 0.47 during the crisis. However, we see a much more diverse pattern than for synchronicity. In fact, in four countries (Austria, Belgium, Finland, and Spain) similarity dropped. This suggests that the impact of the COVID-19 pandemic on the output gap in these countries differs from that in other countries in the euro area. So despite the fact that the COVID-19 crisis was a common shock, countries have been affected differently.

4.2 Core versus periphery

We can use our findings to shed light on the discussion of core versus periphery countries. Table 2 shows the average number of times a particular country has synchronicity equal to 1 per year. The average output gap synchronicity (as shown in the last row of Table 2 suggests a clear demarcation. Most countries are pretty close to each other. They have an average synchronicity above 0.80 and can therefore be considered core countries, except for Greece, Ireland and (perhaps) Portugal. This is good news for the ECB as it implies that the sign of the output gap in most countries in the euro area is very often the same. In other words, the direction of the stance of monetary policy required was the same for most countries in the euro area. This also holds also for countries that were previously frequently identified as periphery countries, like Italy and Spain.

Table 2: The average number of times per year the output gap of a particular country has the same sign as the reference

Year	Austria	Belgium	Finland	France	Germany	Greece	Ireland	Italy	Netherlands	Portugal	Spain	Average number of countries with a synchronicity equal to 1
2002	1.00	1.00	1.00	1.00	1.00	0.00	0.00	1.00	1.00	1.00	1.00	9.00
2003	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.25	1.00	1.00	1.00	8.25
2004	0.75	0.75	1.00	1.00	0.75	0.25	0.25	0.25	0.75	1.00	0.75	7.50
2005	0.50	1.00	0.25	0.75	0.00	1.00	1.00	1.00	0.50	0.50	0.50	7.00
2006	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.50	1.00	10.50
2007	1.00	1.00	1.00	1.00	1.00	1.00	0.75	1.00	1.00	1.00	1.00	10.75
2008	1.00	1.00	0.75	1.00	1.00	1.00	0.25	1.00	0.75	0.75	1.00	9.50
2009	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	11.00
2010	1.00	0.75	1.00	1.00	1.00	1.00	1.00	0.50	1.00	0.25	0.75	9.25
2011	0.25	0.50	1.00	0.75	0.75	0.50	0.25	1.00	0.75	0.50	0.75	7.00
2012	0.00	0.00	0.75	0.25	0.00	0.50	1.00	1.00	1.00	1.00	1.00	6.50
2013	1.00	1.00	1.00	0.50	0.50	0.00	1.00	1.00	1.00	1.00	1.00	9.00
2014	0.75	1.00	0.75	0.00	0.50	0.25	0.50	0.75	1.00	1.00	0.50	7.00
2015	0.25	0.75	0.25	1.00	0.75	0.50	0.75	0.25	0.75	0.25	0.75	6.25
2016	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.25	1.00	0.50	1.00	8.75
2017	1.00	1.00	1.00	1.00	1.00	0.25	0.25	1.00	1.00	1.00	1.00	9.50
2018	1.00	1.00	1.00	1.00	1.00	0.25	1.00	1.00	1.00	1.00	1.00	10.25
2019	1.00	1.00	1.00	1.00	1.00	0.00	0.75	1.00	1.00	1.00	1.00	9.75
2020	1.00	1.00	0.25	1.00	1.00	1.00	0.75	1.00	0.75	0.50	1.00	9.25
2021	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	10.00
Average	0.82	0.89	0.85	0.86	0.81	0.53	0.63	0.81	0.91	0.79	0.90	8.80

Note: The final row presents the overall average number of times the output gap of a particular country has the same sign as the reference, whereas the final column shows the average number of countries per year with a synchronicity equal to 1.

However, the results for the output gap similarity given in Table 3 suggest that the magnitude of the amplitude of the business cycle in Italy deviates quite substantially from the reference. To some extent, this also holds for Spain. Quite remarkably, Table 3 suggests that also the business cycle amplitude of Germany deviates substantially from the reference. The difference between the mean and median similarity measure as well as the minimum similarity for Germany suggests that this may reflect that in some particular years Germany deviated a lot. Also Finland has a relatively low value for business cycle similarity, suggesting that the amplitude of its business cycle differs a lot from the reference.

Table 3: Summary statistics of output gap similarity for the period 2002 Q3 until 2021 Q1

	Mean	St.dev	Median	Min	Max
Austria	0.71	0.33	0.83	−0.51	1.00
Belgium	0.74	0.24	0.80	0.09	1.00
Finland	0.49	0.47	0.53	−1.40	1.00
France	0.71	0.33	0.79	−0.64	1.00
Germany	0.41	0.57	0.51	−1.54	1.00
Greece	−0.65	1.27	−0.33	−5.01	1.00
Ireland	−1.13	1.59	−0.94	−5.91	1.00
Italy	0.31	0.45	0.39	−1.05	1.00
Netherlands	0.75	0.27	0.84	−0.16	1.00
Portugal	0.44	0.47	0.57	−0.67	1.00
Spain	0.53	0.38	0.66	−0.28	1.00

So overall these results suggest that the sign of the output gap in countries in the euro area indicate that only a few countries would be considered periphery countries. However, once the amplitude of the business cycle is taken into account, the outcome is less optimistic: for many countries the ECB policies are not in line with their domestic economic situation. This even holds for countries that are generally considered as core country, notably Germany. Of course, one may

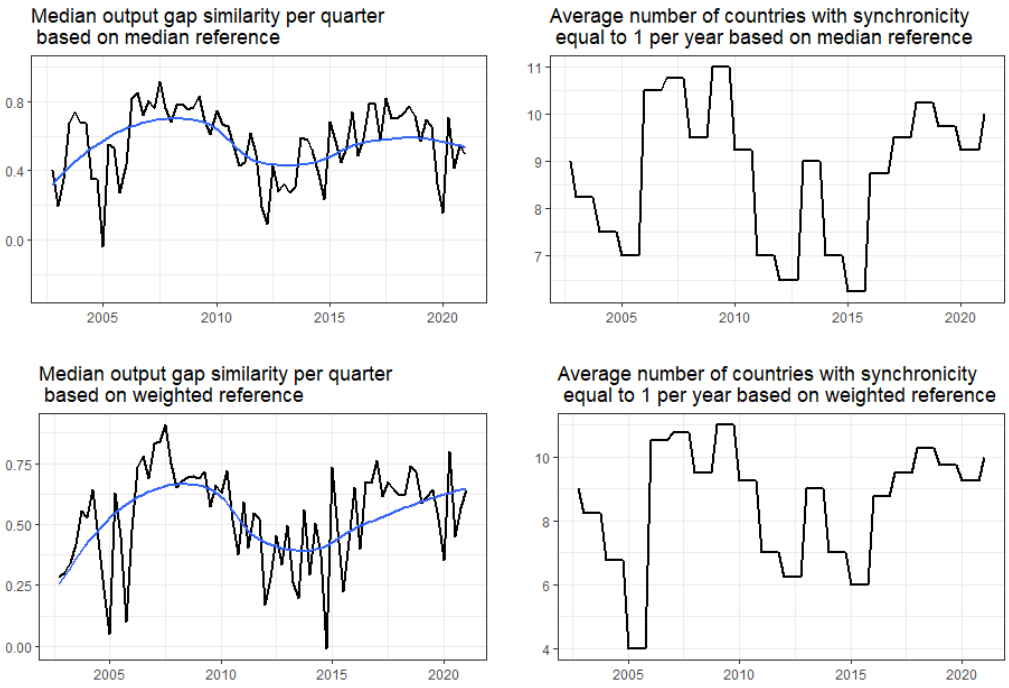
object that this conclusion is based on an analysis in which we define the reference in a way that deviates from what the ECB does, namely focusing on the output gap in the euro area as a whole. In the robustness section, we will therefore re-examine this issue using the GDP-weighted average output gap in the euro area as benchmark instead of the median output gap.

5 Robustness analysis

5.1 Weighted reference

As pointed out in Section 2.4, the ECB focuses on the economic situation in the euro area as a whole, which can be proxied by using GDP-weighted output gaps. If we take this series as reference instead of the median output gap, the results are remarkably similar. The graphs on the left-hand side of Figure 3 show the median output gap similarity measures using the median reference (upper part) and the GDP-weighted reference (lower part). Although the similarity measure based on the weighted reference is more volatile and slightly lower, it shows a very similar pattern as the similarity measure constructed with the median output gap as reference. The synchronicity measures as shown in the right-hand side part of Figure 3 are also very similar. This suggests that our main conclusions are not driven by using the median output gap as reference.

Figure 3: Descriptive figures of the median reference and weighted reference



Note: The graphs in the left panels show the median value of the similarity measure for each year and the loes curve.

Table 4 replicates Table 3 using the GDP-weighted reference instead of the median. The table suggests that business cycles in Greece, Ireland, and Portugal deviate quite substantially from the reference and can these countries can therefore be considered as periphery countries, thus confirming our previous finding. Likewise, the magnitude of the output gap of Italy deviates quite substantially from that of most other countries, although the sign of its output gap is pretty much in line with that of the GDP-weighted reference (results available on request). However, the results for Germany and Spain suggest that these countries can be considered as core countries.

Table 4: Summary statistics of output gap similarity with weighted reference for the period 2002 Q3 until 2021 Q1

	Mean	St.dev	Median	Min	Max
Austria	0.65	0.28	0.71	−0.26	1.00
Belgium	0.73	0.25	0.79	−0.16	0.99
Finland	0.39	0.46	0.48	−1.16	0.99
France	0.73	0.20	0.79	0.10	1.00
Germany	0.53	0.45	0.67	−1.18	1.00
Greece	−0.66	1.26	−0.40	−5.07	0.98
Ireland	−1.17	1.51	−0.94	−5.61	0.82
Italy	0.24	0.45	0.38	−1.15	0.94
Netherlands	0.67	0.27	0.71	−0.29	1.00
Portugal	0.31	0.48	0.40	−0.97	0.97
Spain	0.51	0.36	0.60	−0.51	1.00

Finally, Table 5 replicates Table 1 to examine whether our results for the impact of the COVID-19 pandemic on business cycle coherence change if we use the GDP-weighted reference instead of the median. As before, we find that overall synchronicity and similarity increased during the COVID-19 pandemic (as shown in the final column of Table 5). However, these averages mask cross-country heterogeneity. For instance, in Finland and Ireland synchronicity and similarity dropped, while similarity also declined slightly in the Netherlands. Overall, the results concerning the impact of the COVID-19 pandemic as reported previously are thus confirmed when we use the GDP-weighted output gap as reference instead of the median output gap.

Table 5: Mean output gap synchronicity and similarity before and during COVID-19 shock

	Synchronicity		*Similarity*	
Period	2019Q2 - 2020Q1	2020Q2 - 2021Q1	2019Q2 - 2020Q1	2020Q2 - 2021Q1
Austria	1	1	0.66	0.57
Belgium	1	1	0.84	0.83
Finland	0.5	0	0.36	0.02
France	1	1	0.6	0.77
Germany	1	1	0.59	0.77
Greece	−0.5	1	−0.22	−0.28
Ireland	0.5	0	0.04	−0.01
Italy	1	1	0.39	0.69
Netherlands	0.5	1	0.61	0.57
Portugal	0.5	0.5	−0.41	0.38
Spain	1	1	0.27	0.63
Overall	0.68	0.77	0.34	0.45

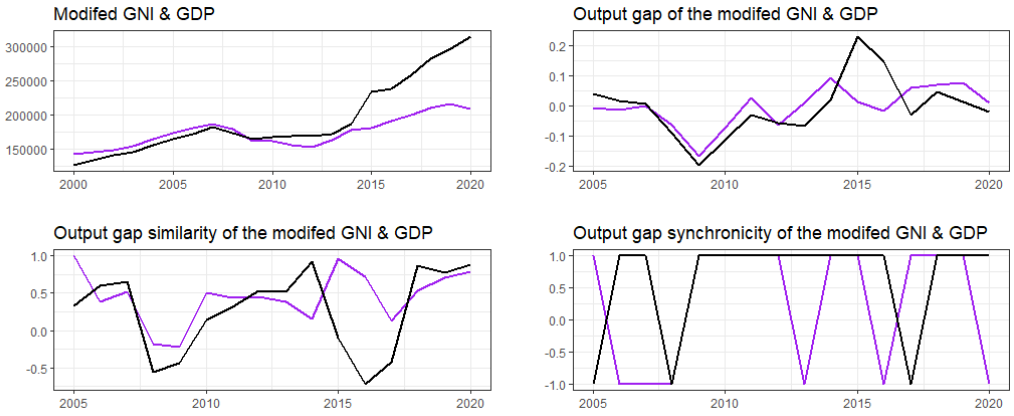
Note: Numbers shown refer to four quarters before the COVID-19 pandemic and four quarters during the COVID-19 pandemic. The last row is the mean of all 11 countries per period.

5.2 Using Modified Gross National Income of Ireland

One criticism that can be raised about our conclusions for Ireland is that they are based on Irish GDP data. The credibility of the GDP statistic in Ireland was strained when the Central Statistics Office (CSO) announced that GDP grew 26.3 percent in 2015. This reflected that a number of large multinational corporations relocated their economic activities, and more specifically their underlying intellectual property, to Ireland. As a result, sales (production) generated from the use of intellectual property now contribute to Irish GDP rather than to other countries' GDP. CSO provides an alternative, namely Modified Gross National Income (GNI). Figure 4 shows that using this alternative makes a difference. The graphs in the bottom left panel of Figure 4 show that notably for the years around 2015 output gap similarity based on modified GNI is higher. In general, output

gap synchronicity is not clearly higher if modified GNI is used instead of real GDP (bottom right panel).

Figure 4: Outcomes for Ireland using annual modified GNI and real GDP



Note: Black and purple line represent real GDP and Modified GNI, respectively.

Table 6 shows summary statistics of output gap similarity for Ireland using annual modified GNI and annual GPD, respectively. In line with Figure 4, the summary statistics suggest that the output gap similarity measure is higher if the modified real GNI is used instead of the real GDD, but Ireland is still considered as a periphery country for both time-series due to the low mean and median.

Table 6: Summary statistics of output gap similarity with median reference for the period 2002 Q3 until 2021 Q1 using annual modified GNI and annual GDP

	Mean	St.dev	Median	Min	Max
Ireland Modified GNI	0.43	0.35	0.46	−0.21	1.00
Ireland GPD	0.23	0.54	0.31	−0.71	0.92

6 Conclusion

Using the measures proposed by Mink et al. (2012), we have reexamined the coherence of business cycles in the euro area over the 2002-2021 period. We have also analyzed the impact of the COVID-19 pandemic on business cycle coherence. Finally, we have examined whether our measures for business cycle coherence indicate a core versus periphery within EMU.

To apply our preferred measures for business cycle coherence, we need to construct output gap measures. For this purpose, we have applied the Hamilton (2018) filter. As pointed out by Schueler (2018), this filter yields more robust cycle estimates at the end of the sample than the Hodrick-Prescott (H-P) filter. As one of the aims of our research is to examine the impact of the COVID-19 pandemic on business cycle coherence in the euro area, we therefore opted for the Hamilton filter.

Our results suggest that although business cycle coherence in the euro area increased, it did not rise monotonically. Notably during crisis periods, coherence increased, and this also holds for the COVID-19 pandemic. During this period, the signs of the output gaps of euro area countries became more similar. However, even during the COVID-19 pandemic, we find large differences in the amplitudes of the output gaps across countries. Our results also shed light on the classification of euro area member states as core or periphery countries. Our results suggest that notably Greece, Ireland, Finland, and Portugal have business cycles that are very different from business cycles in other euro area countries. This makes that the ECB monetary policies will not be optimal for all countries in the euro area.

A suggestion for future research is to use alternative filters, like the H-P filter,

the modified H-P filter as proposed by Phillips and Shi (2021), or the Beveridge-Nelson (1981) decomposition to determine the output gap. It would be interesting to analyze whether using these different filters affect our conclusions about business cycle coherence in the euro area.

References

Alhborn, M. and Wortmann, M. (2018). The core–periphery pattern of european business cycles: A fuzzy clustering approach. *Journal of Macroeconomics*, 55:12–27.

Azcona, N. (2021). Business cycle co-movement in europe: Trade, industry composition and the single currency. *Open Economies Review*. forthcoming.

Baxter, M. and King, R. (1999). Measuring business cycles: Approximate band-pass filters for economic time series. *The Review of Economics and Statistics*, 81:575–593.

Bayoumi, T. and Eichengreen, B. (1993). Shocking aspects of european monetary unification. In Torres, F. and Giavazzi, F., editors, *Adjustment and Growth in the European Monetary Union*. Cambridge University Press, Cambridge.

Bayoumi, T. and Eichengreen, B. (2017). Aftershocks of monetary unification: Hysteresis with a financial twist. IMF Working Paper 1755, International Monetary Fund, Washington D.C.

Belke, A., Domnick, C., and Gros, D. (2017). Business cycle synchronization in the EMU: Core vs. periphery. *Open Economies Review*, 28:863–892.

Beveridge, S. and Nelson, C. R. (1981). A new approach to decomposition of economic time series into permanent and transitory components with particular attention to measurement of the 'business cycle'. *Journal of Monetary Economics*, 7:151–174.

Campos, N. and Macchiarelli, C. (2016). Core and periphery in the european monetary union: Bayoumi and Eichengreen 25 years later. *Economics Letters*, 147:127–130.

Campos, N. and Macchiarelli, C. (2021). The dynamics of core and periphery in the european monetary union: A new approach. *Journal of International Money and Finance*, 112:102325. forthcoming.

Christiano, L. and Fitzgerald, T. (2003). The band-pass filter. *International Economic Review*, 44:435–465.

Comunale, M. (2017). New synchronicity indices between real and financial cycles: Is there any link to structural characteristics and recessions in european union countries? *International Journal of Finance and Economics*, 25:617–641.

de Haan, J., Inklaar, R., and Jong-A-Pin, R. (2008). Will business cycles in the euro area converge? A critical survey of empirical research. *Journal of Economic Surveys*, 22:234–273.

Frankel, J. and Rose, A. (1998). The endogeneity of the optimum currency criteria. *The Economic Journal*, 108:1009–1025.

Furceri, D., Loungani, P., and Pizzuto, P. (2021). Moving closer? Comparing regional adjustments to shocks in EMU and the United States. *Journal of International Money and Finance*. forthcoming.

Gaechter, M. and Riedl, A. (2014). One money, one cycle? The EMU experience. *Journal of International Money and Finance*, 42:141–155.

Gaechter, M., Riedl, A., and Ritzberger-Grünwald, D. (2012). Business cycle synchronization in the euro area and the impact of the financial crisis. *OeNB, Monetary Policy and The Economy*, Q2/12:33–60.

Hamilton, J. (2018). Why you should never use the Hodrick-Prescott filter. *The Review of Economics and Statistics*, 100:831–843.

Hodrick, R. and Prescott, E. (1997). Postwar US business cycles: An empirical investigation. *Journal of Money, Credit and Banking*, 29:1–16.

Joag-Dev, K. (1989). MAD property of a median: A simple proof. *The American Statistician*, 43:26–27.

Matesanz Gomez, D., Ferrari, H., Torgler, B., and Ortega, G. (2017). Synchronization and diversity in business cycles: A network analysis of the european union. *Applied Economics*, 49:972–986.

Miles, W. (2017). Has there actually been a sustained increase in the synchronization of house price (and business) cycles across countries? *Journal of Housing Economics*, 36:25–43.

Miles, W. and Vijverberg, C.-P. C. (2014). Did the classical gold standard lead to greater business cycle synchronization? Evidence from new measures. *Kyklos*, 67:93–115.

Mink, M., Jacobs, J. P., and de Haan, J. (2012). Measuring coherence of output gaps with an application to the euro area. *Oxford Economic Papers*, 64:217–236.

Phillips, P. C. B. and Shi, Z. (2021). Boosting: Why You Can Use the HP Filter. *International Economic Review*, 62:521–570.

Rathke, A., Streicher, S., and Sturm, J.-E. (2020). How similar are country- and sector-responses to common shocks within the euro area? *Journal of International Money and Finance*, 120:102313. forthcoming.

Samarina, A., Zhang, L., and Bezemer, D. (2017). Credit cycle coherence in the eurozone: Was there a euro effect? *Journal of International Money and Finance*, 77:77–98.

Schueler, Y. S. (2018). On the cyclical properties of Hamilton's regression filter. Discussion Papers 03/2018, Deutsche Bundesbank.

Appendix

A Data used

Figure A.1: Real Gross Domestic Product (GDP) in euros for each country from 2000 Q1 until 2021 Q1.

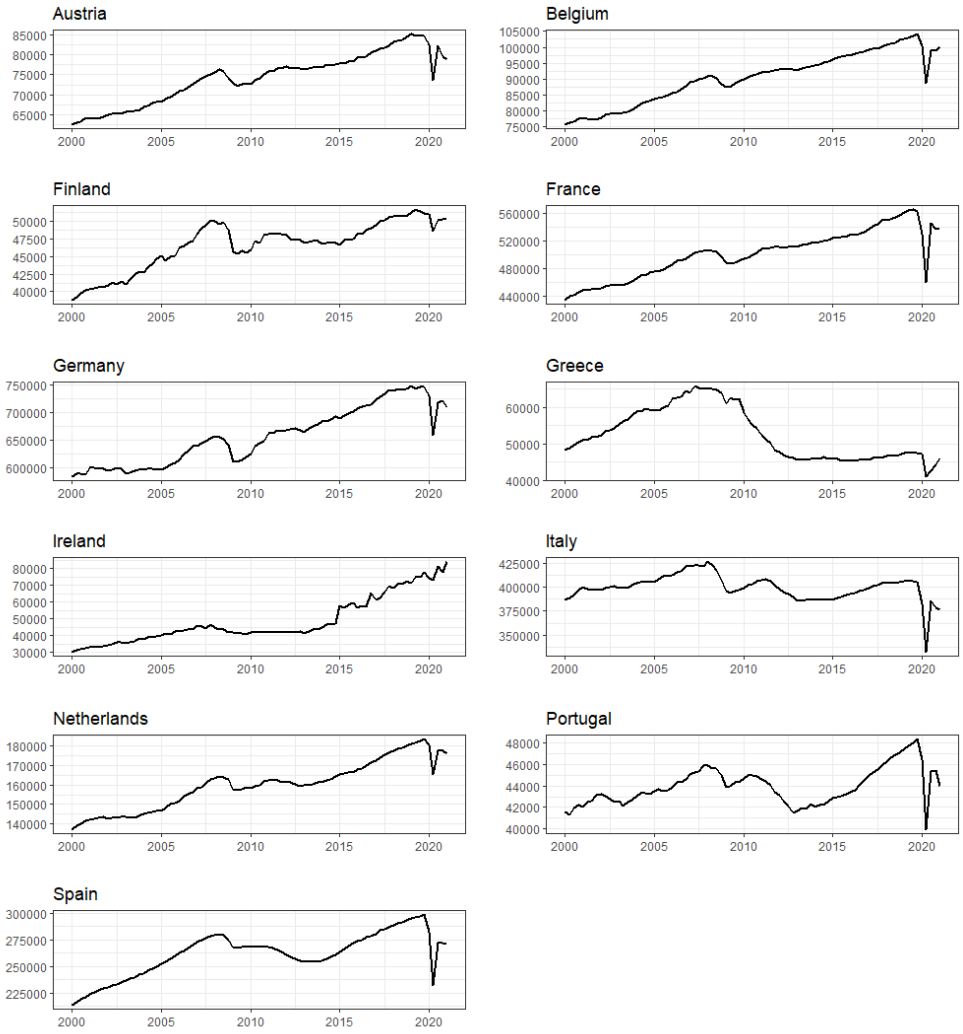


Figure A.2: The output gap (red line) for each country from 2002 Q4 until 2021 Q1 and the corresponding reference (black line) based on the Hamilton (2018) filter.