SYNCHRONIZATION AMONG REAL BUSINESS CYCLES OF U.S. STATES

Margherita Gerolimetto, Stefano Magrini

1. Introduction

Understanding the level of synchronization among real business cycles is relevant from various perspectives. For example, when areas are in a monetary union, the issue of whether their business cycles are coordinated is of crucial importance. If the business cycles are not synchronized, i.e. are in different phases (expansion or recession), then different policies would be required to bring major indicators in these economies on the optimal path. Thus, while an economy entering a recession would require an expansionary policy with a decrease in the interest rate, a booming economy requires a tighter monetary stance. In such a case, a common monetary policy would be suboptimal and lead to higher costs.

In this paper we present a synchronization analysis of the real business cycles of the U.S. states between 2005 and 2019. We employ data on real GDP covering the period stretching from 2005:Q1 to 2020:Q2. These data are somewhat innovative with respect to previous analyses (among others, Beckwork, 2010; Partridge and Rickman, 2005), because they are elaborated making use of Regional price parities (RPPs) by state and offers a more in-depth analysis with respect to studies where prices are assumed to be homogeneous across spatial units, as it happens by adopting a national deflator.

From the methodological point of view, to isolate the business cycles we adopt a recently developed MatLab function for signal extraction. This function, called CiSSA (Circulant Singular Spectrum Analysis), proposed by Bógalo *et al*. (2021a) extracts the underlying signals in a time series identifying their frequency of oscillation in an automated way. Bógalo *et al*. (2021b) adopted CiSSA in case of macroeconomic time series, in particular to obtain revisions at the end of the sample; they show via simulations that the algorithm performs well. CiSSA represents an alternative to the traditional Hodrik-Prescott filter (Hodrik and Prescott, 1997) and has the advantage of being very versatile and working well both in case of stationary and non-stationary time series.

Once the business cycles of the U.S. states are extracted using CiSSA, we study their level of synchronization with the national one using various indices of synchronization. In particular, we will focus on the concordance index (Harding and Pagan, 2006) and the cross-correlations.

Moreover, we also investigate the possibility that immigrant flows might affect the level of synchronization of the state cycles with respect to the national one. This is based on the idea that immigrants tend to exhibit a higher propensity to migrate in reaction to labour market opportunities (Molloy *et al.*, 2011). Consequently, it can be of interest to investigate whether their movements can help synchronizing the business cycles. To do this, we study the correlation between on the variation (in absolute value) between the average share of non-US natives over 2005-2009 with respect to the same share over 2000-2005 and the level of synchronization of the regional cycles with respect to the national one.

The structure of the paper is as follows. We will present the algorithm of signal extraction called CiSSA in the second section and recall two measures of synchronization in the third section. The empirical analysis will be presented in the fourth section while the fifth section concludes.

2. Signal extraction with CiSSA

Circulant Singular Spectrum Analysis, CiSSA, is an algorithm for signal extraction (Bógalo *et al*., 2021). More in general, Singular Spectrum Analysis (SSA) is a nonparametric procedure to reconstruct the original time series as the sum of orthogonal components of known frequencies. It works in two distinct phases. In the first phase, called decomposition, the original time series is transformed into a related trajectory matrix made of pieces of length *L* and then elementary matrices are obtained via the single value decomposition; according to which method is adopted to perform the single value decomposition, there are different versions of the SSA. In the second phase, called reconstruction, the elementary matrices are grouped and the time series is recovered.

More in details, given a time series $X_1,\ldots X_T$, finite realization of a zero-mean stochastic process $\{X_t\}$ and let *L* be a possible integer, called the window width (such that $1< L < T/2$), the decomposition and reconstruction stages of SSA are carried out in 4 steps.

1. *Embedding*: a trajectory matrix is built by putting together lagged pieces of size L of the original series
2. *Decomposition*: the trajectory matrix is decomposed in elementary matrices of rank 1, associated to various frequencies
3. *Basic frequency grouping*: elementary matrices are grouped by frequency
4. *Reconstruction*: the matrices obtained in step 3 are transformed into *M* signals of the same length as the original series for frequencies w_k, where $k=1,\ldots, L$.

The decomposition phase requires the computation of the eigenvectors by diagonalizing the matrix of second moments with the trajectory matrix. Traditionally, the identification of the frequencies associated with the trajectory matrices is made after the time series have been reconstructed. CiSSA replaces the variance covariance matrix of the Toeplitz version with a related circulant matrix. The advantage of adopting circulant matrices is that they allow for exact identification between the eigenvectors and eigenvalues obtained in terms of the frequency of the components they represent. As a result, in the reconstruction phase it is possible to group the matrices by frequency and identify the signal associated to each frequency.

In this study we will adopt a MatLab function for CiSSA algorithm, whose outcome is a set of M time series, one for each frequency w_k. The MatLab function also allows to implementing different grouping strategy that will lead to obtain the default signals typically required in an economic time series: trend, business cycle, seasonality.

3. Business cycle synchronization

Roughly speaking, business cycles synchronization means that their turning points occur at approximately the same points in time. More specifically turning points are defined as local maxima and minima in the sample path of the time series. Synchronization can be measured and here we will focus in particular on two complementary approaches: concordance index and cross-correlation.

The concordance index introduced by Harding and Pagan (2006) measures the amount of time that in which two economies are in the same business cycle phase. For a generic economy X suppose that S_{Xt} is a binary variable taking value 1 when the economy X at time t is in recession and value 0 when it is in expansion. Similarly it is defined S_{Yt} for another economy Y. So, over a period of T instants, the concordance index C_{XY} that measures the degree of synchronization of the two economies X and Y is:

$$C_{XY} = \frac{1}{T}\sum_{t=1}^{T}[S_{Xt}S_{Yt} + (1 - S_{Xt})(1 - S_{Yt})] \quad (1)$$

When C_{XY} = 1 there is perfect concordance, i.e. perfect synchronization. Conversely, when C_{XY} = 0 there is perfect discordance, i.e. cycles are always is opposite phases. Values of the index ranging between 0.5 and 1 indicate weak to perfect synchronization (procyclical) and values of the index ranging between 0 and 0.5 indicate perfect to weak discordance (countercyclical).

Following Harding and Pagan (2006), it is possible to re-write C_{XY} as a monotonic transformation of ρ_{XY} the correlation between the time series Y_t and X_t. Specifically, Harding and Pagan (2006) reparametrize C_{XY} as follows:

$$C_{XY} = 1 + 2\hat{\rho}_S \left(\hat{\mu}_{S_X}(1-\hat{\mu}_{S_X})\right)^{\frac{1}{2}} \left(\hat{\mu}_{S_Y}(1-\hat{\mu}_{S_Y})\right)^{\frac{1}{2}} + 2\hat{\mu}_{S_X}\hat{\mu}_{S_Y} - \hat{\mu}_{S_X} - \hat{\mu}_{S_y} \quad (2)$$

where $\hat{\rho}_S$ is the estimated correlation coefficient between S_{Xt} and S_{Yt}, $\hat{\mu}_{S_X}$ and $\hat{\mu}_{S_Y}$ are, respectively, the estimated E(S_{Xt}) and E(S_{Yt}). As pointed out by Harding and Pagan (2006), due to the binary nature of S_{Xt} and S_{Yt}, the estimated standard deviations are $\hat{\sigma}_{S_X} = \sqrt{(\hat{\mu}_{S_X} - \hat{\mu}_{S_X}{}^2)}$ and $\hat{\sigma}_{S_Y} = \sqrt{(\hat{\mu}_{S_Y} - \hat{\mu}_{S_Y}{}^2)}$. Harding and Pagan (2006) further clarify that the concordance index has a maximum (value 1) when S_{Xt} = S_{Yt} and a minimum (value 0) when S_{Xt} = (1-S_{Yt}) and when either of these holds $\hat{\sigma}_{S_X}\hat{\sigma}_{S_Y} = \hat{\sigma}^2_{S_X}$. Therefore C_{XY}=1 corresponds to $\hat{\rho}_S = 1$ while $C_{XY} = 0$ corresponds to $\hat{\rho}_S = -1$. Moreover, with similar arguments Harding and Pagan (2006) show that it is possible to test synchronization between two cycles with the following regression

$$\frac{S_{Yt}}{\hat{\sigma}_{S_Y}\hat{\sigma}_{S_X}} = \nu + \rho_S \left(\frac{S_{Xt}}{\hat{\sigma}_{S_Y}\hat{\sigma}_{S_X}}\right) + \epsilon_t \quad (3)$$

If ρ_S is not significantly different from zero, there is no synchronization (which is equivalent to C_{XY} = 0.5). Note that because of the possible problems with the error model, the Newey West heteroskedasticity and autocorrelation consistent (HACC) adjusted standard error must be used when testing the significance of ρ_S.

In a complementary perspective to the concordance index, cross-correlations are also capable of providing valuable information about the level of synchronization. Cross-correlations measure linear dependence between two time series at different time lags. In general, two types of co-movements can be analysed with the cross-correlation coefficients. First, contemporaneous co-movements, which could be pro-cyclical (zero lag correlation is positive), countercyclical (zero lag correlation is negative), a-cyclical (zero lag correlation is nonsignificant). Second, non contemporaneous co-movements, or phase shifts, which suggest that a series is leading if the largest absolute value of cross-correlation is on negative lag; a series is coincidental if the largest absolute value of cross-correlation is on zero lag; a series is lagging if the largest absolute value of cross-correlation is on positive lag.

So, supposing X_t. is the US GDP and Y_t is a state GDP, the cross-correlation at lag zero indicates if one state movement is pro-cyclical, counter-cyclical or a-cyclical with respect to the national cycle. On the other hand, the maximum of the absolute value of the cross-correlation indicates if one state cycle is leading, coincident or lagging the national one.

4. Empirical analysis

We now present our empirical analysis. We employ data (in logarithm) on real GDP covering the period stretching from 2005:Q1 to 2020:Q2 from BEA (Bureau of Economic Analysis) for the U.S. states and the overall U.S. These data are somewhat innovative with respect to previous analyses because they are elaborated making use of Regional price parities (RPPs) by state. RPPs measure the differences in price levels across states for a given year and cover all consumption goods and services, including housing rents. Thus, this indeed allow us to offer a more accurate analysis with respect to studies where prices are assumed to be homogeneous across spatial units, as it happens by adopting a national deflator.

Moreover, we employ annual data from ACS (American Community Survey), for the share of non-natives covering the period 2000-2010 for the information about the flows of immigrant, for the second part of the analysis[1].

4.1. Synchronization analysis

Our synchronization analysis starts from the extraction of the business cycles using CiSSA algorithm, presented in the second section. This is done for each of the U.S. states and for the overall national economy. The second step consists in dating all the business cycles, i.e. in identifying the turning points for all the cycles. For this step we implement a simple algorithm, based on the following set-up:

- a minimum distance between consecutive peaks (troughs): 7 years
- a minimum prominence of peaks (troughs): 0.2%
- alternation of peaks and troughs

These rules have been thought to represent a behavior that, firstly, mirrors a cycle with alternation of peaks and troughs, and, secondly, reflects the behavior of business cycle of the U.S. economy analyzed by the National Bureau of Economic Research (NBER). Indeed, in the period between 2001 and 2020 that includes the time span under our examination, the average duration of the peak-to-peak period and trough-to-trough is 10 years, so we choose as minimum distance between consecutive peaks (troughs) to give some flexibility to the behavior of the states. Also for the prominence, we followed the same logic.

[1] Data have been accessed from IPUMS, Integrated Public Use Microdata Series (Ruggles et al. 2020).

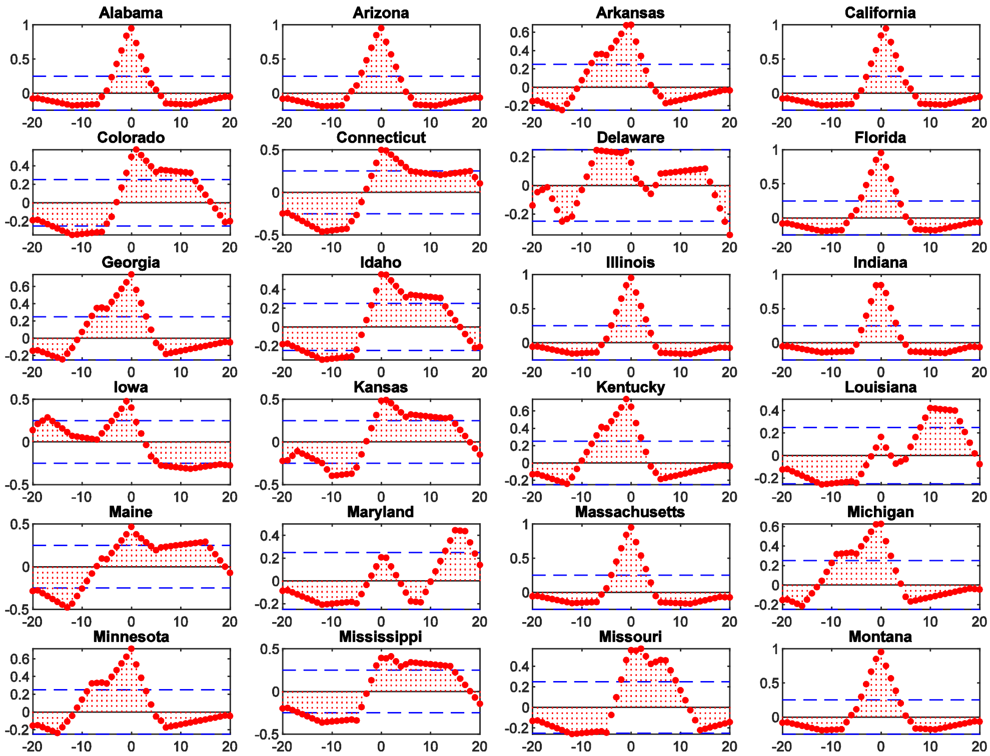
We present in Table 1 the results on the concordance index C_{xy}, coupled with the ρ_S coefficient obtained estimating regression (2) for each pairing of states economies with the U.S. economy. The double stars in the Table indicate strong significance (p-value smaller than 0.001).

Table 1 – *Concordance Index*

State	C_{xy}	ρs	State	C_{xy}	ρs
Alabama	0.984	0.917**	Nebraska	0.766	0.519**
Arizona	0.984	0.981**	Nevada	0.906	0.885**
Arkansas	0.875	0.782**	New Hampshire	0.906	0.756**
California	0.953	0.814**	New Jersey	0.875	0.782**
Colorado	0.781	0.603**	New Mexico	0.656	0.513**
Connecticut	0.703	0.635**	New York	0.766	0.519**
Delaware	0.375	0.167	North Carolina	0.734	0.545**
Florida	0.984	0.981**	North Dakota	0.453	0.006
Georgia	0.891	0.865**	Ohio	0.875	0.846**
Idaho	0.797	0.686**	Oklahoma	0.609	0.519**
Illinois	0.984	0.917**	Oregon	0.766	0.647**
Indiana	0.953	0.75**	Pennsylvania	0.969	0.833**
Iowa	0.703	0.506**	Rhode Island	0.891	0.737**
Kansas	0.734	0.609**	South Carolina	1	1**
Kentucky	0.875	0.718**	South Dakota	0.281	0.051
Louisiana	0.703	0.186	Tennessee	0.906	0.885**
Maine	0.672	0.596**	Texas	0.953	0.942**
Maryland	0.734	0.224	Utah	0.922	0.904**
Massachusetts	0.984	0.917**	Vermont	0.797	0.686**
Michigan	0.844	0.744**	Virginia	0.578	0.481**
Minnesota	0.875	0.846**	Washington	0.891	0.865**
Mississippi	0.734	0.481**	West Virginia	0.906	0.564**
Missouri	0.844	0.615**	Wisconsin	0.906	0.821**
Montana	0.984	0.981**	Wyoming	0.703	0.378*

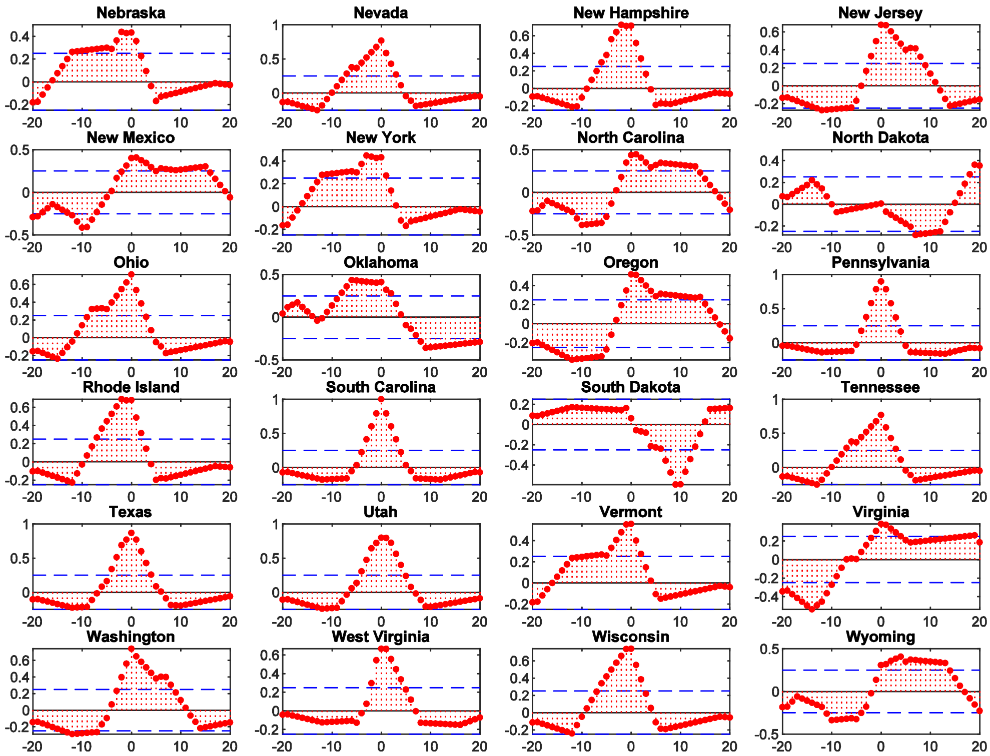
Then, we proceed by analysing the degree of synchronization between the cycle of each state and the cycle of the national economy. This step consists of the calculation of the concordance index between each state and the national economy, and then in the determination of the cross-correlations between state and the national economy.

Figure 1a – *Cross-correlations of each state and the national economy.*



As expected, states that are well synchronized with the national economy, such as Alabama, exhibit a cross-correlation with respect to overall U.S. characterized by a very visible positive peak on the zero lag, and this pattern repeats regularly for all states whose concordance index is high. Instead, for those states that are a-synchronized with the national economy, such as Luisiana, the cross-correlation is very irregular and no clear pattern is visible.

Figure 1b – *Cross-correlations of each state and the national economy*



4.2. The role of internal migrations

Immigrants tend not to distribute homogeneously across states. For instance, based on American Community Survey data, in 2010 about two-thirds (65%) of the total foreign-born population lived in just six states (California, New York, Texas, Florida, New Jersey and Illinois) and over one-fourth (25.4%) lived in California. In addition, the skill distribution for immigrants is characterized by a strong polarization as most of them either acquired a low level of schooling or hold a graduate degree. For instance, in 2010 about 32% of immigrants had not completed the equivalent of high-school education, compared with only 11% of natives. At the same time, immigrants are as likely as natives to be highly educated, with 27% of immigrants and 28% of natives having completed a bachelor's degree. In contrast, are underrepresented in the middle of the skill distribution, among workers with high-school or some college education (41% for immigrants, 61% for natives). Also due to these characteristics, immigrants tend to be more reactive to labour market opportunities (Peri, 2013) and so their movements might help smoothing differences between business cycles, thus improving synchronization.

To study the role of immigrants on the degree of synchronization, we focus on the variation (in absolute value) between the average share of non-US natives over 2005-2009 with respect to the same share over 2000-2005. In particular, we firstly calculate the correlation between the degree of synchronization and the level of mobility; then, we run a simple regression between the same variables.

Table 2 – *Correlation and regression analysis results.*

Correlation	Estimated regression coeff	Standard error	p-value
0.349	10.395	3.931	0.011

The results are presented in Table 2; they clearly show that an increase in the share of non-natives within the population is associated with an increase in the degree of synchronization with the national cycle, thus confirming the intuition that, given their larger level of mobility in response to labour market opportunities, they can effectively improve business cycles synchronization.

5. Concluding remarks

In this paper, we present a synchronization analysis of the real business cycles of U.S. states. We employ data on real GDP covering the period stretching from 2005:Q1 to 2020:Q2. Once the business cycles of the U.S. states are extracted using CiSSA, we study their level of synchronization with the national one using two measures of synchronization.

Moreover, based on the literature that documents how workers with different levels of education and human capital exhibit different level of propensity to migrate, we also investigate the possibility that immigrant flows might affect the level of synchronization of the state cycles with respect to the national one.

Results show that there is a remarkable variability in the degree of synchronization across states. More in details, Delaware, Luisiana, Maryland, North and South Dakota are a-synchronized with the national economy. Instead, Alabama, Arizona, Florida, Illinois, Massachusetts, Montana, South Carolina are strongly synchronized. In addition, an increase of the share of non-natives in the population is associated with an increase in the degree of synchronization with the national cycle.

Acknowledgements

The authors wish to thank warmly an anonymous referee for the valuable comments to an earlier version of this paper. The authors are also grateful to the Editor for the suggestions. The usual disclaimer applies and the views are the sole responsibility of the authors.

References

BECKWORTH D. 2010. One nation under the Fed? The asymmetric effect of US Monetary Policy and its implications for the United States as an Optimal Currency Area, *Journal of Macroeconomics*, Vol. 32: pp. 732-746.

BOGALO J., PONCELA P. and SENRA E. 2021a. Circulant spectrum analysis: a new automated procedure for signal extraction, *Signal Processing*, Vol. 179, 2021. doi:10.1016/j.sigpro.2020.107824

BOGALO J., PONCELA P. and SENRA E. 2021b. Circulant Singular Spectrum Analysis to Monitor the State of the Economy in Real Time, *Mathematics*, Vol. 9, 1169. https://doi.org/10.3390/math9111169

HARDING D, PAGAN A. 2006. Synchronization of cycles, *Journal of Econometrics*, Vol. 132, pp. 59-79.

HODRIK R., PRESCOTT E. C. 1997. Postwar US business cycles: an empirical investigation. *Journal of Money Credit and Banking*, Vol. 29, pp. 1-16.

MOLLOY R., SMITH C.L. and WOZNIAK A. 2011. Internal migration in the United States, *Journal of Economic Perspectives*, Vol. 25, pp. 173-196.

PERI G. 2013. The economic benefits of immigration. *Berkeley Review of Latin American Studies, Fall 2013*, pp. 14-19.

PARTRIDGE M., RICKMAN D.S. 2005. Changes in asymmetric shocks in an optimal currency area: an analysis using US state data, *Oxford Economic Papers*, Vol. 57, No. 3, pp. 373-397.

RUGGLES S., FLOOD S., GOEKEN R., GROVER J., MEYER E., PACAS J. and SOBEK M. 2020. *IPUMS USA: Version 10.0 [dataset]*. Minneapolis, MN: IPUMS. https://doi.org/10.18128/D010.V10.0

SUMMARY

Synchronization among real business cycles of U.S. states

In this paper we present a synchronization analysis of the real business cycles of U.S. states. We employ data on real GDP covering the period stretching from 2005:Q1 to 2020:Q2. From the methodological point of view, to isolate the business cycles we adopt a recently developed MatLab function for signal extraction. Once the business cycles of the U.S. states are extracted using CiSSA, we study their level of synchronization with the national one using various indices of synchronization. Moreover, based on the literature that documents how workers with different levels of education and human capital exhibit different level of propensity to migrate, we study the correlation between immigrant flows and the level of synchronization of the regional cycles with respect to the national one.

Margherita GEROLIMETTO, Università Ca' Foscari Venezia, Dipartimento di Economia. E-mail: margherita.gerolimetto@unive.it

Stefano MAGRINI, Università Ca' Foscari Venezia, Dipartimento di Economia. E-mail: stefano.magrini@unive.it