ECONOMIC ANNALS, Volume LXVIII, No. 237 / April – June 2023
UDC: 3.33 ISSN: 0013-3264

https://doi.org/10.2298/EKA2337069Z

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INVESTIGATION OF THE SUNSPOTS AND GDP NEXUS: THE CASE OF BALKAN COUNTRIES

ABSTRACT: *The phenomenon known as sunspots refers to regions of the Sun's photosphere that are darker than their surroundings because their surface temperature is lower. The sunspot growth theory, however debatable, is one of the first explanations for economic development that explains how variations in the Sun's activity affect the business cycle. Jevons developed the sunspot hypothesis in 1875. To reevaluate this notion, this research uses correlation and regression analysis to explore the relationship between sunspots and GDP in the context of 11 Balkan nations over the years 1960–2021. By extending the sample of nations in panel regression models to include all nations on Earth, further robustness testing is accomplished. It was found that there exist significantly negative medium strength correlations between sunspots and gross domestic product values of 8 out of 11 Balkan countries. Similar findings were obtained using simple linear regression analysis. The results of the cross-country panel regression models further highlight the negative impact of solar activity on economic activity, which is also associated with nations that are located at higher latitudes.*

KEY WORDS: *sunspots; GDP per capita; Balkan countries; correlation and regression; H-P filter, panel data.*

JEL CLASSIFICATION: E32, F44, Q54.

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1. INTRODUCTION

The theory on the link between variations in the solar cycle and economic activity was first put forth by Sir William Herschel in 1801 (Herschel, 1801). Hyde Clarke, who noticed a link between 11-year solar cycles and economic activity, advanced this theory (Clarke, 1847). William Stanley Jevons was the first person to seriously consider this notion, however. A "wonderful coincidence", was how he described it. Sunspots, according to Jevons (1875), have an impact on the weather on Earth, which in turn affects crops and the global economy (Jevons, 1879). Jevons' sunspot idea, however, was disproved since there was no theoretical justification for it in the evidence. In economics, a random variable that is external to the economy and has no bearing on its foundations is referred to as "a sunspot". Rifts in the Sun's surface, known as sunspots, reveal a lower layer. The environment is cooler when there are more sunspots because the lower layer emits less light and heat than the surface. Sunspots, which wax and wane over a period of about 11 years, are the most well-known aspect of the Sun's activity, according to Eddy (1976). The physical effects of the Sun's influence on Earth are discussed by Lean (2015). Eastwood et al. (2017) provided a thorough literature review of the economic impact of space weather through various channels, including the power grid, the oil and gas industry, communications, ground transportation, satellite infrastructure, global navigation satellite systems, and aviation. Large magnetic storms are common around the peaks of the sunspot cycle, inducing powerful polar light (auroras). Extreme space weather events, such as geomagnetic storms, are widely known to pose a serious threat to infrastructure.

Sunspot activity, according to Alexander Chizhevsky's hypothesis, has had an impact on human history throughout time (Chizhevsky, 1924). The three-year maximum of the sunspot cycles, according to his research, were the time when the most significant historical events took place. The behaviour of people is negatively impacted by solar activity, according to Chizhevsky. He divided an 11-year period into four sub-periods: (1) a three-year period of minimum solar activity marked by passivity and autocratic rule, (2) a two-year period during which people organise under new leaders, (3) a three-year period of maximum excitability, revolutions, and war around the solar maximum, and (4) a three-year period of a gradual decrease in excitability until the people are apathetic.

According to Gorbanev (2012), peak solar activity somehow affects people's mental, and even physical, health, which in turn affects their behaviour and expectations. As a result, consumer demand and labour productivity change, causing the economy to experience cyclical oscillations. The data regarding the connection between solar cycles and business activity, specifically how they affect crops, was reviewed by Garcia-Mata and Shaffner in 1934. The authors discovered a statistically significant association between the variations in non-agricultural economic activity in the United States and solar cycles, despite the fact that the sunspot theory had been rejected. Sidis (1918) connected sunspot activity with the occurrence of revolutions, whereas Sorokin (1938) identified sunspot activity as a disregarded component in conflict.

Our study uses correlation and regression analysis to look at the effect of solar activity on the GDP of 11 Balkan nations. With the exception of Greece, the data for the various countries could only be obtained for periods of time that are relatively short. A robustness check was conducted by broadening the sample to include all nations using cross-country panel regression models. This was examined to see whether variations in solar activity across 11-year cycles have a discernible impact on variations in the gross domestic product per capita, the broadest gauge of economic activity; in other words, whether variations in solar activity have an impact on how individuals act, which has an impact on the economy. The two hypotheses to be tested are as follows:

H_1: Increased solar activity has a detrimental effect on the gross domestic product (GDP) per capita in the Balkans and other nations.

H2: Countries at higher latitudes are more adversely affected by solar activity.

The economies of the Balkan countries and other nations are anticipated to be significantly and negatively impacted by solar activity. Similar to how greater geomagnetic activity is reported to have a negative impact on countries at higher latitudes, so too should increased solar activity. Cross-country panel regression models with their three specifications, pooled OLS, fixed effects model, and random effects model, were employed for further analysis.

There are five sections in the paper. The most significant pertinent theoretical and empirical studies on this topic are presented and expanded upon in the

literature review. The data and methodology employed in this study are detailed in the methodology and data section. The primary findings of the analysis are presented in the results and discussion section. Concluding thoughts are presented in the last section.

2. LITERATURE REVIEW

This section presents and elaborates on a chronological literature review of the effect of solar activity on economic activity. Collins (1965) has shown that since 1871, the years in which the average number of sunspot counts surpassed 50 have always coincided with, or been followed by, a high percentage decline in stock markets. According to Dewey (1968), the Sun's 11-year cycle affects 43 different cycles, including those of stock and commodity markets, industrial output, and agricultural productivity. Using data from the years 1866 to 1973, Harrison (1976) investigated the relationship between agricultural yields (wheat, corn, cotton, and rice) and different solar cycle stages. The key conclusion was that lower yields and decreased sunspot activity are correlated with one another.

Sunspots contribute to variations in business to only a relatively minor extent. Gallegati and Mignacca (1994) estimate that they account for only about 4% to 5% of the variance in the series with a lag of one to two years. The authors described Jevons' hypothesis as an appealing but imperfect idea, yet they did not fully reject it. Based on information from the period between 1971 and 2001, Otsu et al. (2006) investigated relationships between the number of sunspots, the unemployment rate, and suicide mortality in Japan. With R equal to -0.17, there was a substantial inverse relationship between the sunspot count and unemployment. Sunspots' impact on the German economy between 1927 and 1932 was demonstrated by Weder (2006). Important information about economic activity can be found in sunspots. Weder highlights a quantifiable portion of output volatility that can be attributed to nonfundamental expectations and provides an explanation for the start of the German Depression. According to Jevons, ripples, or panics, seemed to occur periodically (Peart, 1991). Moods were derived from changes in economic indicators that were used to forecast investment returns.

On the basis of historical data, Modis (2007) found links between the GDP of the United States, the Dow Jones Industrial Average index, and the number of

sunspots. He provided solid evidence that there is a connection between stock market fluctuations and sunspot activity. Similar findings were made in a fairly systematic way for the GDP peaks that come before the sunspot peaks. According to McClellan (2010), sunspots are the hidden cause of unemployment. Maxima in the jobless rate in the United States coincided with sunspot activity peaks and occurred roughly three years later. In many areas related to human endeavour, including growth, inflation, demographics, sentiment, and stock market seasonality and waveform, solar phenomena have an impact on people and drive cyclical patterns that reoccur throughout time (Hampson, 2012). The relationship between solar cycle activity and the timing of recessions in the US and other G7 nations was examined by Gorbanev (2015). He discovered that throughout the course of the previous 77 years, recessions in the United States and the G7 countries coincided with solar activity maximums. In his 2012 paper, Gorbanev found a similar outcome when examining the connection between solar cycle maximums and rising jobless rates. The new pattern of financial and economic crises occurring throughout the world at times of solar activity minimums was also noted by Gorbanev (2020).

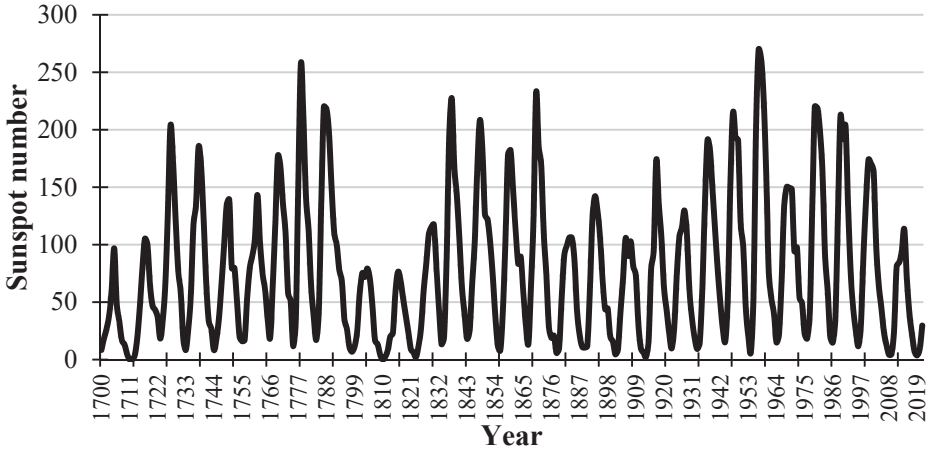
Gupta et al. (2015) used monthly data from January 1880 to September 2013 to examine if sunspots affect global temperatures. For both complete samples and sub-samples, conventional domain causality tests were unable to disprove the null hypothesis that sunspots do not affect world temperatures. Sunspots increase the Earth's geomagnetic activity, which alters people's psychology and behaviour, claim Dimitrijevic et al. (2016). As a result, stock markets are affected by waves of optimism and pessimism. Dimitrijevic et al. (2016) discovered a statistically significant negative association between the indexes of four stock markets (in Serbia, Slovenia, Croatia, and Hungary) and sunspot activity, as determined by sunspot number, between 2005 and 2012. Therefore, a rise in solar activity has a detrimental effect on stock markets and investment decisions. Using a vector error correction approach, Burakov (2017) evaluated a hypothesis regarding the impact of sunspot cycles on the Russian wheat market from 1990 to 2015. Sunspots, wheat yields, wheat prices, and non-performing loans (NPL) were all correlated over the long term, demonstrating the significance of solar activity for agricultural financing. Zhao (2019) estimated the negative effects of solar activity on the Canadian economy using a three-sector real business cycle model (RBC). Shocks to solar activity reduce output, consumption, and investment. More

specifically, for every percentage point increase in solar activity, the GDP per person fell by 0.26 per cent.

3. DATA AND METHODS

The purpose of this study is to examine the relationship between solar cycles and their subsequent effects on variations in the level of economic activity on Earth as measured by the gross domestic product per capita variable. The annual mean total sunspot number was monitored for the analysis. The occurrence of sunspots was initially tracked on a daily basis.

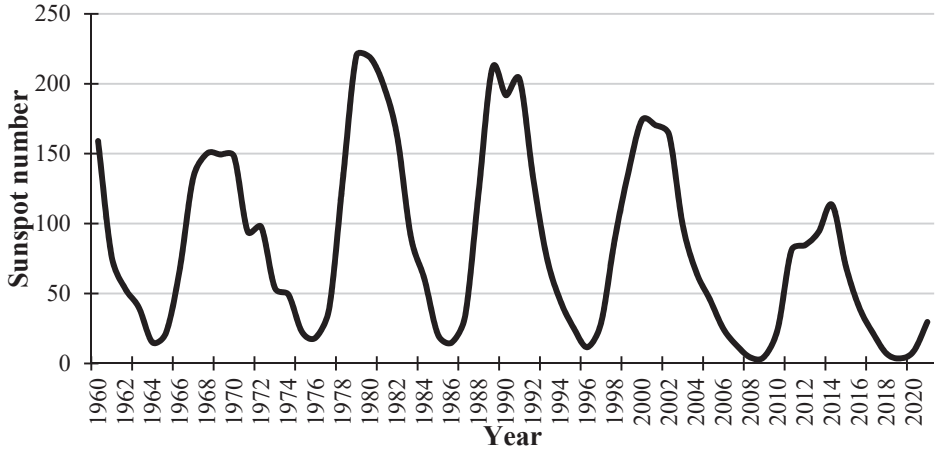
Figure 1. Yearly mean total sunspot number from 1700 to 2021



Source: WDC-SILSO (2022).

The occurrence of the sunspots were tracked annually because the gross domestic product is not calculated on a daily basis. A simple arithmetic mean of the daily total sunspot number across all days of each year was calculated to approximate the annual sunspot number (WDC-SILSO, 2022). It is feasible to identify the recurring patterns of the maximum and minimum number of sunspots by tracking the number of sunspots each year. The annual mean total number of sunspots from 1700 through 2021 is shown in Figure 1. This extremely long period of observation, more than 300 years, indicates a cycle of about 11 years between the highest and lowest annual sunspot number.

Figure 2. Yearly mean total sunspot number from 1960 to 2021



Source: WDC-SILSO (2022).

The period from 1960 onwards is the subject of the research because of restrictions on data collection for the gross domestic product per capita variable. Therefore, the annual mean total sunspot number for the years 1960 through 2021 is shown in Figure 2. The years 1964, 1976, 1986, 1996, 2008, and 2019 are those in which the number of sunspots each year was at its lowest. Contrarily, the years 1968, 1979, 1989, 2000, and 2014 have the highest number of sunspots observed in a single year. This means that there are six periods of minimum sunspot number and five periods of maximum sunspot activity. The next annual highest number of sunspots is anticipated to occur in 2025, following the 11-year cycle of repetition.

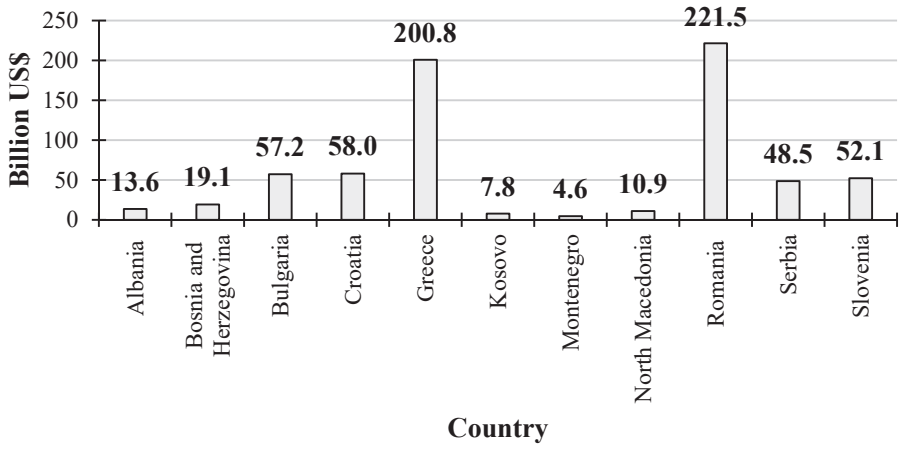
Table 1. Descriptive statistics of yearly mean total sunspot number from 1700 to 2021 and from 1960 to 2021

Statistics	Period	
	1700-2021	1960-2021
Mean	78.37	83.16
Median	65.15	68.30
Standard Deviation	62.05	64.52
Range	269.3	216.5
Minimum	0	3.6
Maximum	269.3	220.1
Sum	25234	5156
Count	322	62

Source: Authors' calculations.

Table 1 presents the main descriptive statistics data for the annual mean total sunspot number variable based on the time spans from 1700 to 2021 and from 1960 to 2021.

Figure 3. Gross domestic product of Balkan countries in 2021, constant 2015 US$, in billion US$



Source: World Bank (2023a).

The average of the annual means of the total sunspot number for the period 1960 to 2021 is somewhat greater than that for the period 1700 to 2021. However, the range of the yearly means of the total sunspot number is smaller between 1960 and 2021 than between 1700 and 2021. The annual mean total sunspot number variable was observed together with the gross domestic product variable. Only Balkan countries were initially monitored for the variable of gross domestic product, which is presented in constant 2015 US dollars (World Bank, 2023a). This sample of nations was chosen in an effort to depart from mainstream theory, which mostly focuses on the US, the G7, and developed OECD nations.

The following 11 nations are included among the Balkan nations: Albania, Kosovo, Montenegro, North Macedonia, Romania, Serbia, Slovenia, Bosnia and Herzegovina, Bulgaria, Croatia, and Greece. Figure 3 displays the gross domestic product for the Balkan nations in 2021. Three groupings of countries can be distinguished based on the value of their gross domestic products. With the greatest gross domestic product values, the first group includes Greece and Romania. Four nations make up the second group of Balkan nations with comparable gross domestic product values: Bulgaria, Croatia, Serbia, and Slovenia. The final group of five Balkan nations – Albania, Bosnia and Herzegovina, Kosovo, Montenegro, and North Macedonia – has the lowest projected gross domestic product in 2021 of all the Balkan nations.

Table 2. Descriptive statistics of gross domestic product variable, Balkan countries, constant 2015 US$, in billion US$

Country	Statistics						
	Count	Mean	Median	Std. dev.	Range	Min.	Max.
Albania	42	7.59	6.31	3.05	10.06	3.53	13.59
Bosnia and Herzegovina	28	13.11	14.88	4.40	16.67	2.44	19.11
Bulgaria	42	40.74	38.01	8.59	28.40	29.04	57.44
Croatia	27	47.66	49.28	6.81	24.49	33.56	58.05
Greece	62	158.75	160.02	58.20	224.06	41.91	265.97
Kosovo	14	6.18	6.12	1.02	3.22	4.58	7.80
Montenegro	25	3.57	3.71	0.66	2.18	2.60	4.78
North Macedonia	32	8.02	7.52	1.78	5.44	5.75	11.19
Romania	32	143.03	139.69	40.57	129.43	92.10	221.54
Serbia	27	34.50	37.68	7.97	27.32	21.21	48.52
Slovenia	27	39.56	41.47	7.07	25.63	26.42	52.05

Source: Authors' calculations.

Additionally, the results of the descriptive statistics for the Balkan countries, shown in Table 2, serve to support Figure 3 and the gross domestic product variable. The average values of the gross domestic product are shown in Table 2. The difference in the GDP between the Balkan countries can be seen. It should be emphasised that only Greek gross domestic product data were available over the whole observation period, which ran from 1960 to 2021. The gross domestic product figures for the other Balkan nations were only available for specific timeframes. All the Balkan nations have continuous data series until the year 2021, despite the fact that the number of data points for variables relating to gross domestic product differs between the Balkan nations. The most significant variation is the base year for which data on the gross domestic product was available. As an illustration, Kosovo's gross domestic product numbers for the years 2008 to 2021 are covered by just 14 data points.

Regression and correlation analyses were used to examine the association between the annual mean total sunspot number and the gross domestic product figures of the Balkan nations. The correlation analysis demonstrates whether there is a statistically significant linear relationship between the former and the latter. For each Balkan nation separately, the gross domestic product value serves

as the dependent variable in the regression models, while the yearly mean total sunspot number always serves as the explanatory variable. Unstandardised values of the variables were used in the analysis. The natural logarithm of the gross domestic product variable was used in the regression and correlation studies. Additionally, the yearly mean total sunspot number was first be expressed in absolute values before being converted to natural logarithms for the regression and correlation analysis. Furthermore, the regression and correlation analysis were conducted by taking into account lagged natural logarithms of total sunspot number.

In addition, both variables were then standardised in order to graphically illustrate and contrast the values of the gross domestic product of the Balkan countries and the yearly mean total sunspot number. Next, a Hodrick–Prescott high-pass filter was used to extract cyclical components from the standardised variables (Stata, 2022). The cyclical movement of the yearly mean total sunspot number and the gross domestic product variables could then be compared to determine whether or not there is a relationship between them. It is known that the yearly mean total sunspot number achieves the minimum and maximum values in a cyclical way; hence cyclical component examination and comparison are the subjects of this study. In the next step of the analysis, cross-country panel regression models with pooled OLS, fixed effects, and random effects specifications were employed to conduct a more thorough analysis. The sample of nations was widened to include all nations to obtain more reliable conclusions on how solar activity affects economic activity. Equation 1 gives the cross-country panel regression specification:

$$y_{it} = \beta_0 + \beta_1 solar\_activity_{t-1} + \beta_2 solar\_activity_{t-1} \cdot latitude_i + \beta_3 unemp\_rate_{i,t-1} + \varepsilon_{i,t} \quad (1)$$

where y represents the gross domestic product per capita in constant 2015 US dollars as a measure of economic activity. These data came from OECD National Accounts data files and World Bank national accounts statistics (World Bank, 2023b). The variable $solar\_activity$ represents the annual variability in sunspot frequency observed with a one-year lag. As a result, this variable serves as a stand-in for solar activity measurement. The $latitude$ variable takes values between 0 and 100, with 0 denoting the equator, and represents the country's absolute

latitude as measured by distance from the equator. Data were obtained from DistanceLatLong (2023) for this variable. A variable called $solar\_activity_{t-1} \cdot latitude_i$ with a lag of one period was created to quantify the impacts of solar activity on economic activity depending on the country's latitude. The unemployment rate (World Bank, 2023c), $unemp\_rate_{i,t-1}$, was added as a control variable to the regression equation to establish a causal relationship between the variables of interest and prevent research bias. Along with the pooled OLS model, two additional panel cross-country regression models with fixed effects and random effects were generated to account for the heterogeneity of the nations. The Hausman test and the loglikelihood ratio test were used to distinguish between the aforementioned models and determine which model best fits the data. For the panel estimations, time-series data were available from 1973 through 2021. Overall, 217 nations and dependencies were taken into account in the analysis of the entire sample of nations from around the world. The two panel models were estimated to perform a robustness check, one with the control variable and the other without it.

4. RESULTS AND DISCUSSION

Correlation and regression analysis were used to examine the link between the annual mean total sunspot number and variables relating to the gross domestic product in the Balkan nations. The existence of cyclical and random time-series components is evident in the yearly mean total sunspot number variable (Figure A1). The gross domestic product variable, on the other hand, also has a few time-series components, mostly trend and random components, although with varying intensities. Consequently, it was decided to use transformed values for the variables.

Table 3. Correlation coefficients between yearly mean total sunspot number (Sunspot) and gross domestic product (GDP) variables, Balkan countries

Country	n	Sunspot & log GDP	Log Sunspot & log GDP	Log Sunspot (lag t-1) & log GDP
Albania	42	-0.4575***	-0.4764***	-0.5027***
Bosnia and Herzegovina	28	-0.0609	-0.1525	-0.1099
Bulgaria	42	-0.5040***	-0.5415***	-0.5617***
Croatia	27	-0.4407**	-0.4408**	-0.3339*
Greece	62	-0.1159	-0.2130*	-0.1015
Kosovo	14	-0.1837	-0.0682	-0.0253
Montenegro	25	-0.6519***	-0.6051***	-0.5625***
North Macedonia	32	-0.3912**	-0.4295**	-0.4209**
Romania	32	-0.5464***	-0.5688***	-0.5530***
Serbia	27	-0.4573**	-0.4270**	-0.3893**
Slovenia	27	-0.3919**	-0.4108**	-0.3156

Source: Authors' calculations.

Note: The correlation is statistically significant at the * 0.10 level, ** 0.05 level, *** 0.01 level.

Table 3 presents the values of the correlation coefficients between the annual mean total sunspot number and the gross domestic product in the Balkan countries. Observing the log gross domestic product variable, it can be seen that there is a negative association between the annual mean total sunspot number and the variables relating to the gross domestic product for all the Balkan countries. Montenegro, Romania, and Bulgaria appear to have the strongest correlations between the two variables. However, for three Balkan nations – Bosnia and Herzegovina, Greece, and Kosovo – there is no statistically significant correlation between the annual mean total sunspot number and the gross domestic product. Similar findings are obtained and a comparable conclusion can be drawn when the lagged natural logarithms of total sunspot number are examined. In this case, there is no statistically significant correlation between the annual mean total sunspot number and the gross domestic product of Slovenia.

Table 4. Estimates of simple linear regression coefficients, with GDP as the dependent variable, Sunspot as the exploratory variable, Balkan countries

Country	n	Sunspot & log GDP	Log Sunspot & log GDP	Log Sunspot (lag t-1) & log GDP
Albania	42	-0.0027357***	-0.1644958***	-0.0028878***
Bosnia and Herzegovina	28	-0.0005857	-0.066594	-0.0010617
Bulgaria	42	-0.001558***	-0.0966481***	-0.0016679***
Croatia	27	-0.0012532**	-0.0568636**	-0.000954*
Greece	62	-0.0008272	-0.0916487*	-0.0006829
Kosovo	14	-0.0008261	-0.0094206	-0.0001117
Montenegro	25	-0.0022776***	-0.0952803***	-0.0019447***
North Macedonia	32	-0.0014311**	-0.080335**	-0.0014389**
Romania	32	-0.0025521***	-0.1358553***	-0.0024139***
Serbia	27	-0.0021164**	-0.0896351**	-0.0018099**
Slovenia	27	-0.001387**	-0.0659405**	-0.001122

Source: Authors' calculations.

Note: The regression coefficient is statistically significant at the * 0.10 level, ** 0.05 level, *** 0.01 level.

The findings in Table 4, which presents the estimates of the simple linear regression coefficients obtained from the linear regression analyses, are consistent with the inferences drawn from the results of the calculated correlation coefficients in Table 3. The results in Table 4 show that the rise in the annual mean total sunspot number has the greatest effect on the average decline in the Albanian and Romanian gross domestic products. Once more, in Bosnia and Herzegovina, Greece, and Kosovo, the effect of the rise in the annual mean total sunspot number on the gross domestic product is not statistically significant. The findings are similar to those of earlier investigations. According to Poluyakhtov and Belkin (2011), the solar cycles closely correlate with both the US and the world gross domestic products. Using this data, Poluyakhtov and Belkin predicted that there would be worldwide economic crises in 2013–2014 and 2018–2019. In addition, they used a 9-quarter moving average for both series to take out noise and the effects of sudden shocks that would have made the 11-year cycle in the data harder to see. It was discovered that GDP growth slowed down in the years immediately preceding the sunspot maximum. In the case of the US

economy and the advanced nations of the G7, Gorbanev (2012) discovered only a weak association between the GDP statistics and sunspots using quarterly seasonally adjusted series beginning in 1948. In the original series, he applied the Hodrick–Prescott filter to determine departures from the long-term trend.

The cyclical components of the variables annual mean total sunspot number and gross domestic product are compared in Figure A1 in the Appendix. The original values of the variables were first standardised, and then the Hodrick–Prescott filter was used to remove the cyclical component so that extracted cyclical components could be directly compared. There is a clear cyclical component associated with the indicated changes in the yearly mean total sunspot number variable. In contrast, the gross domestic product variable has substantially lower values of the cyclical component. It might prove to be too challenging to compare the development of the annual mean total sunspot number to the development of the gross domestic product when the values of both variables are used. Therefore, we compare the occurrence of the maximum and minimum values instead.

Table 5. The occurrence of maximum and minimum values of the yearly mean total sunspot number and gross domestic product variables of Balkan countries across 11-year periods, using the Hodrick–Prescott filter

Variable	Country	Years	
		Minimum	Maximum
Yearly mean total sunspot number		1965; 1977; 1987; 1996; 2009; 2018	1967; 1979; 1989; 2000; 2014; 2021
Gross domestic product	Albania	1985; 1992; 2006; 2020	1989; 1996; 2008; 2018
	Bosnia and Herzegovina	2003; 2012; 2020	2008; 2019
	Bulgaria	1992; 1999; 2014; 2020	1988; 1996; 2008; 2019
	Croatia	2001; 2014; 2020	2008; 2019
	Greece	1968; 1974; 1987; 1993; 2005; 2012; 2020	1973; 1979; 1991; 1998; 2008; 2019
	Kosovo	2014; 2020	2019
	Montenegro	2005; 2012; 2020	2008; 2019
	North Macedonia	2003; 2012; 2020	2000; 2008; 2019
	Romania	2003; 2010; 2020	1996; 2008; 2019
	Serbia	2014; 2020	2008; 2019
	Slovenia	2009; 2020	2008; 2019

Source: Authors' calculations.

Table 5 highlights the years in which the annual mean total sunspot number and gross domestic product variables were recorded at their maximum and minimum values during the course of the 11-year periods. For simpler comparison, Figure A2 also displays the emergence of the maximum and minimum values graphically in the form of a timeline. These maximum and minimum values of the cyclical components are based on the original standardised values of the variables. In all Balkan nations, the minimum and maximum values of the GDP variable appear to occur in nearly the same years. Additionally, compared to the maximum values of the gross domestic product variable, the minimum values of the annual mean total sunspot number variable tend to occur with a slight lag. If the maximum values of the annual mean total sunspot number variable and the minimum values of the gross domestic product variable are compared, the same conclusion can be drawn. We can infer that the gross domestic product of 8 of the 11 Balkan countries is negatively impacted by an increase in sunspot numbers. Greece, Kosovo, and Bosnia and Hercegovina are the outliers. This conclusion may highlight the inconsistent nature of the data, but it may also suggest some causes for these exceptions. Greece has the greatest number of sunny days per year compared to other Balkan nations; hence, its gross domestic product may not have been impacted. Kosovo is the youngest state in Europe. Therefore, the discordance in the data could be caused by the short time period of the GDP data. A civil conflict in Bosnia in the early 1990s had a significant impact on the time series of GDP statistics. However, these are merely conjectural explanations that should be treated with caution. Additionally, it should be remembered that a variety of factors, not just solar activity, affect variations in the gross domestic product. The impacts of solar activity on the GDP per capita of Balkan nations are shown in Table 6.

Table 6. The effects of solar activity on the GDP per capita of Balkan countries

Dependent variable: Log GDP per capita (constant 2015 US$)	Models (with control variable Unemp)			Models (without control variable Unemp)		
Independent variables	Pooled OLS	Fixed effects	Random effects	Pooled OLS	Fixed effects	Random effects
Constant	10.92623*** (0.30711)	9.73546*** (0.19874)	9.80120*** (0.25822)	9.26243*** (0.29442)	9.32106*** (0.11003)	9.27943*** (0.26305)
Log(Sunspots (t-1))	0.01734 (0.05245)	-0.03581** (0.02521)	-0.03309 (0.025167)	-0.05809*** (0.05780)	-0.05491** (0.02168)	-0.05492** (0.02168)
Log(Sunspots (t-1) X Latitude	-0.05146 (0.05288)	-0.05209** (0.02454)	-0.05001** (0.02454)	-0.04399 (0.05879)	-0.05343** (0.02193)	-0.05335** (0.02193)
Log(Unemp (t-1))	-0.70322*** (0.06738)	-0.017918** (0.07139)	-0.20613*** (0.06992)			
Diagnostics						
Adjusted R squared	0.29277	0.84877	0.15990	0.01793	0.86371	0.16085
S.E. of regression	0.61476	0.28428	0.28628	0.74501	0.27753	0.27656
Prob. (F-stat.)	<0.001	<0.001	<0.001	0.01672	<0.001	<0.001
Mean dependent var.	8.76309	8.76309	8.76309	8.71611	8.71611	8.71611
Akaike info criterion	1.87884	0.36699		2.25782	0.31118	
Durbin-Watson stat.	0.04172	0.10454	0.10164	0.01384	0.10820	0.10571
Hausman test	Chi-square stat. 7.09, Prob. 0.069			Chi-square stat. 1.14, Prob. 0.56		
Loglikelihood ratio test	Cross-section F 115.38, Prob. 0.0, Cross-section Chi-square 447,36, Prob. 0.0			Cross-section F 213.24, Prob. 0.0, Cross-section Chi-square 691.58, Prob. 0.0		
Sample/Cross-sections	1992-2021/10	1992-2021/10	1992-2021/10	1973-2021/11	1973-2021/11	1973-2021/11
Observations	284	284	284	345	345	345

Notes: Standard errors in parentheses, * denotes p<.10, ** p<.05, and *** p<.01.

Source: Authors' calculations.

In our study, the independent variables are the logarithmic values of sunspot activity, sunspot activity times latitude, and unemployment rates, all of which are lagged by one period. The dependent variable is the logarithmic value of gross domestic product per capita expressed in 2015 constant US$. Ten Balkan

countries are represented in the sample of data, which spans the years 1992 to 2021, and there are a total of 284 observations. In contrast, the time period in the model with the removed control variable is larger, spanning the years 1973 through 2021, with a total of 345 observations. According to the Hausman and loglikelihood ratio tests, fixed effects models are preferred, with the exception that random effects models are preferred in models without a control variable, even if the results of both specifications are fairly comparable in that situation. Lower values of the Akaike information criterion also indicate adoption of the fixed effects model as the best fit of the data. The estimated model is well described by its explanatory variables, as evidenced by the extremely high R squared value of 0.85 in the fixed effects model. The independent variables included in the model are statistically significant when the F-stat probability value is zero. The Durbin-Watson test result is nearly zero, indicating a potential positive autocorrelation. The findings for the estimated model are as follows: (1) There is a significant and negative relationship between annual variations in solar activity, as measured by the number of sunspots, and GDP per capita in the Balkan countries, ranging from 0.03 to 0.05 percentage points; (2) There is a significant and negative relationship between solar activity and GDP per capita, depending on the latitude of the country. Our findings with and without the control variable unemployment are comparable. In line with economic theory, there is also a negative and statistically significant link between unemployment and GDP per capita. Expanding the sample to include all nations in the world allowed for a robustness check that led to more comprehensive results. Table 7 presents the impact of solar activity on the GDP per capita of various nations. Data are available from 1973 to 2021 without considering the control variable unemployment and from 1992 to 2021 when this variable is taken into account in the specifications. The whole sample included 211 nations and dependent territories.

Table 7. The effects of solar activity on GDP per capita of countries worldwide

Dependent variable: Log GDP per capita (constant 2015 US$)	Models (with control variable Unemp)			Models (without control variable Unemp)		
Independent variables	Pooled OLS	Fixed effects	Random effects	Pooled OLS	Fixed effects	Random effects
Constant	7.18917*** (0.08825)	8.87563*** (0.02828)	8.86518*** (0.10323)	7.55861*** (0.06930)	8.890*** (0.02286)	8.95037*** (0.09660)
Log(Sunspots (t-1))	-0.03196*** (0.01989)	-0.04454*** (0.00505)	-0.04584*** (0.00504)	-0.36097*** (0.01654)	-0.04025*** (0.00532)	-0.04192*** (0.00532)
Log(Sunspots (t-1) X Latitude	0.31588*** (0.01485)	-0.02541*** (0.00521)	-0.02379*** (0.00521)	0.34091*** (0.01194)	-0.04397*** (0.00535)	-0.04189*** (0.00534)
Log(Unemp (t-1))	0.20257*** (0.02270)	-0.06359*** (0.01119)	-0.06108*** (0.01114)			
Diagnostics						
Adjusted R squared	0.10383	0.96968	0.09172	0.09064	0.95180	0.07005
S.E. of regression	1.39014	0.25569	0.25658	1.42872	0.32893	0.32979
Prob. (F-stat.)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mean dependent var.	8.43153	8.43153	8.43153	8.43914	8.43914	8.43914
Akaike info criterion	3.49744	0.14499		3.55179	0.63861	
Durbin-Watson stat.	0.02742	0.09276	0.08877	0.02764	0.06362	0.06121
Hausman test	Chi-square stat. 37.37, Prob. 0.0			Chi-square stat. 37.93, Prob. 0.0		
Loglikelihood ratio test	Cross-section F 826.55, Prob. 0.0, Cross-section Chi-square 18,113.87, Prob. 0.0			Cross-section F 729.94, Prob. 0.0, Cross-section Chi-square 25,388.89, Prob. 0.0		
Sample/Cross-sections	1992–2021/184	1992–2021/184	1992–2021/184	1973–2021/211	1973-2021/211	1973-2021/211
Observations	5,294	5,294	5,294	8,571	8,571	8,571

Notes: Standard errors in parentheses, * denotes p<.10, ** p<.05, and *** p<.01.
Source: Authors' calculations.

The findings from panel regression models for all the countries across the globe support those found for the Balkan countries, i.e., they are quite comparable, thus supporting both our hypotheses. The key point is that this estimate allows for a better evaluation of the impact of solar activity on the GDP per capita of a country

depending on latitude, which was not possible for the Balkan countries, which are situated at latitudes ranging from 39° to 46° North. The influence of solar activity on a country's GDP per person is roughly 0.04, according to estimates. This result is in line with earlier findings in this field (Batu & Zhao, 2021). According to the empirical data of Batu and Zhao (2021), there is a poor correlation between sunspot volatility and GDP in OECD nations. The authors claim that the economic sectors most severely impacted by space weather are those that deal with information and communication. It was discovered that the gross domestic product in OECD nations declines on average by at least 0.06 per cent for every 1 per cent rise in solar activity, which is a statistically significant effect of solar activity, the finding being comparable to the result obtained in this study. Additionally, a one percentage point increase in solar activity results in a 1.07 percentage point decrease in production in the information and communication industry. Higher latitude nations are more strongly affected by the impacts of extreme solar activity, which is the same result as ours. According to Zhao (2019), who used data from Canada, every percentage point rise in solar activity results in a 0.26 percentage point decline in real GDP per capita. Sunspots could only account for 3% of Canada's gross domestic output fluctuation.

5. CONCLUSIONS

Using data for Balkan nations, this paper sought to reevaluate Jevons' sunspot theory. The following can be used to sum up the main findings: (1) The results of the correlation and regression analyses show that sunspots and gross domestic products have significant and negative medium correlations and regressions for 8 of the 11 Balkan countries; (2) The results of the cross-country panel-regression models show that there is a statistically significant and negative relationship between increased sunspot activity and economic activity both for Balkan countries and for all other countries in the world; (3) Nations at higher latitudes are more negatively impacted by solar activity. The fundamental conclusions reached in this research, that an increase in solar activity has a negative effect on economic activity, are therefore equivalent to those of the earlier studies. The two hypotheses of the paper were found to be valid, but more investigation is required to obtain a more definitive conclusion. The uneven distribution of GDP statistics for the Balkan countries is one of the paper's limitations. For instance, time-series data, for Greece spans 62 years, compared to just 14 years for Kosovo. In addition,

data on GDP per capita and unemployment rates were unavailable for numerous small countries. Future studies should examine how solar activity affects economic activity by examining other macroeconomic factors including inflation, stock market fluctuations, recession forecasting, the onset of epidemics, and others. The separation of nations into groups such as the G7 and EU 27 as well as in-depth research of only major economies such as the United States, Germany, France, Japan, and the United Kingdom, among others, are further comparative analysis techniques that could be used., The United States is the nation for which this approach would be most appropriate since the effect of solar activity on GDP could be measured there with the greatest degree of precision. The reason is that even though the United States as a nation was involved in major global wars, the conflicts were fought elsewhere, and hence the damage to GDP was not as severe. Another crucial point is that because it is a huge country, the potential effects of external influences on its economic activity are mitigated.

Future research may need to change the research sample to provide for adequate comparison analysis, particularly for nations without complete historical data (such as Kosovo, which has only 14 data points). Differentiating between nations' income levels and the resulting influence of solar activity in the panel cross-country regression models could provide more analysis. Missing data for some of the important variables, particularly for small nations and when taking into consideration a variety of countries, is one of the main issues when analysing all countries (i.e., the World). The results that have been provided by this research lead to the conclusion that Jevons' sunspot theory is still valid and cannot simply be dismissed as unfounded.

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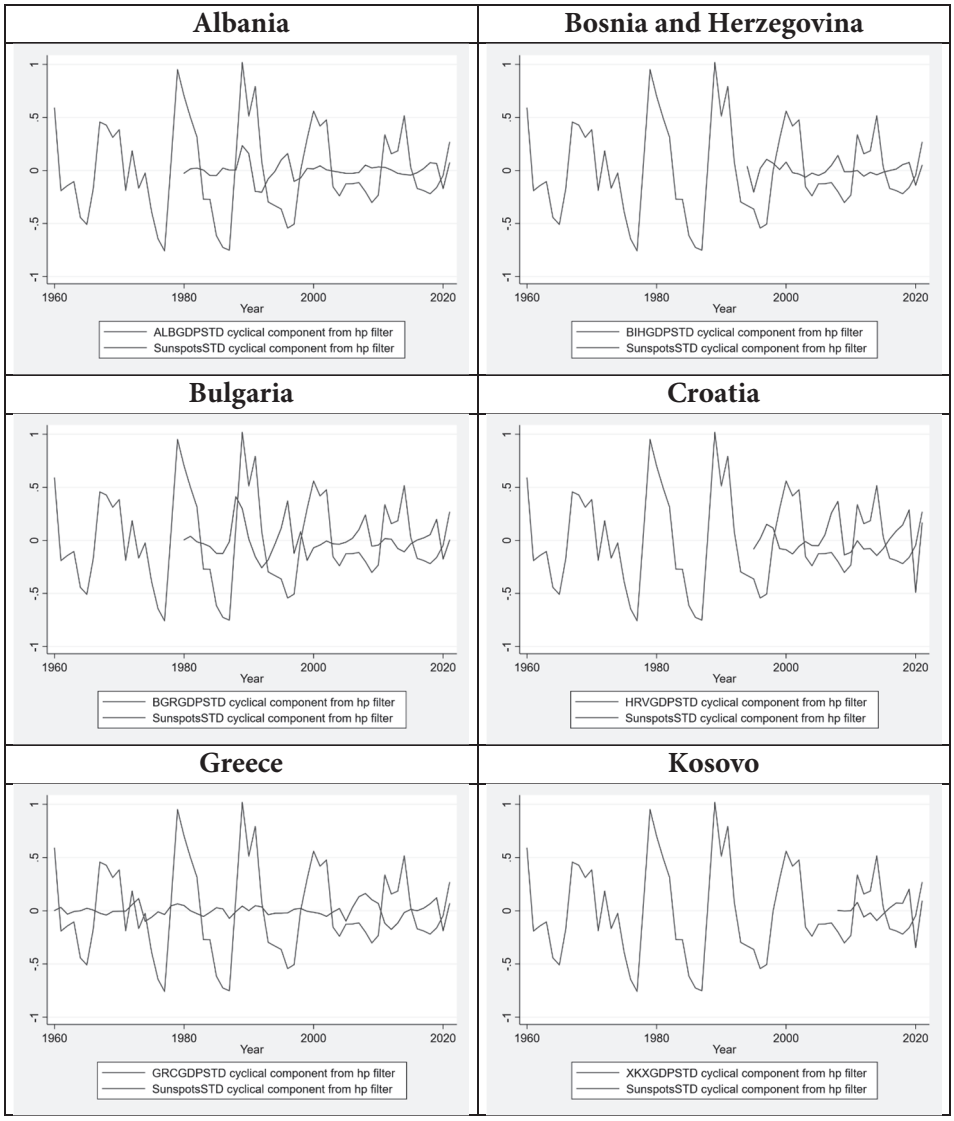
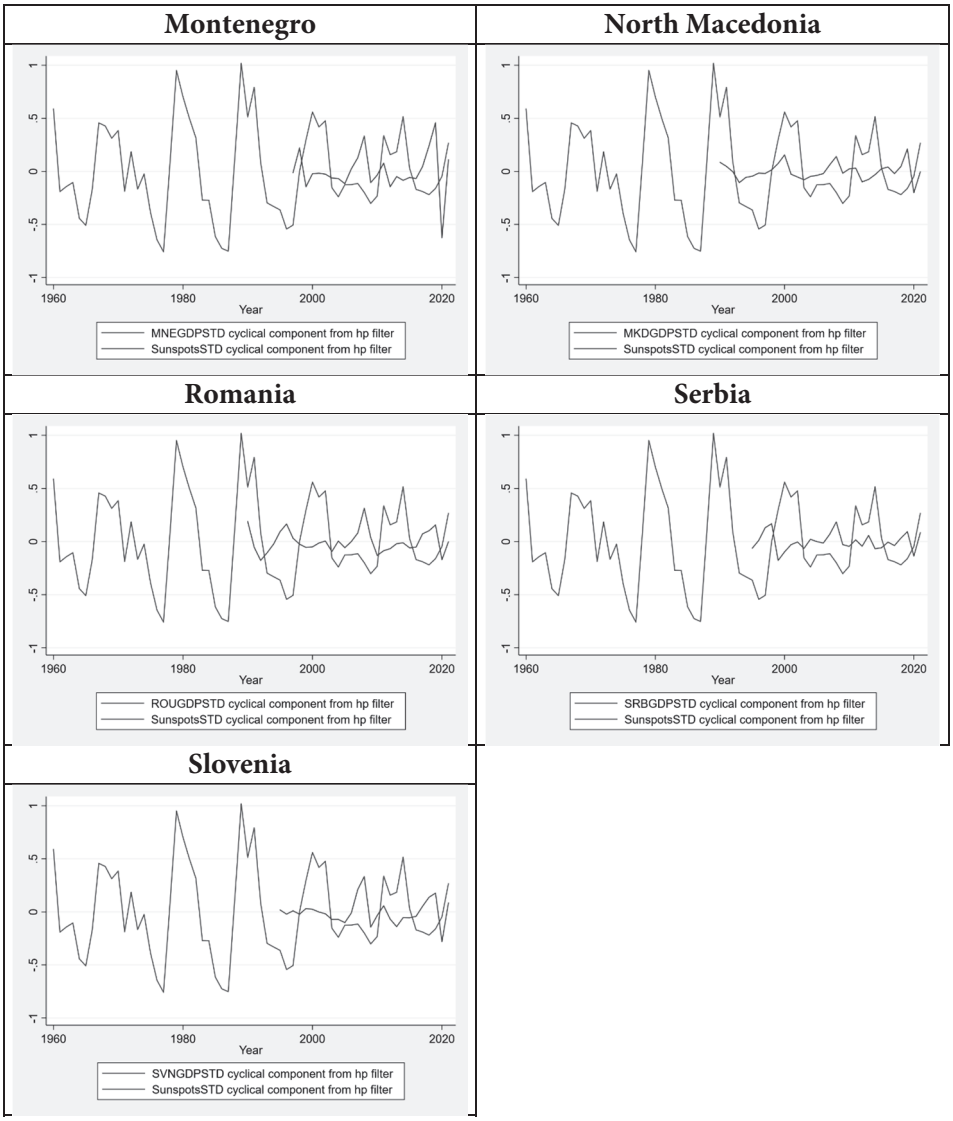
Received: February 28, 2023
Accepted: May 10, 2023

APPENDIX

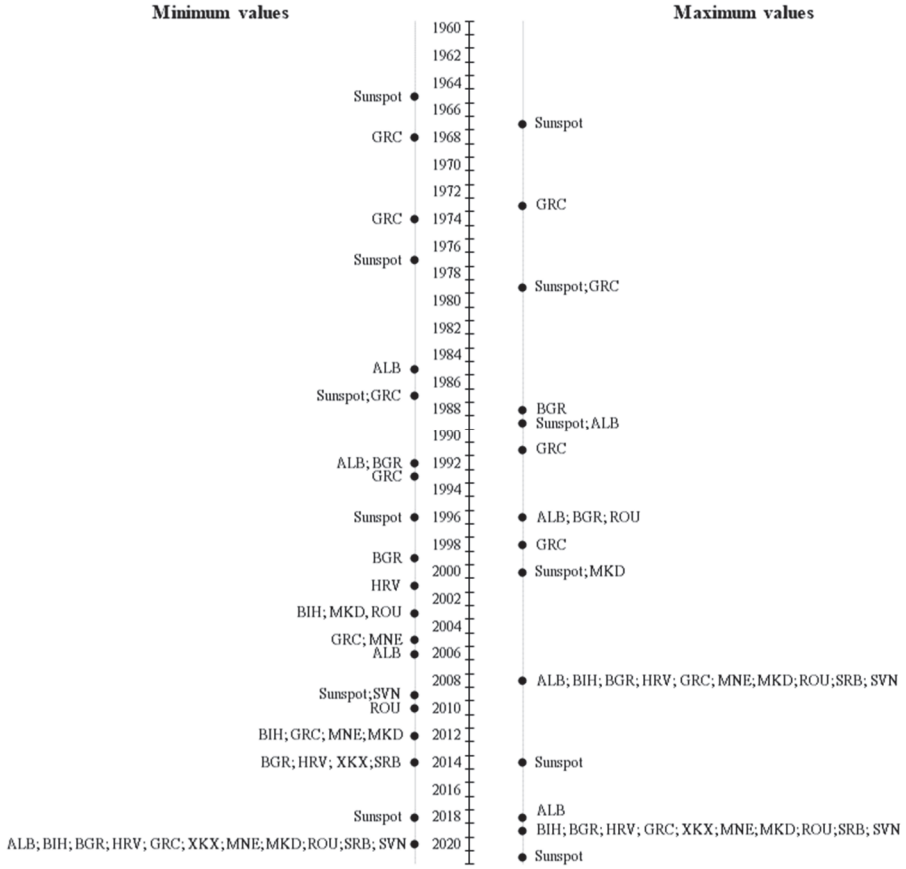
Figure A1. Cyclical component comparison of yearly mean total sunspot number and gross domestic product variables, standardised original values of variables, Hodrick-Prescott filter, Balkan countries





Source: Authors' calculations.

Figure A2. The timeline of occurrence of maximum and minimum values in 11-year periods of gross domestic product and yearly mean total sunspot number variables, cyclical component based on standardised original values of variables, Hodrick-Prescott filter, Balkan countries



Source: Authors' calculations.