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**Sunspots, Unemployment, and Recessions, or
Can the Solar Activity Cycle Shape the Business Cycle?**

Abstract

Over the last 77 years (from 1935), all 7 cyclical maximums of the solar activity overlapped closely with the US recessions, thus predicting (or triggering?) 8 out of 13 recessions officially identified by NBER (including one “double-deep” recession). Over the last 64 years (from 1948), all 6 maximums of the solar activity were preceded by minimums of the US unemployment rate, and the spikes in the unemployment rate followed with lags of 2-3 years. On the world scale, over the last 44 years (for which the data is available), all 4 maximums of the solar activity overlapped with minimums of the unemployment rate in the G7 countries, followed by its spikes within 2-3 years. From 1965, when consistent recession dating is available for all G7 countries, nearly 3/5 of the recessions started in the 3 years around and after the sunspot maximums. Was it a mere coincidence or a part of a broader pattern? This paper explores the correlation between the solar activity cycles (as measured by the number of sunspots on the sun surface) and the timing of recessions in the US and other economies. It finds out that the probability of recessions in G7 countries greatly increased around and after the solar maximums, suggesting that they can cause deterioration in business conditions and trigger recessions. This opens new approach for projecting recessions, which can be applied and tested with regard to the next solar maximum in 2013.

Caution: This research is not in the “mainstream” of the economic thought. Read at your own risk!

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Keywords: unemployment, recession, business cycle, sunspot, solar cycle

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A. Background

This paper revisits empirical evidence and theoretical explanations of the possible link between the business activity cycle in the US and other advanced economies and solar cycles (measured by the number of sunspots on the sun's surface and other indicators of sun activity). Our results confirm that the chances of a recession starting in the US and other advanced economies are much higher in 2-3 years around and after solar maximums, which happen on a cyclical pattern about once in 11 years. Moreover, we found that certain economic indicators that fluctuate with the business cycle have their minimums (or maximums) just before solar maximums and deteriorate shortly after them. Most notably, these include US and entire G7 unemployment rate and composite leading indicators of economic activity, though the results varied in individual country cases. At the same time, we could not find a strong correlation between solar cycles and GDP, the most comprehensive indicator of economic activity. Our results suggest that the hypothesis that the solar activity cycle is somehow linked with the business cycle and, in particular, solar maximums trigger recessions cannot be rejected.

Even though our findings suggest that solar maximums can trigger recessions, there are no conclusive evidences as to how exactly the solar activity can affect economy. Building on the existing literature and empirical results, we can advance a hypothesis of the possible impact. We can presuppose that the peaks in the solar activity somehow affect the people's psychological and even physical conditions, thus influencing their behavior and expectations and inducing shifts in labor productivity and consumer demand. Directly and by affecting other economic variables, these shifts produce the cyclical fluctuations in the economy. The empirical facts presented below are broadly consistent with this hypothesis, but do not prove it directly, thus leaving this question open for future research.

The rest of the paper is organized as follows. Section B outlines the basic facts about the solar cycles and their measurements, and discusses how various types of solar radiation can impact the earth and, ultimately, affect the economic performance. Section C provides a summary of the existing literature on the subject, and, building on it, outlines the theoretical rationale for our research and formulates a few hypotheses about the link between the solar activity and business cycles that can be tested empirically. Section D presents the results of our research, which confirms the link between solar maximums and recessions, but reports little evidence in support of several other hypotheses. Using these results, section E sketches forecasts of economic activity in the US and other advanced economies in the years around the next solar maximum currently projected for May 2013. Section D summarizes key conclusions sets agenda for future research.

B. What Are the Sunspots and Solar Cycles, and How Can they Impact Earth?

Sunspots are temporary phenomena on the photosphere of the Sun that appear visibly as dark spots compared to surrounding regions. They are caused by intense magnetic activity, which inhibits convection, forming areas of reduced surface temperature. In 1610, Galileo Galilei and Thomas Harriot recorded first observations of sunspots by the European astronomers. Continuous daily observations began at the Zurich Observatory in 1849, and the records were extended back to 1610 using earlier observations.

The “international sunspot number” — also known as Wolf number or Zurich number — is calculated by first counting the number of sunspot groups and then the number of individual sunspots. The sunspot number is obtained as the sum of the number of individual sunspots and ten times the number of groups. Since most sunspot groups have, on average, about ten spots, this formula for counting sunspots gives reliable numbers even when the observing conditions are less than ideal and small spots are hard to see.

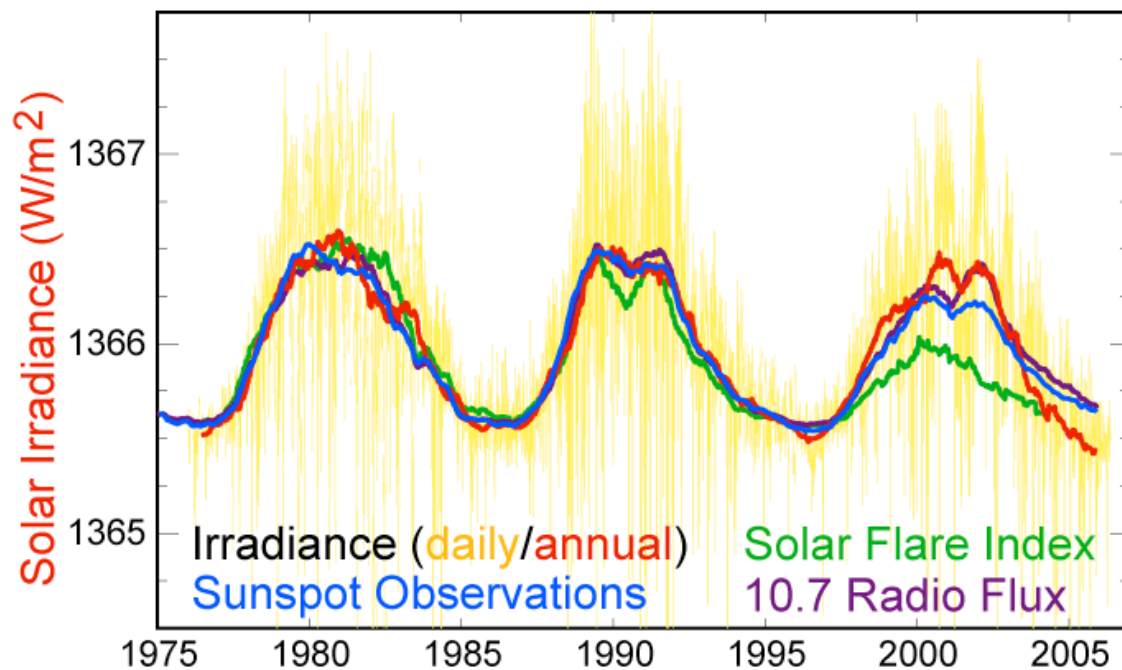
Monthly averages of the sunspot numbers show that the quantity of sunspots visible on the sun fluctuates with an approximate 11-year cycle known as the “solar cycle”, which was first discovered in 1843 by Heinrich Schwabe. Sunspot populations quickly rise and more slowly fall on an irregular cycle of 11 years. Significant variations in the length of this cycle are known over longer spans of time. The cycles are numbered since 1750 (cycle 1 = 1755 minimum to 1766 minimum). Currently, the 24th cycle is unfolding from a minimum in December 2008 towards its projected maximum in May 2013.

In addition to the sunspot number, which remains the primary index of solar activity, many other solar indices have been established and recorded, particularly in recent years. Notably, they include the 2800MHz, 10.7cm radio emission flux, denoted as F10, recorded since 1947. All these indices broadly follow the solar cycle as measured by the sunspot index and reach their maximums around sunspot maximums. During sunspot minimum when sunspot numbers almost reach zero, most of the other indices reach a minimum non-zero level (Kane, 2002).

The degree of variation from minimum to maximum differs widely among these indices, with some of them barely detectable. For example, the total solar irradiance (TSI) measured as the amount of solar radiative energy incident on the Earth's upper atmosphere varies with an amplitude of just about 0.1 percent (and maximum deviations of about 0.3 percent) around its average value of about 1366 W/m² (named the “solar constant”). Variations of this magnitude were undetectable until satellite observations began in late 1978. At the same time, variation of the 10.7cm radio emission flux is broadly comparable to that of sunspot numbers.

Index	Origin	Cyc. 18	19	20	21	22	23
Years of maximum		1946–50	1956–60	1967–71	1978–82	1988–92	1997–01
Years of minimum		1942–45	1952–55	1963–66	1974–77	1984–87	1994–97
Radio emissions	Corona			*	*	*	*
Cor. green line	Corona	*	*	*	*	*	*
Protons	Corona					*	*
X-rays	Corona			*		*	*
F10	Corona	*	*	*	*	*	*
EUV (Pio. Vênus)	Corona				*	*	
EUV (Hinteregg.)	Corona				*		
EUV (SOHO)	Corona						*
UV emissions	Chrom.						*
PSI 6723 Å	Chrom.					*	
Lyman Alpha	Tra.Reg.		*	*	*	*	*
He I 10830 Å	Chrom.				*	*	*
Total Irradiance	Chrom.				*	*	*
Mg II 2800 Å	Chrom.				*	*	*
Solar Flare Index	Chrom.			*	*	*	*
Solar Mag. Field	Surface			*	*	*	*
Sunspot Gr. Area	Surface			*	*	*	*
Cal. II Plage area	Surface	*	*	*	*		
Cal II K Intensity	Surface	*	*	*	*	*	*
Sunspots	Surface	*	*	*	*	*	*

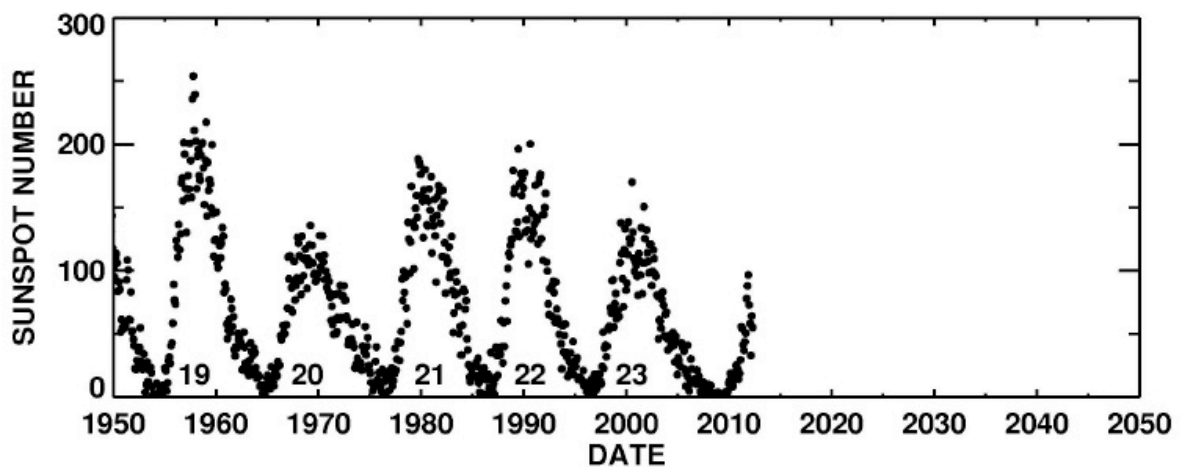
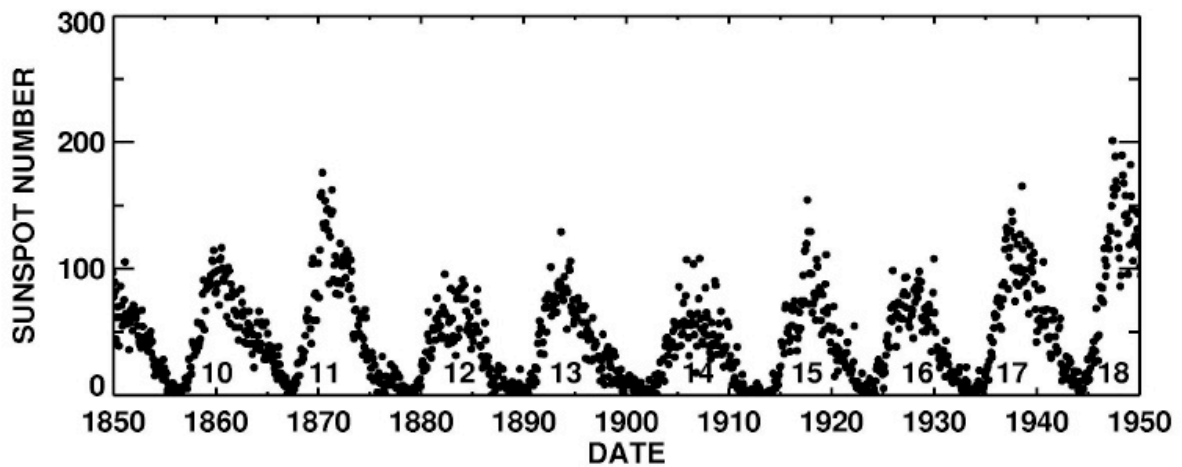
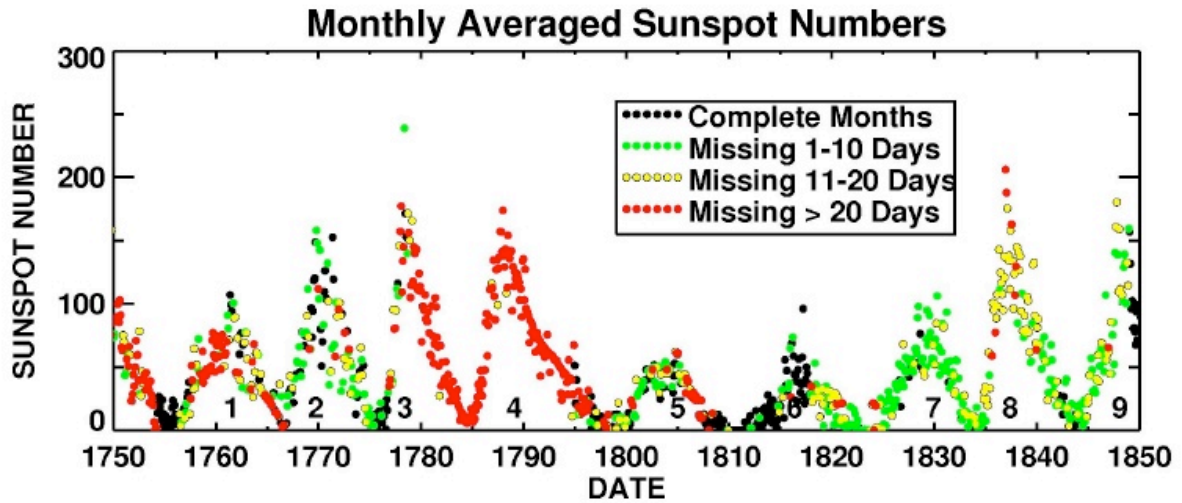
Solar Cycle Variations



Sunspots cycles' statistics is easily available from several respected sources. In this paper, we mostly relied on data from the US National Oceanic and Atmospheric Administration (NOAA) and National Aeronautics and Space Administration (NASA). This includes the monthly data on sunspot numbers as well as dating of cyclical maximums and minimums. According to this data, the length of cycles and their phases varies significantly. For cycles 1-23, the longest recorded length of cycle was 13.6 years, while the shortest was only 9.0 years.

Regarding their direct impact on earth, the fluctuations in the solar activity are mostly known for their "physical" consequences. This includes disrupting telecommunications, causing fluctuations in the earth's magnetic (geomagnetic) field, and even inducing electromagnetic impulses in electric equipment and power lines. In particular, large magnetic storms are most common around the peaks of the sunspot cycle and in the three years after them. Such storms can induce particularly powerful polar lights (auroras), which become visible in much lower latitudes than normal (the usual "aurora zones" are located around north and south poles). Historically, this created the most visible manifestations of solar maximums, which were recorded by ancient human observers well before the telescope was invented.

To sum it up, sunspot numbers provide the longest available and, probably, the most reliable measure of the cyclical fluctuations in the sun activity. This very much justifies using sunspots number in our research as a proxy for studying the correlations of cyclical solar activity and the business cycle on earth.



HATHAWAY/NASA/MSFC 2012/05

Sources: NASA (<http://solarscience.msfc.nasa.gov/SunspotCycle.shtml>), Wikipedia (<http://en.wikipedia.org/wiki/Sunspot>).

MINIMA AND MAXIMA OF SUNSPOT CYCLES (As defined by NOAA)

Sunspot Cycle Number	Year of Min*	Smallest Smoothed Monthly Mean**	Year of Max*	Largest Smoothed Monthly Mean**	Rise to Max (Yrs)	Fall to Min (Yrs)	Cycle Length (Yrs)
-	1610.8	--	1615.5	--	4.7	3.5	8.2
-	1619	--	1626	--	7	8	15
-	1634	--	1639.5	--	5.5	5.5	11
-	1645	--	1649	--	4	6	10
-	1655	--	1660	--	5	6	11
-	1666	--	1675	--	9	4.5	13.5
-	1679.5	--	1685	--	5.5	4.5	10
-	1689.5	--	1693	--	3.5	5	8.5
-	1698	--	1705.5	--	7.5	6.5	14
-	1712	--	1718.2	--	6.2	5.3	11.5
-	1723.5	--	1727.5	--	4	6.5	10.5
-	1734	--	1738.7	--	4.7	6.3	11
-	1745	--	1750.3	92.6	5.3	4.9	10.2
1	1755.2	8.4	1761.5	86.5	6.3	5	11.3
2	1766.5	11.2	1769.7	115.8	3.2	5.8	9
3	1775.5	7.2	1778.4	158.5	2.9	6.3	9.2
4	1784.7	9.5	1788.1	141.2	3.4	10.2	13.6
5	1798.3	3.2	1805.2	49.2	6.9	5.4	12.3
6	1810.6	0	1816.4	48.7	5.8	6.9	12.7
7	1823.3	0.1	1829.9	71.7	6.6	4	10.6
8	1833.9	7.3	1837.2	146.9	3.3	6.3	9.6
9	1843.5	10.5	1848.1	131.6	4.6	7.9	12.5
10	1856	3.2	1860.1	97.9	4.1	7.1	11.2
11	1867.2	5.2	1870.6	140.5	3.4	8.3	11.7
12	1878.9	2.2	1883.9	74.6	5	5.7	10.7
13	1889.6	5	1894.1	87.9	4.5	7.6	12.1
14	1901.7	2.6	1907	64.2	5.3	6.6	11.9
15	1913.6	1.5	1917.6	105.4	4	6	10
16	1923.6	5.6	1928.4	78.1	4.8	5.4	10.2
17	1933.8	3.4	1937.4	119.2	3.6	6.8	10.4
18	1944.2	7.7	1947.5	151.8	3.3	6.8	10.1
19	1954.3	3.4	1957.9	201.3	3.6	7	10.6
20	1964.9	9.6	1968.9	110.6	4	7.6	11.6
21	1976.5	12.2	1979.9	164.5	3.4	6.9	10.3
22	1986.8	12.3	1989.6	158.5	2.8	6.8	9.7
23	1996.4***	8	2000.3***	120.8	4	8.5	12.5
<i>Memorandum: Averages of cycles and their phases</i>							
1-23		6.1		114.1	4.3	6.7	11.0
10-16		3.6		92.7	4.4	6.7	11.1
17-23		8.1		146.7	3.5	7.2	10.7

*When observations permit, a date selected as either a cycle minimum or maximum is based in part on an average of the times extremes are reached in the monthly mean sunspot number, in the smoothed monthly mean sunspot number, and in the monthly mean number of spot groups alone. Two more measures are used at time of sunspot minimum: the number of spotless days and the frequency of occurrence of "old" and "new" cycle spot groups.

**The smoothed monthly mean sunspot number is defined here as the arithmetic average of two sequential 12-month running means of monthly mean numbers.

***May 1996 marks the mathematical minimum of Cycle 23. October 1996 marks the consensus minimum determined by an international group of solar physicists. April 2000 marks the mathematical maximum of Cycle 23. However, several other solar indices (e.g., 10.7 cm solar radio flux) recorded a higher secondary maximum in late 2001.

Source: US National Oceanic and Atmospheric Administration (NOAA); and author's calculations.

C. Literature Survey and Theoretical Rationale of Our Research

Brief literature survey

Probably, the earliest recorded hypothesis about the relation between the solar and business activity appeared in 1801. In a paper presented that year, Sir William Herschel, an astronomer, called attention to an apparent relationship between sunspot activity and the price of wheat (Herschel, 1801). In 1838 and again in 1847, Dr. Hyde Clarke noted an 11-year cycle in trade and speculation and advanced the idea of a physical cause for this regularity (Clarke, 1847).

These hypotheses got serious attention in the 1870s, when British economist and statistician William Stanley Jevons suggested that there was a relationship between sunspots and business cycle crises. He reasoned that sunspots affect Earth's weather, which, in turn, influences crops and, therefore, the economy (Jevons, 1875, 1878). His supporting evidence and calculations were not very convincing, though, and his views did not get much traction.

In 1934, Carlos Garcia-Mata and Felix I. Shaffner revisited the evidence about the links between solar activity and business cycle in the US (Garcia-Mata and Shaffner, 1934). They did not find support for Jevon's theory about cyclical solar activity affecting crops. However, they uncovered a statistically significant correlation between the fluctuations in non-agricultural business activity in the US and the solar cycle.

Meanwhile, Russian scientist Alexander Chizhevsky proposed, in a much more fundamental way, that the entire human history was influenced by the cycles in sunspot activity (Chizhevsky, 1924). He analyzed sunspot records comparing them to riots, revolutions, battles and wars in Russia and seventy-one other countries for the period 500 BC to 1922. He found that a significant percent of what he classified as the most important historical events involving large numbers of people occurred in the three-year periods around sunspot maximums. Chizhevsky proposed to divide the eleven-year solar cycle into four periods: (1) a 3-year period of minimum activity (around the solar minimum) characterized by passivity and autocratic rule; (2) a 2-year period during which people "begin to organize" under new leaders and one theme; (3) a 3-year period (around the solar maximum) of "maximum excitability", revolutions and wars; (4) a 3-year period of gradual decrease in "excitability", until the people are apathetic.

In his subsequent book first published in France in 1938 and issued in Russia only in 1974-76, Chizhevsky claimed that correlations with the solar cycles could be found for a very diverse set of natural developments and human activities (Chizhevsky, 1938). In the book, he compiled a list of as many as 27 of them that allegedly

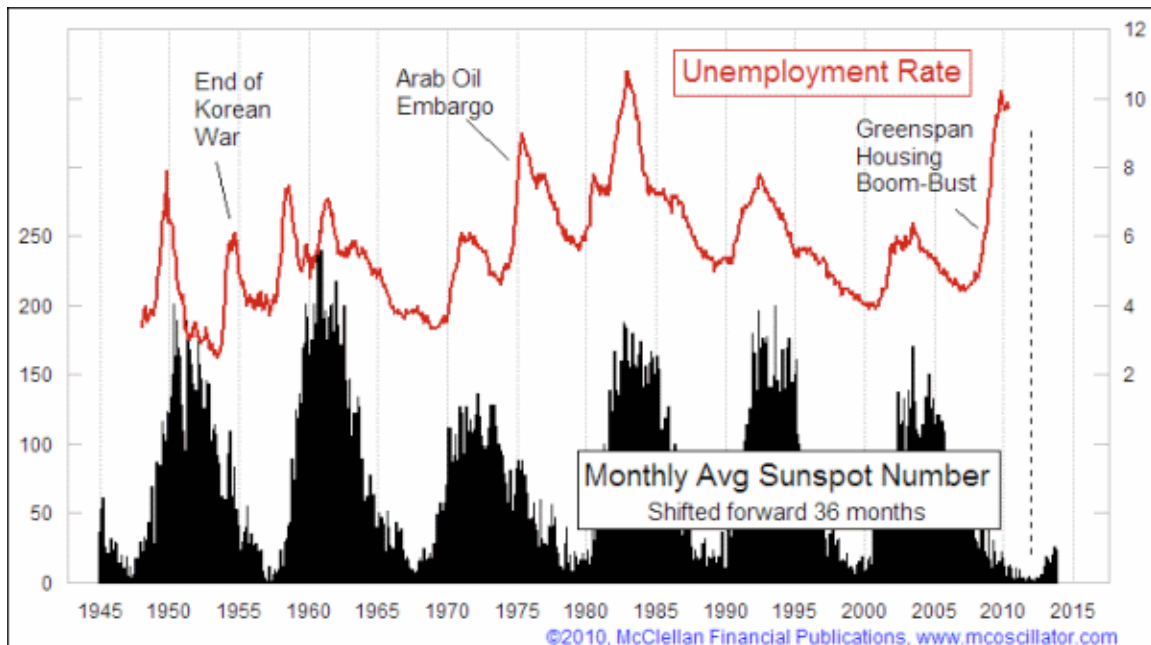
fluctuated with the solar cycle, ranging from crop harvests to epidemic diseases to mortality rates. Chizhevsky presented various quantitative and anecdotal evidences in support of his views. According to his studies, the periods of maximums of the solar activity were generally associated with negative effects, such as lower harvests, proliferation and intensification of diseases (including psychological ones), and higher mortality rates.

In 1968, Edward Dewey reported that cycles of 43 activities fluctuated with the sun's 11-year cycle, including commodity and stock prices, banking and business activity, industrial production and agricultural productivity (Dewey, 1968). He also compiled a comprehensive review of the previous literature on the subject.

In 1993, Bryan Walsh revisited Dewey's findings using the newly available data for the changes in geomagnetic field that broadly followed the solar cycle (as noted in section B above). He claimed that perturbations in the geomagnetic field preceded several common indicators of economic and financial performance (GNP, CPI, stock prices, etc.) by 6 to 12 months, with correlations as high as 65 percent (Walsh, 1993).

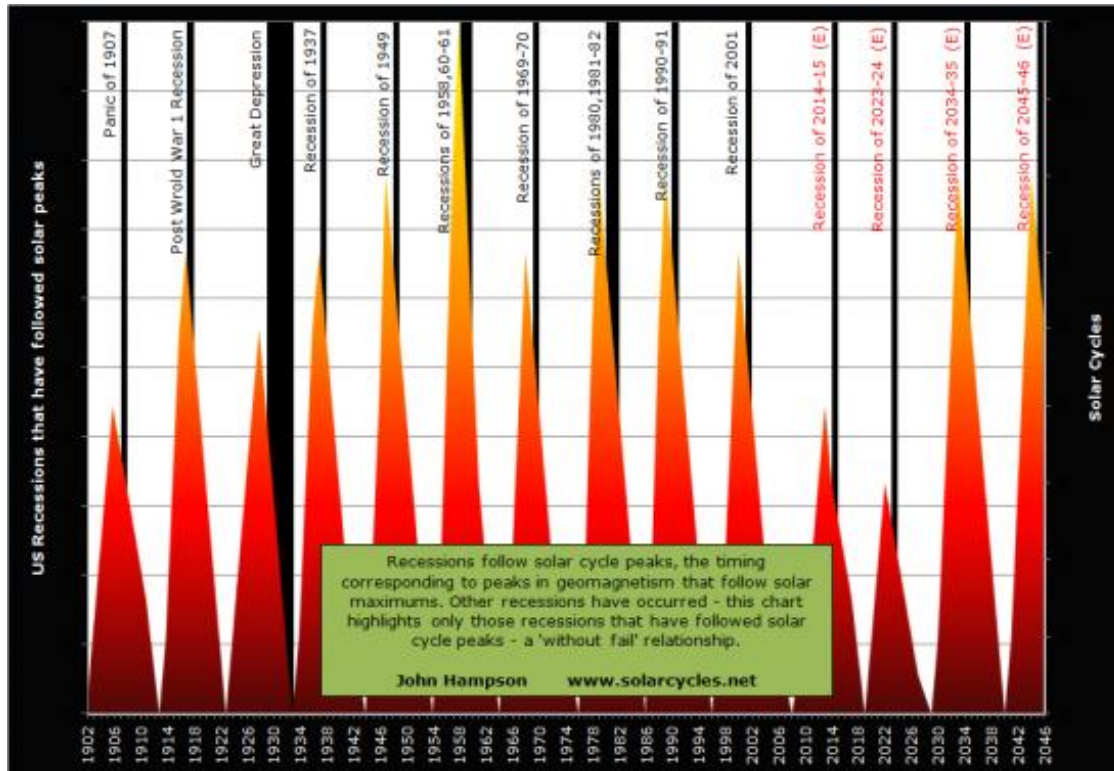
A more recent study claimed that there was a significant negative correlation between sunspot numbers, unemployment rate and suicides in Japan in 1971-2001. Their results prompted the authors to advance the hypothesis that variation of sun activity may affect the economy and the unemployment rate (Otsu et al., 2006).

In 2010, Tom McClellan noted in a short memo that in the postwar period, peaks in the US unemployment rate followed about 3 years after the peaks in sunspot activity (McClellan, 2010). Certainly, there were other peaks in the US unemployment rate during this period, but those could be attributed to policy actions undertaken by the US or foreign governments. For example, in the mid-1970s, the Arab Oil Embargo had a big negative effect on the U.S. economy. And the most recent spike up in the unemployment rate came because the Fed first eased the monetary policy in 2003-04, fueling the housing bubble, and then kept rates too high for too long and brought about the violent collapse of the bubble. According to McClellan, the next bottom in unemployment rate will be around August 2012, 3 years after the sunspot number bottomed in August 2009. Then the natural rise in the sunspot number will have its echo in a natural rise in the unemployment rate.



In 2011, a paper by two Russian scientists reported that from 1968, the cyclical fluctuations of the banking interest rate (“prime-rate”) closely followed the solar activity cycle (Poluyakhtov and Belkin, 2011). In their other paper, those scientists reported a close correlation of the US and global GDP with the solar cycles. This correlation led the authors to forecast new global economic crises in 2013-14 (after the next solar maximum) and in 2018-19 (before the next solar minimum).

In early 2012, John Hampson wrote in an unpublished mimeo that “the period of rising solar activity (sunspots) into and around the solar maximum correlates positively with economic growth, inflation and risk-asset returns. What links these is risk-taking, spending and investing, or in other words, human excitability, which leads us back to Chizhevsky’s work. According to his studies, the period of declining sunspots after the solar maximum was one of change from activity to apathy. Perhaps appropriately, as the money stops circulating in the economy, this is typically a time of recession. Recessions [in the US economy] follow solar cycle peaks, corresponding to the peaks in geomagnetism that lag solar maximums” (Hampson, 2012). Other recessions not related to solar maximums have occurred as well, but once we focus on those that have followed solar peaks, we get a “without fail” relationship. Each solar maximum was closely followed by a recession in the US since the 1900s. Extending this trend into the future, the author forecasted the US recessions in 2014-15, 2023-24, 2034-35, and even 2045-46.



Theoretical rationale

After studies of the subject spanning for more than 140 years, why there is still no convincing and generally accepted evidence of the solar activity influencing business cycle on Earth? Apart from the apparent possibility that there is no such influence, there may be several reasons. First, in the early years of studies, shortage of long-term high-frequency data hindered statistical analysis of causality. Second, the data were affected by multitude of both economic and political shocks (including wars) that had nothing to do with the very fundamental impact of solar activity. This is very much illustrated by high frequency of NBER recessions for 1854-1933 (discussed below). Third, these local shocks could be easily misinterpreted as reflecting some influence of the sun activity, thus leading to proliferation of hypotheses about its impact on crops and stock market. These hypotheses disproved by subsequent data very much discredited the very idea of looking for fundamental correlations between solar activity and the business cycle.

The positive changes of the last decades have greatly increased the opportunities for inquiries into the fundamental factors of the business cycles. First, we have the long-term data of high quality, and computers and software to analyze them. Second, the recent data for the US and other major economies, at least the data since the World War II, are much less distorted by isolated local shocks. Third, globalization and trade integration have led to convergence of the local business cycles towards what

could be considered as the global business cycle, which reduced the impact of local events even more. These developments imply that if there is indeed a correlation between the solar activity and business cycle, it should be most visible in the more recent economic data and wane somewhat when we look deeper into the history using the available data series.

By themselves, sunspots are just somewhat darker areas on the sun surface, which are not visible from the earth without special equipment. However, their appearance is a sign of changes in the underlying processes on the sun that affect the earth. The early works of Chizhevsky and other scientists suggested that these processes could impact not only the physical conditions on the earth (like sun storms triggering magnetic storms disrupting telecommunications), but also affect human behavior. The latter can lead to changes in economic conditions, including labor productivity, consumer tastes, expectations, and unemployment. The exact mechanism of this impact of the sun activity on the human behavior is not yet known (and, well, we have to admit the possibility that there is no such impact). However, we can still look for the likely signs of this impact in the available economic data.

What can we test with the economic data?

Starting with the oldest and most fundamental of the hypotheses summarized above, we can look for correlations between solar cycles and agricultural prices and output. In a more fundamental way, we can check correlation between cyclical solar activity and the time series for average temperatures or rainfalls on earth.

Second, we can compare solar cycles with fluctuations in GDP, which is the most comprehensible measure of the economic activity.

Third, we can compare cyclical solar activity with unemployment rates.

Fourth, we can look whether the recessions in the US and other economies occurred more often around solar maximums. For this, we can use recession timing as determined by the National Bureau of Economic Research (NBER) for the US and by the Economic Cycle Research Institute (ECRI) for other countries. Also, we can use Aruoba-Diebold-Scotti (ADS) business conditions index for the US and composite leading indicators (CLIs) compiled by OECD staff for all advanced economies. Both ADS and CLIs were designed to measure real business conditions at high frequency. Moreover, according to OECD, CLI was specifically geared to display “a reasonably consistent leading relationship with the reference series for the macroeconomic cycle in a country. Thus, CLI can be used to give an early indication of turning points in the reference series.”

We can start by running the tests for the US economy, but in case of positive results, we would need to verify them with the data for other advanced economies and for G7, OECD or world economy in general, where such data are available.

Indeed, there are several reasons to believe that if a relation between solar cycle and economy exists, it should be most easily discoverable in the data for the US economy. First, US have a large advanced economy, where temporary or local shocks would have less of an impact on the aggregate data. Second, the US were largely insulated from wars that ravaged other industrial countries and thus distorted their economic time series. The last major military conflict on the US soil was the Civil War in 1861-85. And in the First and Second World Wars that devastated Europe and Asia, famously, no single enemy shell or bomb dropped on the continental part of the US. Third, high frequency long-term data series for the US are of high quality and easily available, which simplifies research and makes it easier to verify results.

However, we consider that any positive results obtained for the US should be verified against the similar data series for other economies. Indeed, the links that we are trying to uncover should be so global in their nature that once they are found to work in the US economy, it is quite reasonable to expect them to manifest themselves in other countries as well. Alternatively, a good explanation must be provided why the discovered effects are country-specific.

Finally, which data series should we use for representing solar cycles? As we discussed in Section B above, the sunspot numbers remains the best series approximating cyclical changes in the solar activity, and we will use it consistently in this paper.

D. The Empirical Results of Comparing the Solar and Economic Activity

Agriculture and sunspots

We have found no strong link between sunspot numbers and agricultural output or prices in the US. We looked for correlations between the US total agricultural output and sunspots in the post-war period, and between agricultural prices paid to the US farmers and sunspots, but could not find a strong link between them.

Moreover, we looked at the correlations between solar cycles and climate fluctuations, which, allegedly, were behind the solar impact on agriculture. We checked the correlations between sunspot cycles and average monthly temperatures on earth, but could not find a meaningful link. Hence, the fundamental rationale for the old hypothesis about solar cycles affecting harvest through cyclical climate fluctuations does not seem to be consistent with the data.

Broadening the view of the subject, there is an intense debate on whether the long-term trends in solar activity are behind the climate changes on the earth. However, this discussion largely concerns long-term trends of 100-200 years or longer. From what we know about the subject, this discussion has not led to conclusions that the 11-year solar cycles induced climate fluctuations on earth.

GDP and sunspots

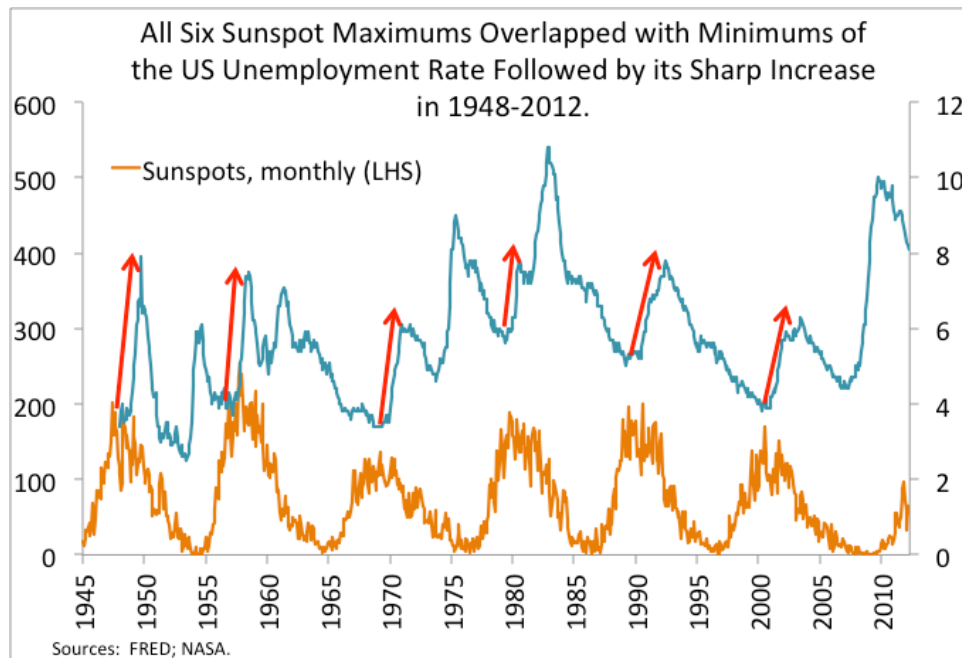
We found only a weak correlation between GDP data and sunspots, for the US economy for advanced economies in general. For the US, we used the quarterly seasonally adjusted series starting from 1948. For them, we calculated quarterly and annual growth rates, and deviations from long-term trend obtained by applying Hodrick–Prescott (HP) filter to the original series. Furthermore, we applied 9-quarter moving average to these GDP series and to the sunspots numbers, to eliminate the noise and impact of short-term shocks that could have obscured the 11-year cycle in data. In all cases, we got a weak correlation of the GDP series with the sunspot series, which did not appear statistically significant. Indeed, the GDP growth was slower in the years around the sunspot maximum than in the years on the “slopes” of the sunspot cycle. However, the difference between the average GDP growth rates in these periods did not appear statistically significant.

For the growth in advanced economies, we used the consolidated quarterly data series compiled by the International Monetary Fund (IMF) for the World Economic Outlook (WEO). Again, we calculated quarterly and annual growth rates, and deviations from the long-term trend obtained with the HP filter, and smoothed the

data with 9-quarter moving average. Here too, we did not see strong enough correlation with the sunspot numbers. And again, we spotted lower GDP growth in the years around sunspot maximums, but the difference with the years on the “slopes” of the cycle was not statistically significant.

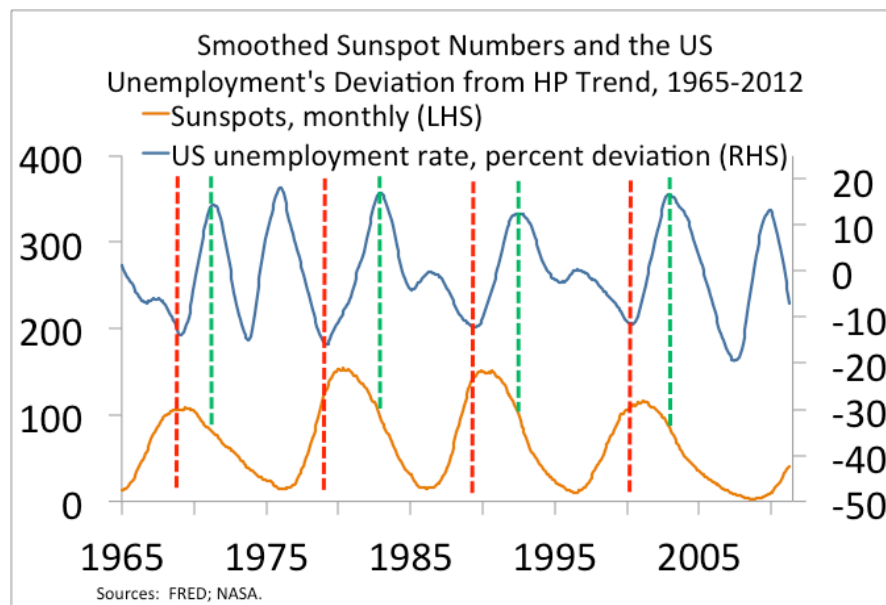
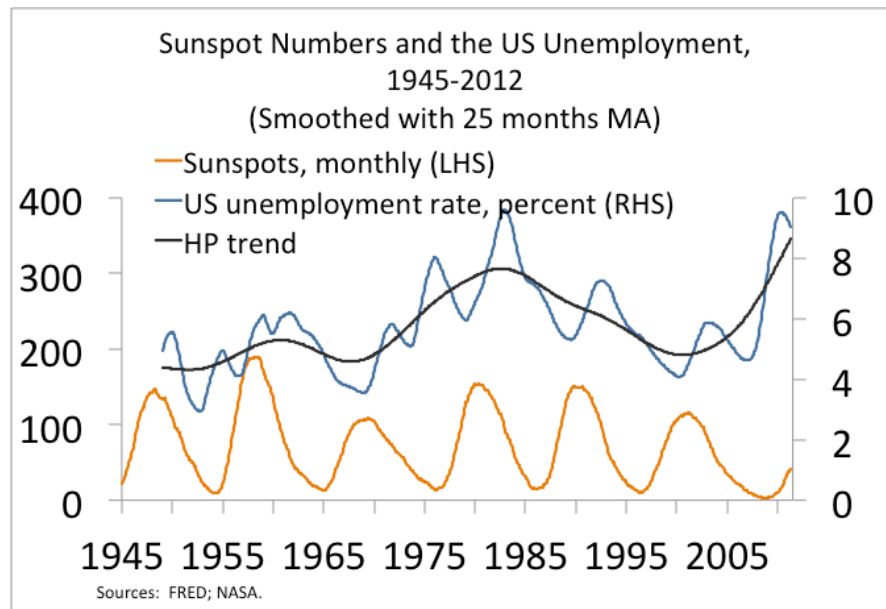
Unemployment rate and sunspots

For the US, we can confirm the existence of visually fascinating concordance between the unemployment rate and sunspot numbers. The monthly US unemployment data is available from 1948 till now. In the 64 years from 1948 to 2012, all 6 periods of sunspot maximums overlapped with minimums of the US unemployment rate. Moreover, each time the dynamics of unemployment changed from the declining trend to a rapid increase, with the unemployment rate peaking 2-3 years after the sunspot maximums.



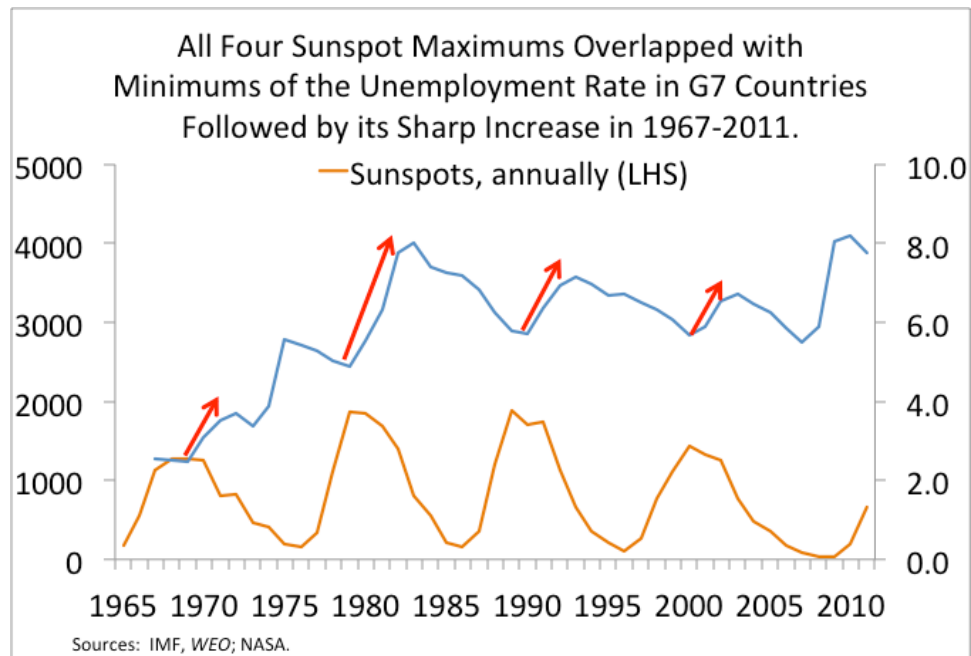
Looking deeper into the data, we searched for a stable relation between unemployment and sunspot numbers. For this, we removed the long-term trend from the unemployment rate using HP filter and smoothed the data with 25-month moving average. The resulting unemployment series seemed to exhibit two highly regular patterns between the peaks of solar cycles, which were particularly visible for the period from 1965-2012. In two cases over these years, the de-trended and smoothed unemployment increased after a sunspot maximum, then declined significantly by the period of sunspot minimum, only to rise again after it and decline again before the sunspot maximum. In two other cases, the unemployment increased after a sunspot maximum, and then remained on a declining trend towards the next sunspot maximum, which was only temporary interrupted around

the sunspot minimum. The common in both cases was that the unemployment bottomed out just before a solar maximum and reached its peak in 2-3 years later. In so far, our research has not revealed the reasons why the US unemployment rate would follow one of these two different patterns between the solar cycles. While the resulting chart looks fascinating, we cannot be sure at this point whether it reflects a genuine stable relation or an interesting coincidence.



On the world scale, the available data also confirm the remarkable concordance between the solar cycles and unemployment. Regrettably, we could not find monthly or quarterly long-term data for the world unemployment. Consolidated annual unemployment data for G7 countries the period of 1967-2011 are available

from the IMF WEO database. Over this period, all 4 maximums of the solar activity overlapped with minimums of the unemployment rate in the G7 countries. And just as in the US, spikes in unemployment followed within 2-3 years (Figure 3).



Our attempts to find the same concordance between unemployment and sunspots for all G7 economies yielded mixed results. On the one hand, the data for Canada revealed very much the same concordance as we have documented for the US. On the other hand, the long-term monthly data for Japan did not confirm the existence of such concordance. In fact, volatility of unemployment in Japan was remarkably low for many years, and this began to change only in the last 30 years or so. And the available data for the European G7 economies indicated a weak link between sunspots and unemployment. Attempts to confirm it with higher significance were hindered by lack of uniform unemployment data for all these countries. For example, the available data for the UK suggested that unemployment rate bottomed out before the sunspot maximum and increases sharply after it. However, the relatively short data span covering just two solar cycles did not allow claiming that this was a reliable pattern rather than just an interesting coincidence.

Generally speaking, why would there be a strong concordance between the unemployment and sunspots in the US, rather weak signs of it in the European G7 economies, and no clear link in Japan? The easiest would be to say that the concordance in the US, however fascinating, is just a coincidence. Then one can speculate that the similar relation in Canada is a result of a close proximity between the business cycles and labor market conditions in the two countries. Links between the Europe, Japan and US are much weaker (though significant), hence, we have even weaker or negligible signs of the link between their unemployment and sunspots.

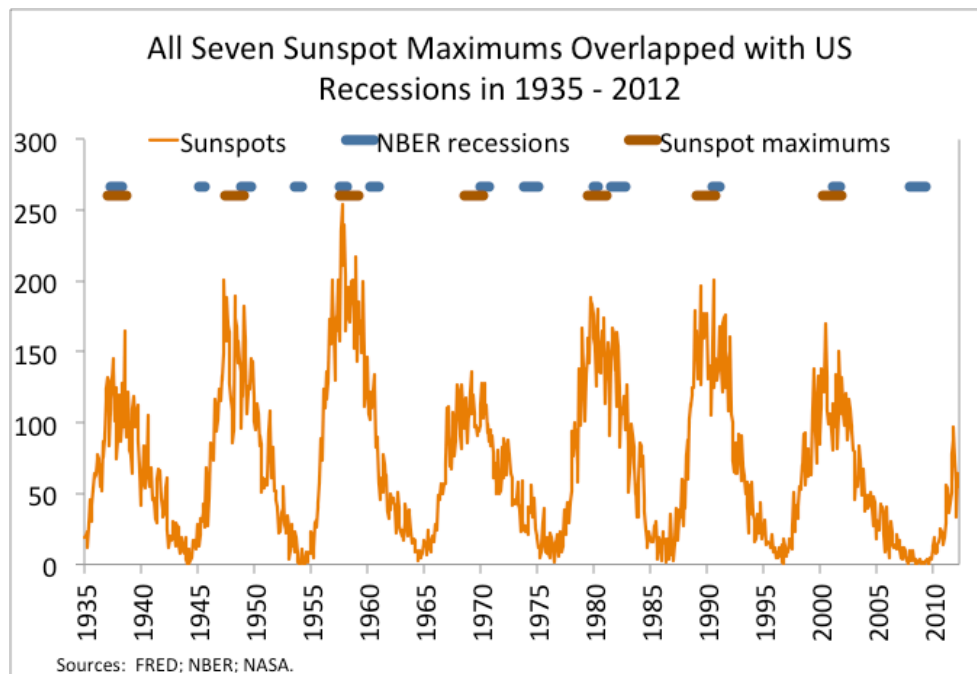
However, let's assume for a moment that the concordance between the unemployment rate in the US and sunspots is not entirely coincidental. In this case, why the same link is not so strong in Europe or Japan? Probably, the answer would be in the historical differences in the labor market practices in the G7 countries. The US labor market is the least regulated, which allows the greatest flexibility in hiring and firing decisions. On the contrary, Japanese corporations for a long time relied on the life-time employment, and did not fire people even in difficult times. This very much explains the absence of large fluctuations in the Japanese unemployment rate for many years in the post-war period. However, this practice has been phased out under the pressure from the international competition and following "westernization" of Japanese society. This opened the way for much wider variation in unemployment rate in the last 20 years. In the same vein, labor market rigidities could have suppressed the unemployment fluctuations in Europe, thus weakening the possible correlation with the sunspots. And again, labor market reforms have raised labor mobility and allowed wider fluctuations in unemployment in the recent years. However, the "recent" data that reflect higher fluctuations in unemployment rate in Japan and, to some extent, in Europe are just not long enough to confirm a robust link between the unemployment and sunspots.

Recessions and sunspots

Fascinating coincidence?

Our data confirm that, indeed, for a long period of time, sunspot maximums overlapped closely with the US recessions. Over the last 77 years, all 7 periods of sunspot maximums overlapped with a recession. In two cases, they overlapped closely with two recessions that occurred with short intervals. Apparently, the sunspot maximums predicted 8 or 9 out of 13 recessions identified by NBER over 1935-2012. However, historical data for XIX century suggest that it was not exactly a "without fail" relation, as we discuss below.

What about the remaining 4 recessions that occurred in 1935-2012, including the Great Recession of 2008-09? The brief recession of 1945 was likely caused by reduction of the US government supply and military orders in the end of the WWII. And the similar causes likely triggered the recession of 1953-54 after the end of Korean War (historically, the recessions quite often happened after the end of major wars). The painful recession of 1974-75 was caused by the oil price shock. And the Great Recession of 2008-09 was triggered by the collapse of sub-prime lending in the US, which exposed massive overvaluation of the housing stock and flaws in mortgage lending and securitization practices.



In other words, for those 4 recessions that happened in “irregular” times between solar maximums, we can easily name strong and largely exogenous factors that caused them. This supports the attempts to classify the US recessions into those related to solar maximums and others, caused by exogenous shocks. That said, the economists who follow the US economy closely could name specific factors that triggered those 9 recessions that overlapped with solar maximums. For example, the “dot.com” bust preceded the recession of 2001, and Volcker’s Fed anti-inflation policy tightening bias probably contributed to the double-deep recession of 1980-81.

An historical perspective

The precise monthly dating of the US recession is available from NBER starting from mid-XIX century (from December 1854, to be exact). With regard to the recession length and frequency, the entire period of 1854-2012 can be broadly divided into “before” and “after” the Great Depression of 1929-33. In the time up to and including the Great Depression, the recessions occurred more frequently and lasted much longer (actually, about twice as longer!) as in the period after it. Consequently, the US economy spent nearly half the time (exactly, 46.4 percent) in recession in 1856-1933 (corresponding to solar cycles 10 to 16). This compares to only 15 percent in recession in 1933-2008 (solar cycles 17-23). Apparently, a structural break in recession data occurred with the Great Depression.

Recessions in 1856-2008
(Before and after the Great Depression of 1929-33)

Time period	Jan 1856 - Oct 1933	Nov 1933 - Nov 2008
Months, total	934	901
Corresponding solar cycles	10 to 16	17 to 23
Recession starts	20	13
Total recession length, months	433	136
Average recession length, months	21.7	10.5
Time in recession, percent of total	46.4	15.1

Source: NBER; and author's calculations.

And why would the Great Depression lead to a “structural break” in recessions? Most notably, it exposed the dangers of deep and prolonged recessions, which prompted powerful shifts in government policies and regulation. They were explicitly geared towards minimizing the chances of recessions and alleviating and shortening them as much as possible. This involved a significant increase of the role of the US government in economic life. In practice, it meant that many random shocks, such as bank runs or stock market crashes, were either pre-empted (e.g., through timely bank resolution) or no longer resulted in economy-wide recessions. And if the recession happened, after all, the government rushed to apply powerful economic stimulus to re-start the growth as quickly as possible. This was not the case in the XIX century.

On top of it, there were significant shifts in economic structure and social and political life that helped reduce the occurrence of recessions after WWII. First, falling share of agriculture in the economy and progress of agricultural technologies have greatly reduced the impact of weather-related shocks. Second, the occurrence of military conflicts and civil disorders has declined markedly after the end of WWII, at least in the advanced economies. These developments have curtailed the impact of “random exogenous shocks” on the economy and, naturally, reduced the occurrence and severity of recessions triggered by them.

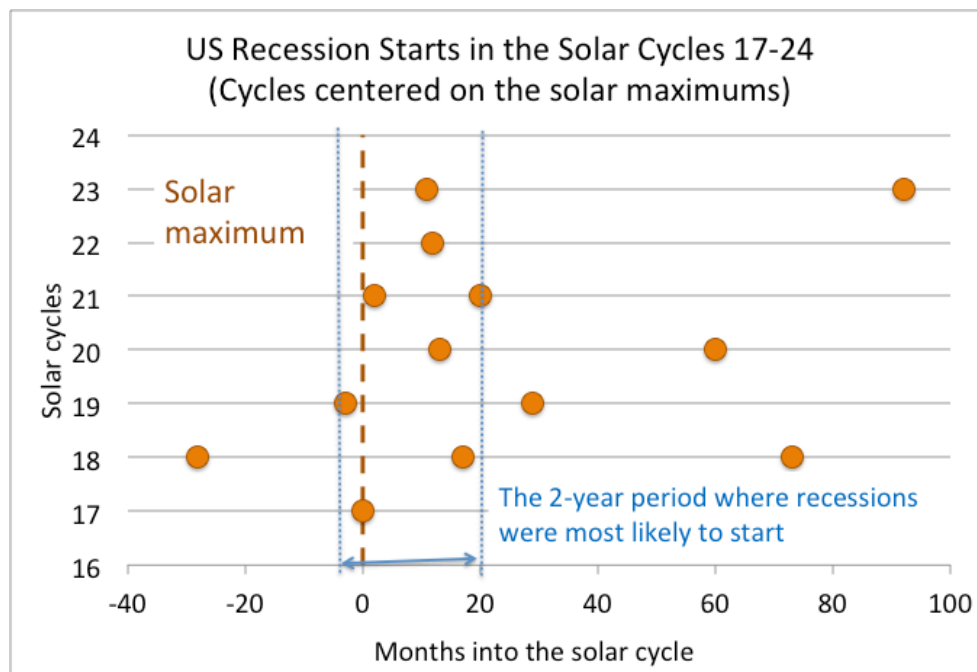
For the purposes of our study, this warrants a separate consideration of the periods of before and including the Great Depression (1854-1933) and after it (starting from 1934 or 1935). Moreover, we can conveniently assume that whatever correlations between the economic activity and solar cycles we can find, they should be most visible in the more recent data, starting after WWII or even from 1960s.

Comparing US recessions across solar cycles

To compare the data, we will re-stack the time series pertaining to various solar cycles so that the maximums points of the solar cycles would overlap. This is the same approach that Chizhevsky applied in his books. Also, this is very much in line with the common way of analyzing co-movements in business and other cycles, when the data points belonging to the same phases of the cycles are compared. This

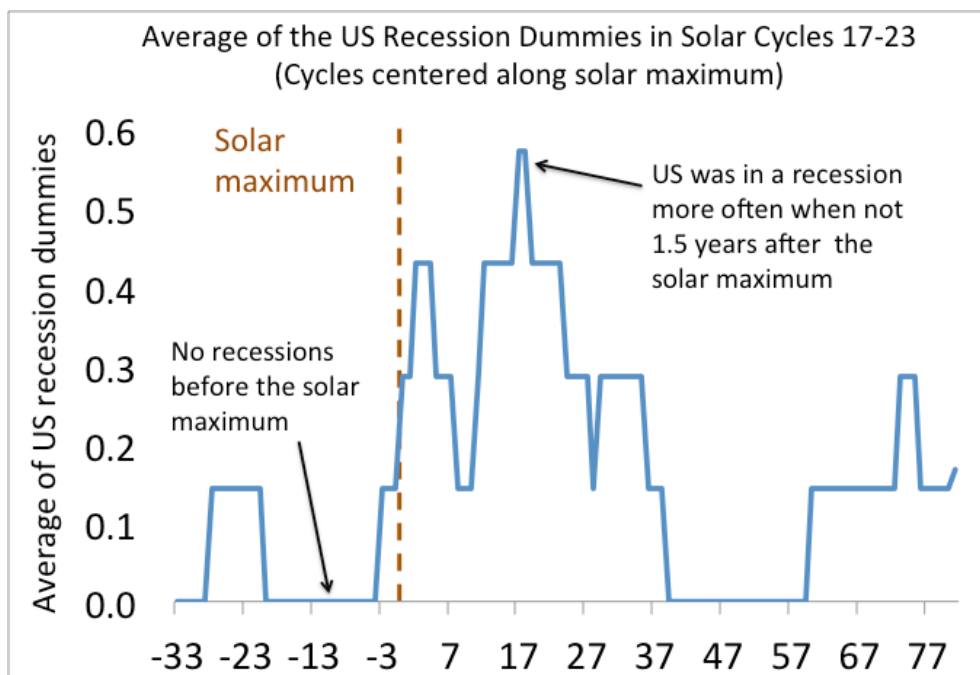
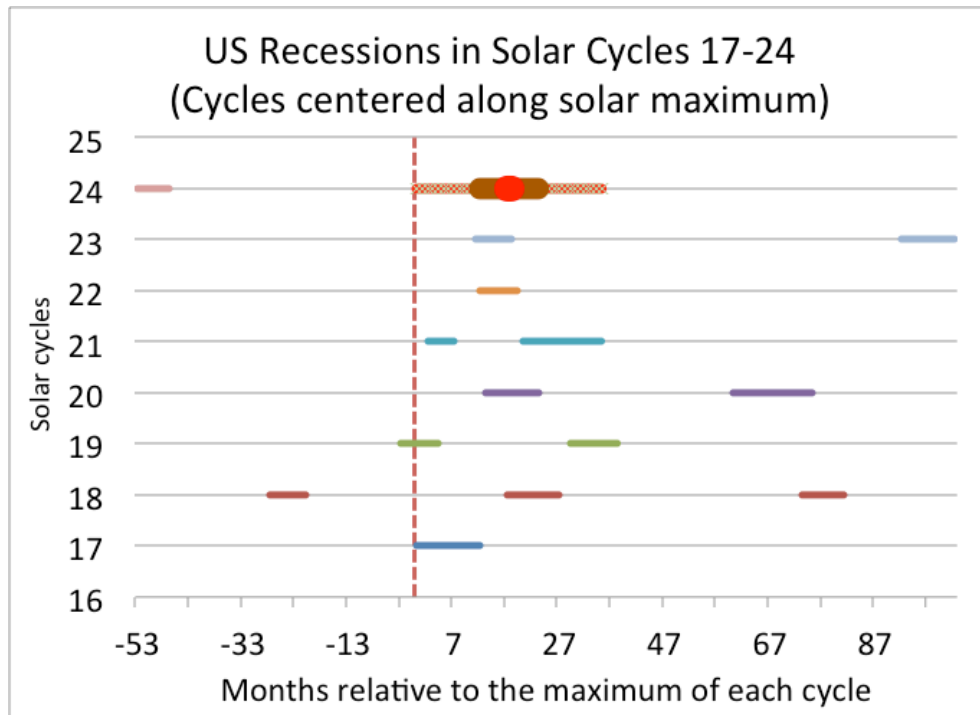
approach would highlight what happens around the solar maximums. At the same time, because of varying length of the solar cycles, the picture can be somewhat distorted at the beginning and end of the cycles (corresponding to periods around solar minimums). As argued above, we are going to look separately at solar cycles 10 to 16 (corresponding to 1856-1933) and cycles from 17 to 23 and to the currently unfolding 24th cycle.

For 1934-2012, our analysis confirms that the US recessions occurred in the months around and after the solar maximums much more often than in other periods. Out of 13 recessions in this period, 8 started in the 2 years around solar maximums, counting from 3 months before until 20 months after them. More precisely, 8 recessions started within 168 months in this period. This compares with only 1 recession start in 274 months in the “ascending” phases (from solar minimum towards solar maximum) of solar cycles 17-23. And with only 4 recession starts in the “descending” phases of those cycles covering 459 months.



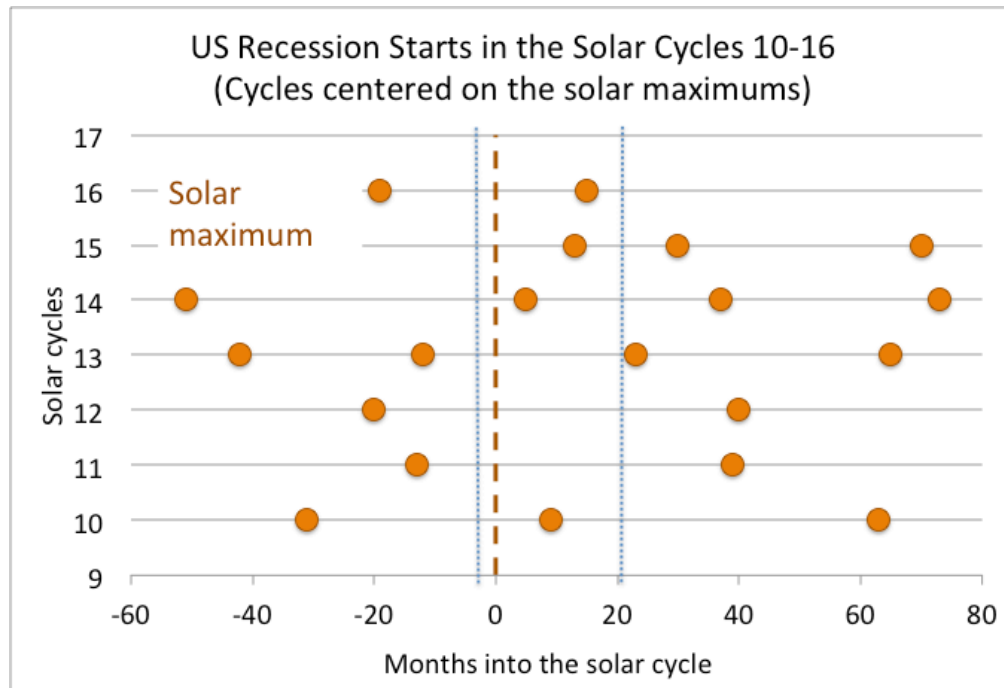
Also, our results highlight that the US economy was most likely to be in recession in about 3 years after the solar maximums (out of 10.7 years of the average length of the cycles 17-23). To calculate the ex-post probability of the recession, we averaged the NBER recession dummies over solar cycles 17-23 (with “1” standing for recession months and “0” for no recession). It turned out that in 36 months including and after the month of the solar maximums, this “recession” indicator averaged 0.34 (in other words, the US economy was in recession about 1/3 of this time). Moreover, in about 1 year in the middle of this range, from 12th to 24th months after the solar maximums, the “recession” indicator averaged 0.44. And even more so, in the very middle of this range, exactly 1½ years after the solar maximums, there were two months when the “recession” indicator averaged 0.57. In

other words, the US economy was more likely than not to be in recession exactly $1\frac{1}{2}$ years after a solar maximum. To be precise, in the 7 solar cycles under consideration (17 to 23), in 4 cycles the US economy was in a recession $1\frac{1}{2}$ years after a solar maximum.

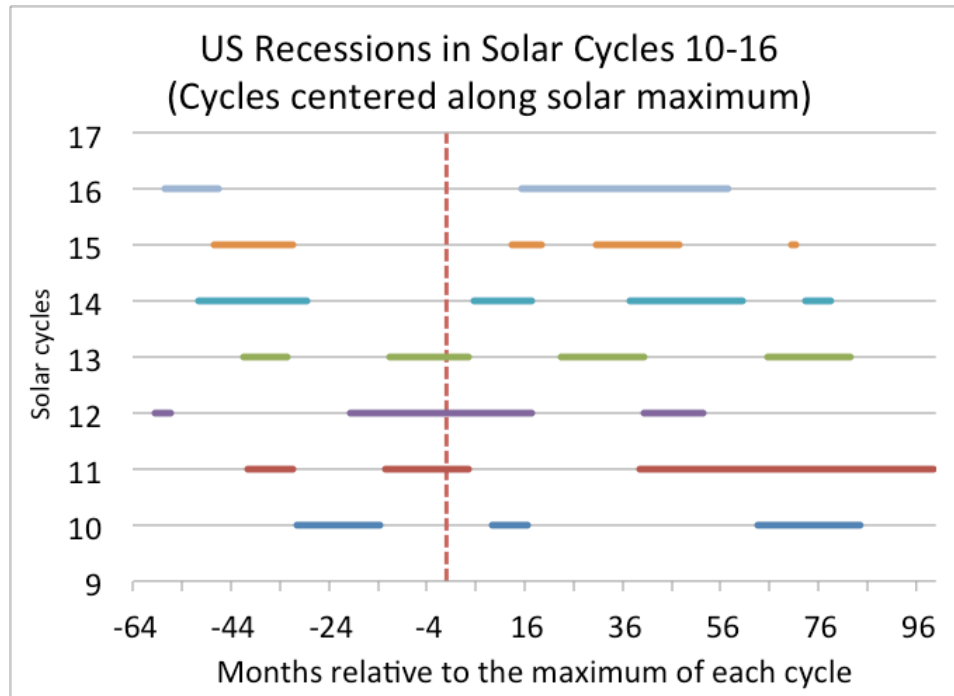


For the period of 1856-1933, however, there was not that robust link between solar maximums and recessions. The “without fail” relationship between solar maximums

and US recessions could be traced back only to the solar cycle 14, when the recession of 1907-08 started just 5 months after a solar maximum. Probably, we can confirm it even for the solar cycle 13, counting the recession of 1896-97 that started 23 months after a solar maximum. However, it apparently did not work for the solar cycles 11 and 12, but worked again in solar cycle 10. And what is even more important, there were many other recessions in 1856-1933 outside the years after the solar maximums. Certainly, for this time span we can select another 2-year period in a different phase of the solar cycle that would cover even more recession starts than the months around solar maximums.



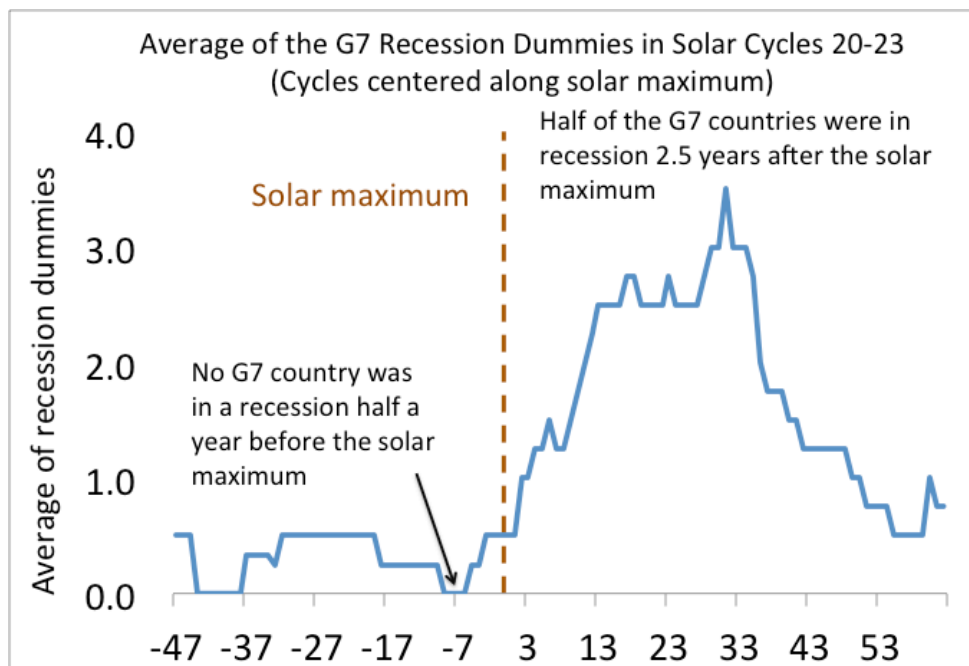
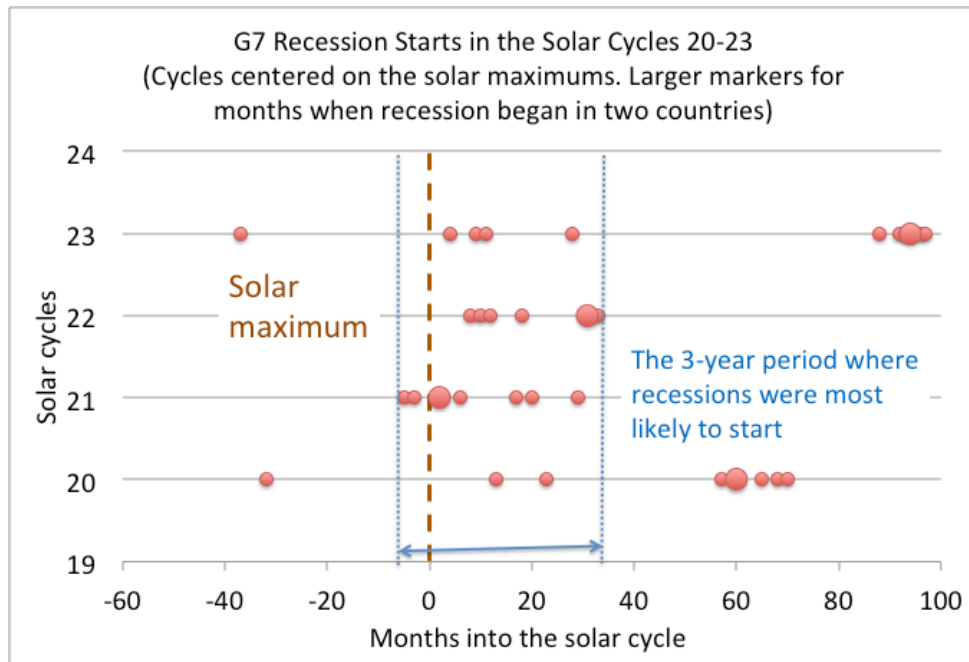
In 1856-1933, in every solar cycle the US economy was always in a recession for at least a few months in the 3 years after the solar maximum. However, it does not come as a big surprise, given frequency and length of recessions at that time. According to NBER, the US economy spent nearly half the time in recessions in 1854-1933. This made it hard to select a 3-year window in any phase of the solar cycle when the US was not in a recession. Consequently, the average "recession" indicator (calculated as average of the NBER recession dummies) for 3 years after solar maximums did not deviate substantially from its values for other phases of the solar cycle.



Comparing G7 recessions across solar cycles

For the G7 countries, we found that from 1965, the recessions occurred much more often in the years after sunspot maximums. In the period from 5 months before solar maximum till 33 months after it (covering 156 months), 21 recessions started in the G7 countries, out of the total of 36 recession starts in 1965-2008. This compares with only 2 recession starts in 149 months in the “ascending” phases (from solar minimum towards solar maximum) of solar cycles 20-23. And with 13 recessions starts in the “descending” phases of those cycles covering 223 months.

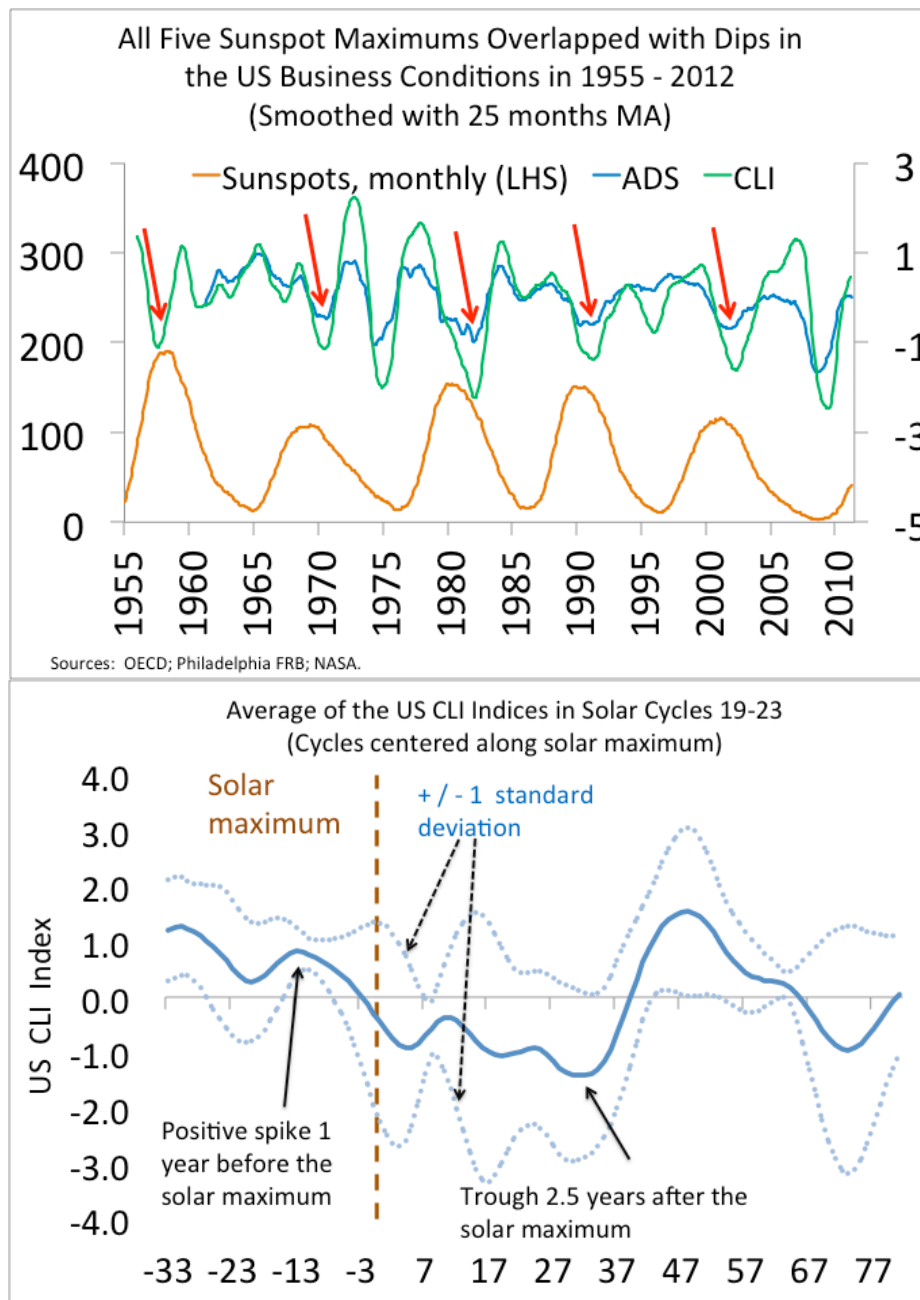
In 1965-2008, no G7 country was in a recession half a year before solar maximums. From this point, the average of the recession dummies for G7 countries increases steadily until about 3 years after the solar maximum, when about half of the G7 countries were in a recession. Computed for 7 countries, the values of this indicator would range from “0” (no country is in recession in that month in all 4 solar cycles, as half a year before the sunspot maximum), till “7” (if all 7 countries were in recession).

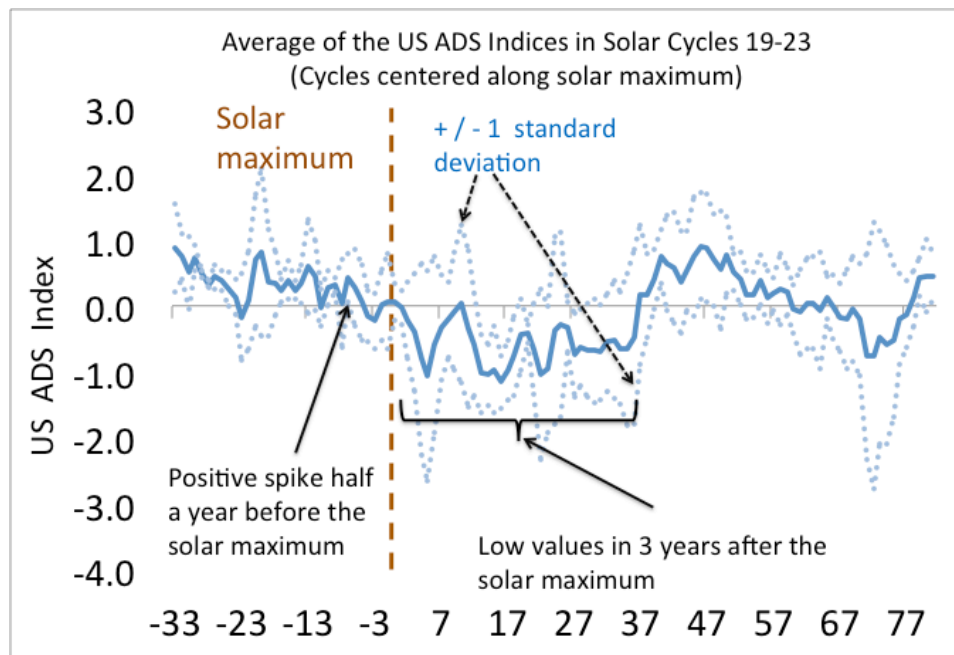


Regrettably, consistent monthly dating of the US and G7 recessions is available only from 1966. For this study, we relied on NBER dating for the US available from end-1854, and ECRI dating for other G7 countries. We had to assume that there were no recessions in Germany in 1965, to extend the ECRI data for this country and have the data set for all G7 countries starting in 1965, at the beginning of solar cycle 10.

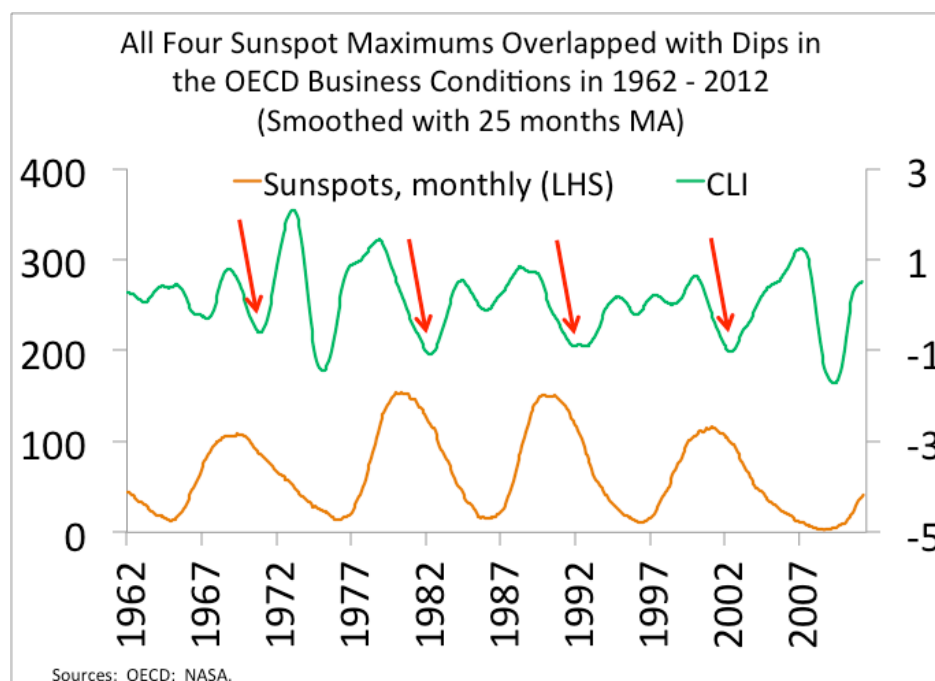
Comparing CLI and ADS indicators across solar cycles

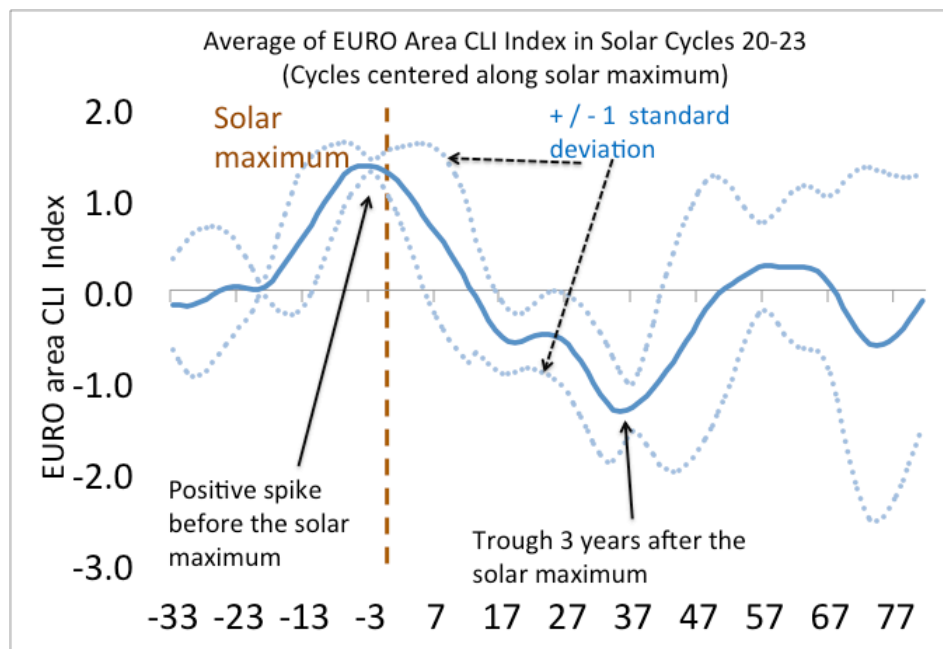
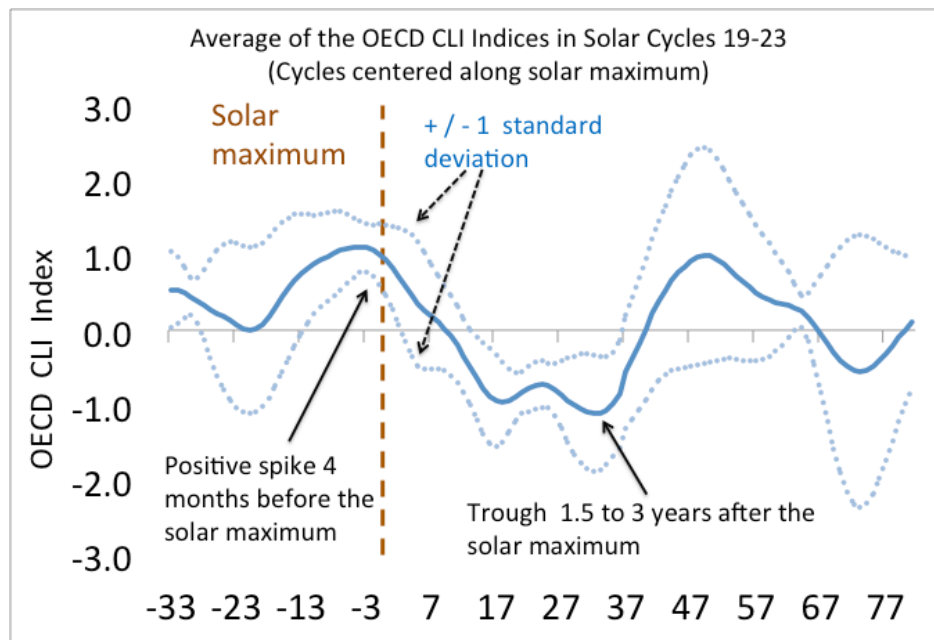
According to our results, CLI indices for all G7 countries and ADS indicator for the US generally reached their maximums before solar maximums and declined to their troughs in years after it. For the US, the pictures presented by CLI and ADS indices look broadly consistent, though CLI values exhibited higher variation. CLI was available starting from an earlier date (from 1955), which increased its value for our study. Both indicators declined after sunspot maximums. In 1955-2012, all five solar maximums overlapped with dips in the CLI index (and four maximums overlapped with dips in ADS, for which the data began only in 1960).



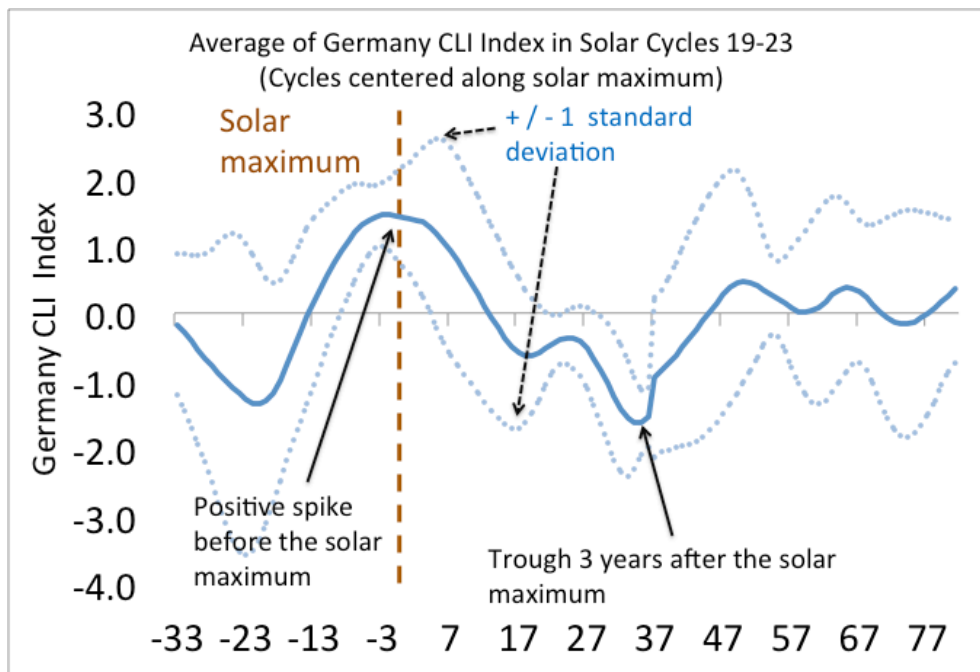
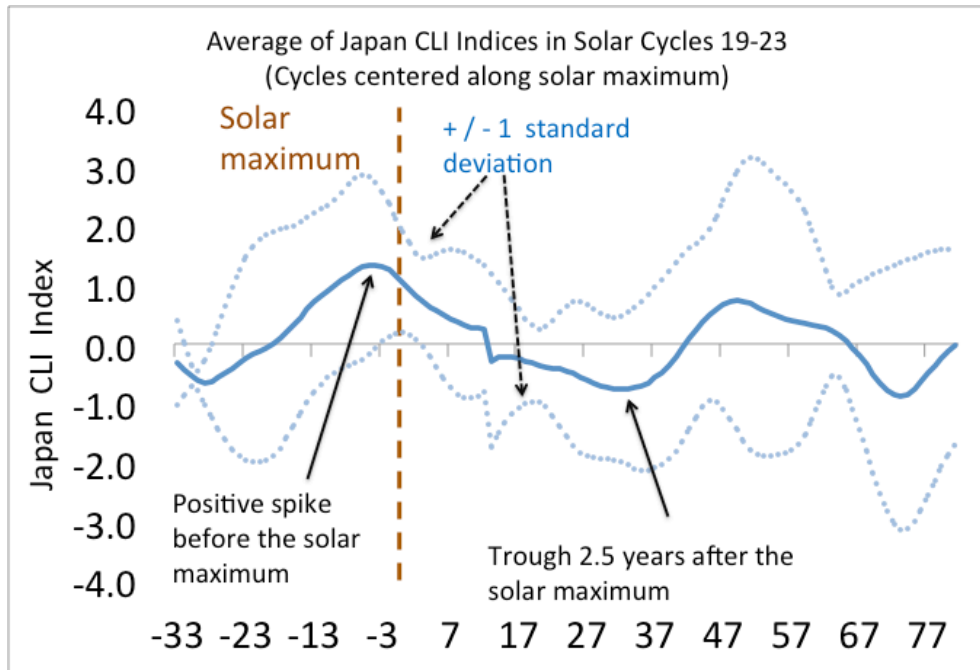


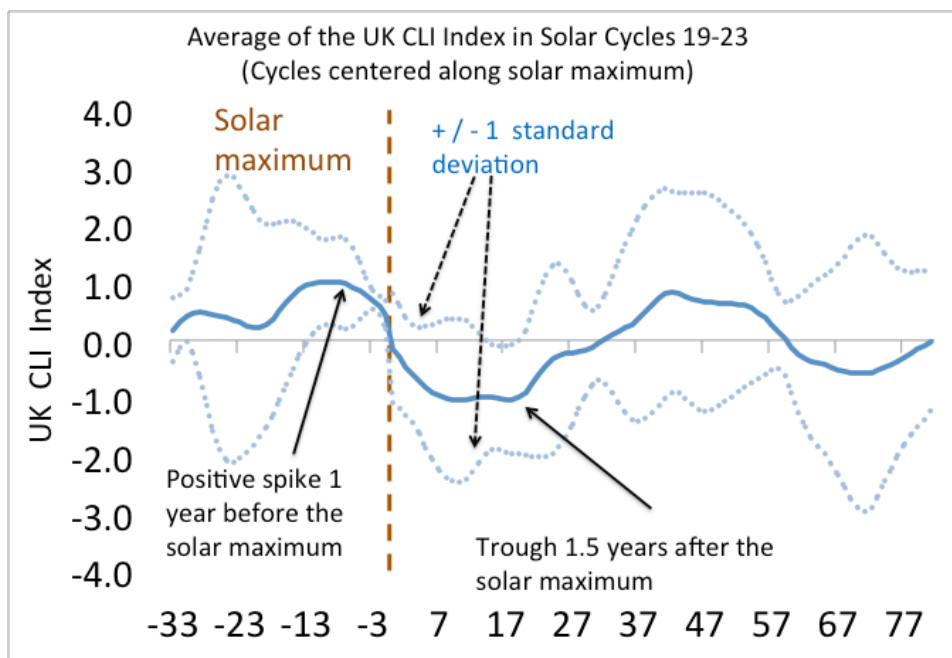
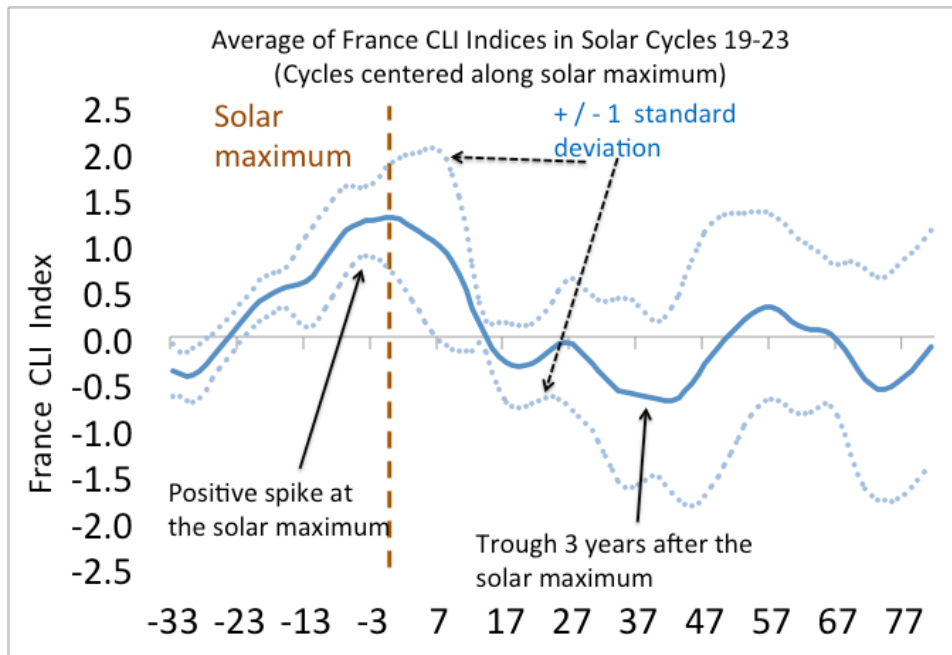
For the entire OECD, the concordance between the CLI index and solar cycle looked even more regular. In 1962-2012, all five solar maximums overlapped with dips in the CLI index, and the index reached its maximum values shortly before the sunspot maximums. When comparing the OECD CLI values across solar cycles, we discovered that standard deviations of the values for these cycles confirmed statistical significance of the indicator's spike before and trough after the solar maximum. The EURO area CLI index followed broadly the same pattern, thus confirming the link with the solar cycle even when the US economy was excluded.





Moreover, the dynamic of the CLI indices was broadly consistent among the largest OECD economies. We observed that in Japan, Germany, France, and UK, the CLI indices reached their maximums shortly before or around the solar maximum, and declined to the troughs in the years after it. The exact months of maximums and minimums varied between countries. Apparently, the statistical significance also varied, from the lowest for Japan and highest for Germany and France.

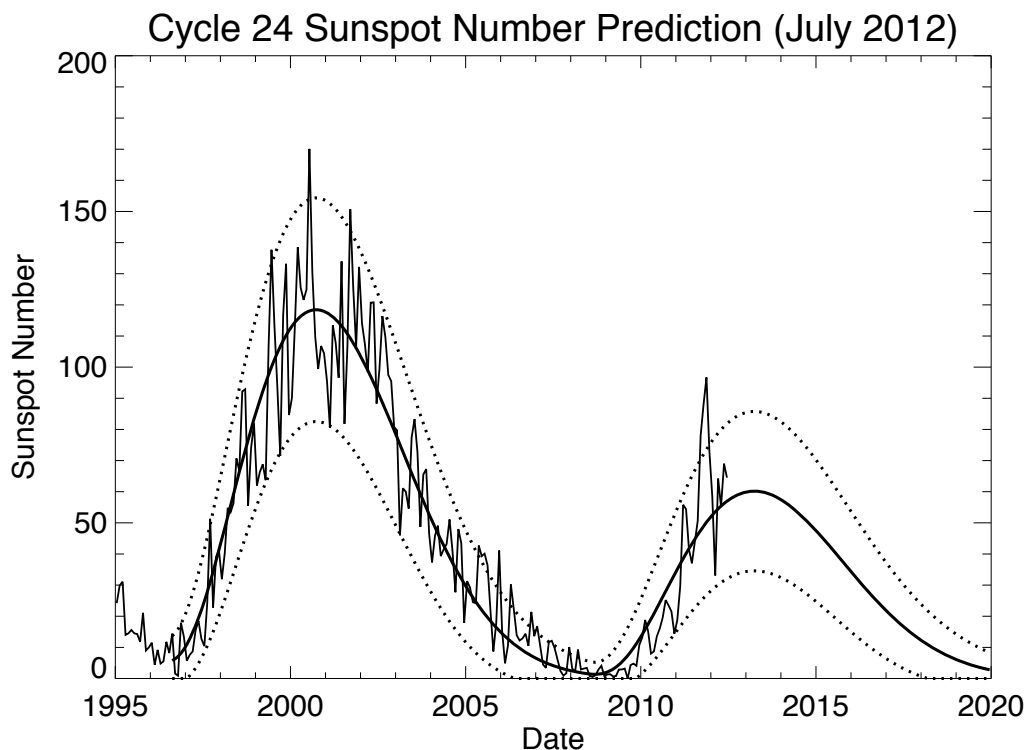


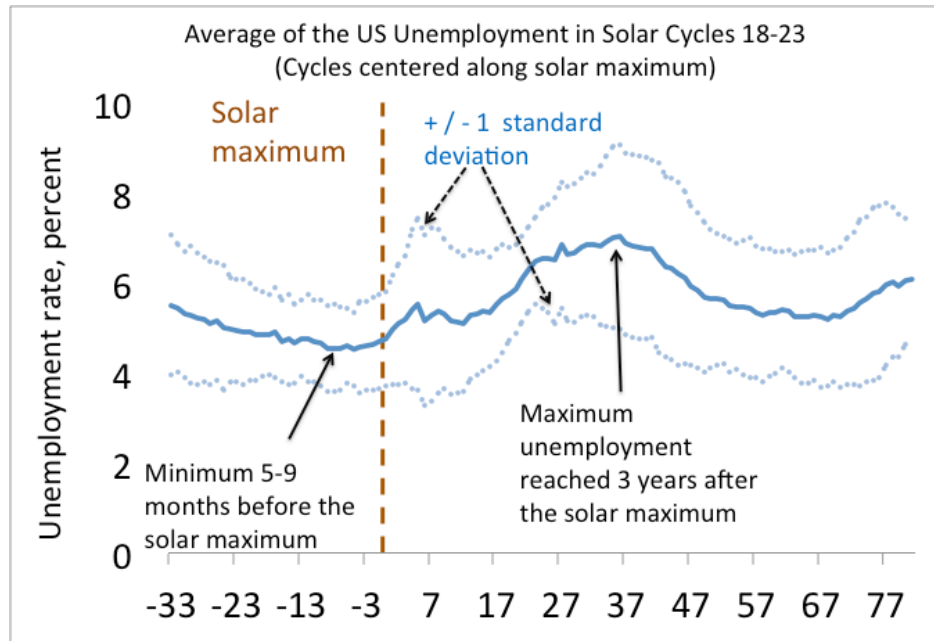


E. What Can We Project for the Next Solar Maximum?

Our study has confirmed that the spikes in solar activity as measured by the cyclical sunspot maximums were associated with the US recessions. The sunspot maximums were good predictors of the US recession over at least the last 77 years (from 1935), effectively predicting at least 8 out of 13 recessions over this period. In view of this, it is reasonable to expect that the next maximum of the solar activity could be associated with another US recession, even if we do not exactly understand the causality link between the two.

According to NASA, the next maximum of the solar activity, as measured by the maximum number of sunspots, is projected for May 2013. Counting from it, we can establish that the 2-year period when the US recession is most likely to start would be from early 2013 until end-2014. The 3-year period when the US economy is most likely to be in recession would run from mid-2013 until mid-2016. And the point when the US economy would be most likely in recession is in the middle of this range, in the winter of 2014/15. With regard to unemployment, we can expect to see its minimum rates in Q4 2012, around 5-9 months before the solar maximum. Then the unemployment can be projected to increase from 2013, and stay on the rising trend for 3 years, until 2015.





For other advanced economies, the upcoming solar maximum also suggests higher chances of recessions. The 3-year period when the recessions are most likely to occur in the G7 countries would run from early 2013 till end-2015.

F. Conclusions and Perspectives for Further Research

Our results imply that we can project recessions, at least some of them. The solar cycle follows a more or less regular 11-year pattern, and its projections are available from several reliable sources. Therefore, we can forecast solar maximums several years in advance. Given the results reported above, these projections can be helpful in forecasting the timing of possible recessions in the US and other countries. Moreover, for the US, they can also help project unemployment trends.

For the lack of space and time, we focused in this paper on discussing the link of the sunspots cycles with only a few selected economic time series. Beyond them, there are other series for the US and other countries that seem to follow the patterns of solar cycles. In case this research gets some traction, it would be useful to widen its scope to cover consumer confidence, labor productivity, purchasing manager's indices (PMI) and other indicators that shape the business cycles.

Another implication of this research is the possibility to classify the recessions as those overlapping with the solar maximums and falling between them. Are there fundamental differences between these two groups of recessions? Can we say that the recessions closely following solar maximums are triggered by fundamental factors influencing economy and human behavior, while those between maximums

are caused by random exogenous shocks? Does it imply that the former are inevitable, while the latter can be avoided?

A more fundamental implication is to study whether the varying parameters of the solar cycle can impact the business cycle patterns. For example, the ongoing 24th cycle of the solar activity is projected to be the weakest in the last 100 years. Does it imply that the recessions possibly associated with it will be rather shallow?

In addition to sunspot numbers, it would be interesting to check correlations with economic data for other series related to solar activity for which the long-term data is available. One such series is the 10.7cm radio emission flux, denoted as F10, recorded since 1947. Another series is the disturbance in geomagnetic field measured by Aa, Ap, and Kp indices, with data available from 1890s or even earlier.

Looking at a broader range of indicators of the solar activity is particularly important for the quest to determine the exact medium (if any) of the solar influence on economic developments. Even if a link of certain economic time series to sunspot numbers is established, it would tell us little about the nature of the relation between them, thus leaving it open to criticism that the link is purely coincidental. However, if a general strong correlation with the sunspot number is confirmed by an even stronger correlation with another indicator of the solar activity, this would point to the possible channel of the solar impact propagation. And this would inform further research on verifying and documenting the exact nature of the impact.

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