Can solar activity influence the occurrence of economic recessions?

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This paper revisits evidence of solar activity influence on the economy. We examine whether economic recessions occur more often in the years around and after solar maximums. This research strand dates back to late XIX century writings of famous British economist William Stanley Jevons, who claimed that "commercial crises" occur with periodicity matching solar cycle length. Quite surprisingly, our results suggest that the hypothesis linking solar maximums and recessions is well anchored in data and cannot be easily rejected.

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I. INTRODUCTION

This paper reviews empirical evidence of the apparent link between cyclical maximums of solar activity and economic crises. An old theory outlined by famous British economist William Stanley Jevons in the 1870s claimed that “commercial crises” occur with periodicity broadly matching the solar cycle length of about 11 years. It is common knowledge that this “beautiful coincidence” claimed by Jevons and its theoretical explanation linking the “commercial crises” to bad harvests did not stand the test and were rejected by subsequent studies. We could not find any publications in reputed economic journals in the last 80 years testing the core proposition of Jevons’s theory, namely, that there is a link between cyclical maximums of solar activity and economic crises. Our results suggest that economic recessions in the U.S. and other advanced economies do occur more frequently in the years around and after the solar maximums. These results are broadly consistent with the hypothesis advanced by Jevons more than 100 years ago with regard to “commercial crises”.

Since the beginning of the XX century, for more than 100 years each of the 10 cyclical maximums of solar activity overlapped closely with a recession in the U.S. economy. This relation became even more apparent from the mid-1930s on, when 8 out of 13 recessions identified by the National Bureau of Economic Research (NBER) began in the 2 years around and after the solar maximums. On a global scale, over the last 50 years (from 1965) when consistent recession dating is available for all G7 countries, nearly 3/5 of these recessions started during the 3 years around and after sunspot maximums. Looking back at the XIX century, out of 12 years that could be identified as episodes of “commercial crises,” 6 were within three years around sunspot maximum (Figures 1, 2, 3). Was it a mere coincidence or a part of a broader pattern?

To verify robustness of these empirical observations, we ran statistical tests. We estimated the probability of so many U.S. recessions starting in the narrow period around sunspot maximums. And we checked the statistical significance of correlations of time series characterizing the occurrence of economic crises and the series of sunspot numbers reflecting intensity of solar activity. Our tests suggest that the hypothesis of the more frequent occurrence of economic crises around the periods of maximum solar activity cannot be rejected. At the same time, our results do not shed much light on the exact factors of solar influence that could trigger these events, nor reveal the channels of their propagation.

The rest of the paper is organized as follows. Section II outlines the basic facts about solar cycles and their measurement. Section III discusses how various types of solar radiation can affect Earth and outlines core propositions of the theories advanced by Jevons and other scientists, most notably Russian scientist Alexander Chizhevsky, about the possible impact of solar activity on the economy and society. Section IV examines the links between solar maximums and recessions as well as with selected indicators of economic activity fluctuating with the business cycle. Building on these results, section V outlines practical implications of our findings for forecasting economic activity in the U.S. and other advanced economies. Section VI concludes and sets an agenda for future research.

II. What Are Solar Cycles and Sunspots?

Sunspots are temporary phenomena on the Sun's surface that appear visibly as dark spots compared to surrounding regions. They are caused by intense magnetic activity that inhibits convection and forms areas of reduced surface temperature. In 1610, Galileo Galilei and Thomas Harriot recorded the first European observations of sunspots. Daily observations began at the Zurich Observatory in 1749. The "international sunspot number"—also known as the 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, though significant variations in the length of this cycle have been recorded over the centuries of observations. The cycles are numbered since 1750, with the first cycle running from the minimum in 1755 to the next cyclical minimum in 1766. Currently, the 24th cycle is unfolding from a minimum in December 2008 through the cyclical maximum estimated by NASA scientists to have occurred in April 2014 toward the next minimum possibly around 2020.

In addition to the sunspot number, which remains the primary index of solar activity, many other indicators have been established and recorded, particularly in recent years. They include the indicators of radio activity, radiance, proton emission, solar wind, flares, and coronal mass ejections (CME). All these indicators broadly follow the solar cycle as measured by the sunspot index and reach their maximums around sunspot maximums (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 1,366 W/m2 (named the "solar constant"). Variations of this magnitude were undetectable until satellite observations began in late 1978.

III. How Does Elevated Solar Activity Affect Earth?

A. Main Channels of "Physical" Impact

Events associated with elevated solar activity can produce a significant "physical" impact on Earth. Solar flares and CMEs can disrupt radio and telecommunications and cause satellite malfunction. In particular, CMEs can trigger fluctuations in the geomagnetic field known as "magnetic storms" and even induce electromagnetic impulses in power grids that damage electric equipment. In their visible manifestation, CMEs can cause particularly powerful polar lights (auroras), which become visible in much lower latitudes than normal. In addition, solar flares produce high energy particles and radiation, such as high-energy protons and x-rays, which are dangerous to living organisms. However, Earth's magnetic field and atmosphere intercept these particles and radiation and prevents almost all of them from reaching the surface.

In 1859, British astronomer Richard Carrington observed a solar flare of enormous proportions. The CME associated with it reached Earth within a day, producing the strongest geomagnetic storm ever recorded. In a visible manifestation of it, the storm induced auroras as far from the poles as Cuba and Hawaii. Reportedly, the people who happened to be awake in the northeastern U.S. could read a newspaper by the aurora's light. The storm caused massive failures of telegraph systems all over Europe and North America. In certain cases, telegraph operators reportedly got electric shocks, and telegraph pylons threw sparks. More recently, in 1989, a much smaller solar event triggered a geomagnetic storm that caused the collapse of northeastern Canada's Hydro-Quebec power grid.

Luckily, the "Carrington event" occurred in the era before electricity. Had it happened today, it would have likely caused up to $2 trillion of damage to electric grids and equipment all over the world, which would have taken years to rebuild (NAS, 2008). A recent study estimated the probability of a comparable "extreme space weather event" impacting Earth at 10-12 percent over a 10 year period (Riley, 2012). Raising awareness of risks associated with elevated solar activity, a CME of a magnitude comparable to that of the "Carrington event" occurred most recently in mid-2012. Luckily, it was not directed at Earth, but had it happened just a week earlier, it would have hit our planet (Baker et. al., 2013).

B. Possible Impact on the Economy and Society

Perhaps the earliest recorded hypothesis about the relationship between 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). Then 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).

Building on these and other anecdotal observations, famous British economist and statistician William Stanley Jevons developed the theory explaining the period of the trade cycle with variations in solar activity. In Jevons' lifetime, the commercial crises had occurred at intervals of 10-11 years (1825, 1836-39, 1847, 1857, and 1866), which broadly matched the average solar cycle length. In his papers, Jevons carried back this history of "commercial crises" at 10-11 year intervals almost to the beginning of the XVIII century (Jevons, 1875, 1878, 1879). This "beautiful coincidence," as he called it, produced in him a strong conviction of causal nexus, going from cyclical solar activity through crop-harvest fluctuations to commercial trade cycles. He linked the crises first to harvests in Europe, and subsequently to Indian harvests, which, he argued, transmitted prosperity to Europe through the greater margin of purchasing power available to the Indian peasants to buy imported goods (Keynes, 1936).

However, there were several significant flaws in Jevons' theory and calculations. First, he assumed that the solar cycles were highly regular, while in fact their length varied considerably. When he later got hold of the actual sunspot number series, he discovered that the “commercial crises” identified by him landed in various phases of solar cycles, thus breaking the perception of the "beautiful coincidence" (Jevons, 1882). Second, he devoted insufficient attention to the exact dating of deficient harvests in relation to the dating of commercial crises. As a result, some of the bad harvests identified by Jevons appeared to have happened after the “commercial crises” that they were supposed to explain. These apparent flaws exposed Jevons’ theory to strong criticism. Also, they diverted attention from his core proposition of the “commercial crises” relationship to the solar cycle to the question of solar influence on crops and agriculture.

Jevons’ writings inspired other researchers to look for possible links between solar activity and events on Earth, which became a popular topic. In 1918, an article by an American “prodigy” became one of the first to extend the causal chain from solar cycles (and poor harvests) to revolutions (Sidis, 1918). It hypothesized that revolutions occur in “warm countries” near the cyclical minimums of solar activity and in “cold countries” near the solar maximums.

Meanwhile, Russian scientist Alexander Chizhevsky advanced a theory suggesting that all of human history was influenced by the cycles in solar activity (Chizhevsky, 1924). His thinking was probably influenced by the striking observation that two Russian revolutions of the early XX century (in 1905-07 and 1917) and several major European revolutions of the XIX century (in 1830, 1848, and 1871) occurred in the years of maximum solar activity (Figure 4). To justify his conviction, Chizhevsky scrutinized the available sunspot records and solar observations comparing them to riots, revolutions, battles and wars in Russia and 71 other countries for the period from 500 B.C. to 1922. He found that a significant percent of revolutions and what he classified as “the most important historical events” involving “large numbers of people” occurred in the 3-year periods around sunspot maximums. Chizhevsky proposed to divide the eleven-year solar cycle into four phases: (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 people are “apathetic.”

Through his subsequent studies, Chizhevsky came to believe that correlations with the solar cycles could be found for a very diverse set of natural phenomena and human activities. In his book, he compiled a list of as many as 27 of them that supposedly fluctuated with the solar cycle, ranging from crop harvests to epidemic diseases to mortality rates (Chizhevsky, 1938, 1976). Chizhevsky presented various quantitative and anecdotal evidence in support of his views. According to his studies, the periods of maximum solar activity were generally associated with negative effects such as lower harvests, intensification of diseases (including psychological ones), and higher mortality rates.

Subsequent studies generally did not confirm the strength and scope of the links between solar activity and various physical and social processes claimed by Chizhevsky and before him by Jevons. Still, occasionally new papers appeared that claimed the existence of such strong links. 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. 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).

And even as the link between solar activity and revolutions was not as strong as originally claimed by Chizhevsky, it appeared to be able to withstand a statistical test. Russian scientist Putilov analyzed large samples of historical events mentioned in the chronology sections of two of the largest Soviet historical encyclopedias (numbering nearly 13,000 events in one book and 4,600 in another). He classified the events into four groups on the dimensions of "tolerance" (e.g., riot-reform) and "polarity" (e.g., civil war-external war). Putilov found that frequency and "polarity" of historical events increased in the year of the maximum of the sunspot cycle and in the next year after it, particularly when compared with the year of the minimum and the year before the minimum. The probability of revolution (the most polar and intolerant of historical events) was the highest during the maximum and the lowest in the year before a minimum of solar activity, with very high statistical significance. The results suggested that solar activity does impact historic events, particularly in the years of sunspot maximums (Putilov, 1992).

And from time to time, researchers come across striking correlations between solar activity and economic events. In 2010, an analytical memo observed that in the postwar period, maximums of solar activity were preceded by troughs in the U.S. unemployment rate, while its peaks followed about 3 years after the peaks in sunspot activity (McClellan, 2010). 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. In their other paper, those scientists reported a close correlation of the U.S. and global GDP with solar cycles (Poluyakhtov and Belkin, 2011A, 2011B). In 2012, another memo observed that recessions in the U.S. economy often occur after solar cycle peaks, corresponding to the peaks in geomagnetism that lag solar maximums (Hampson, 2012).

It is subject to much debate—producing a growing body of literature—whether and how elevated solar activity affects human health. One apparent channel of impact is solar activity causing disturbances in the Earth’s magnetosphere leading to “magnetic storms” that affect people with cardiovascular health conditions and those having particular sensitivity to it (Palmer et al., 2006). Another possible channel is solar or geomagnetic activity affecting the human brain and thus exacerbating psychological and mental illnesses. For example, a recent study reported significant correlation between sunspot periodicity and brain (cervical) pathologies and selected human physiological functions (Hrushesky et al., 2011). These findings suggest that solar-induced magnetic storm periodicities are mirrored by cyclic rhythms of similar periods in the human psyche and in health.

IV. Solar Activity and Economic Crises

A. Solar Cycles and "Commercial Crises" of the XIX Century

By their nature, "commercial crises" of the XIX century stand close to what we define as "recessions" now. In the late XIX century, the commercial crisis was defined as a "disturbance of the course of trade at a given time, arising from the necessity of re-adjusting its conditions to the common standard and measure of value" (Cyclopædia, 1899). Compare this with a standard contemporary definition of recession as a period of temporary economic decline during which trade and industrial activity are reduced, generally identified by a fall in GDP in two successive quarters.

The "commercial crises" appear to be correlated with the solar cycle variation, as Jevons once noticed. If we go with the list of major commercial crises as identified by Hyndman (1892), the resulting annual series (with 1 for crisis years and 0 for no crisis) has a correlation of 0.24 with the annual series of sunspot numbers (Table 1). With 100 data pairs, this correlation appears to be highly significant, suggesting that the hypothesis of a link between the crises and the solar cycle cannot be easily rejected. Out of 12 crises years, 4 fall on the years just before the solar maximum, resulting in a high correlation with the sunspot series (Figure 3).[1] However, with only a dozen observations, the significance of this correlation

[1] To compare data series across solar cycles, we "stack" the data corresponding to particular cycles by aligning the years (or months) of the solar maximum and then calculate averages (or sums) of the observed variable for particular years (or months) of the solar cycle. For the annual data, we define the year of solar maximum simply as the year with the maximum sunspot number across the cycle. For the monthly data, due to high volatility of observations, we follow the NOAA definition that relies on a moving average (http://www.ngdc.noaa.gov/stp/space-weather/solar-data/solar-indices/sunspot-numbers/miscellaneous_in-process/docs/maxmin.new). In the resulting charts, the years of solar maximums are denoted as 0 on the

(continued)

becomes sensitive to the exact dating of the crises. For example, if we treat the event of 1836-39 as one crisis in 1837, the correlation with the annual sunspot series drops to 0.08, which is not statistically significant.

And if we widen the definition of crises events to include bank crises and stock market panics, correlation with the solar cycles disappears. For example, the list of major banking and financial crises in Conant (1915) has a correlation of only 0.05 with the sunspot series for the period from 1798-1912. This low correlation has no statistical significance. The events covered by Conant stand close to what we describe as financial or banking crisis today. This suggests that when searching for correlation with solar cycles, we need to focus on crisis events related to fundamental economic conditions rather than on purely financial or banking crises, which occur much more frequently.

B. Solar Cycles and Economic Recessions

Recessions in the US

During the entire XX century and in the early XXI century, each cyclical maximum of solar activity overlapped closely with the start of a recession in the U.S. economy. There were ten solar cycles from 1901 to 2008 numbered 14 to 23 by astronomers. And each time the solar cycle reached its maximum, a recession in the U.S. economy broke out within a 2-year period counting from 3 months before the maximum to 21 months after it (Figure 1). Out of 22

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horizontal axis, the years immediately preceding the maximum are denoted as -1, and so on. And on the vertical axis, we show observations for particular years of the solar cycle (or their averages or sums), across all cycles in the selected time interval under consideration.

recessions officially identified by NBER from 1901-2008, 11 recessions began in this 2-year period around and after a sunspot maximum. The share of recessions beginning around solar maximums got even higher after the Great Depression. Counting from solar cycle 17 that began in 1933, 8 out of 13 recessions during 1933-2008 began in the 2 years around and after the solar maximum. However, this relationship did not occur in the XIX century. Eleven recessions identified by NBER for 1854-1900 spread rather evenly across solar cycle phases, and only one began in the same 2-year period around the solar maximums.

Statistically, the chances of so many recessions occurring in a given 2-year interval within the 11-year solar cycle are very low. Solar cycles 17-23 corresponding to 1933-2008 run a total of 901 months. Out of this number, the 2-year period around and after solar maximums accounts for 168 months, which is 19 percent of the total. Thus, if we assume that recessions spread evenly over the solar cycle, the probability of a given recession occurring in that 2-year period is 0.19. Further assuming that the recessions occur as independent events, we can estimate that the probability of 8 or more out of 13 recessions occurring in the 2-year period around and after the solar maximum is less than **0.1** percent (in other words, fewer than 1 out of 1,000). Extending the sample to 1901 (corresponding to solar cycles 14-23) we can estimate in a similar way that the probability of 11 or more out of 22 recessions occurring in the 2-year period remains less than **0.1** percent. Even if we consider the entire scope of NBER-identified recessions from 1855 to 2008, including the period from 1855 to 1900 when only one recession occurred in that same 2-year period, the estimated probability of 13 or more out of 33 recessions occurring within it rises to about **1** percent, which is still very low. This indicates that the hypothesis that U.S. recessions occur more often in the 2 years around and after solar maximums cannot be rejected.

Correlation analysis confirms the statistical significance of the link between U.S. recession starts and solar cycles. On a monthly frequency, a series of U.S. recession starts (with 1 for months when recession starts and 0 for all other months) has a correlation of nearly 0.09 with the sunspot series over the period 1933-2008. With 901 monthly pairs, this coefficient is highly significant. However, the value and significance of the correlation coefficient drops if we extend the sample to the beginning of the XX century, and even more so if we include all recessions identified by NBER from 1855 on (Table 2).

Why would the correlation of U.S. recessions and solar cycles become so significant from the mid-1930s on? It might be because of changes in the frequency and nature of U.S. recessions after the Great Depression, in part because of shifts in the U.S. government policies induced by it. Changes in the economic structure also played a role. The diminishing role of agriculture reduced the impact of sporadic weather-related shocks, while rising globalization facilitated synchronization of business cycles across all advanced economies. Further on, after the mid-1940s the occurrence of military conflicts declined markedly, at least in the advanced economies. Apparently, all these developments suppressed the impact of “random shocks” on the economy and increased the relative importance of recessions produced by fundamental factors that could be linked to elevated solar activity.

NBER provides precise monthly dating of U.S. recessions from 1855 on. With regard to the recession length and frequency, the entire period of 1855-2014 can be broadly divided into "before" and "after" the Great Depression of 1929-33. In the time up to and including the Great Depression, recessions occurred more frequently and lasted about twice as long as in the period after it (Table 3). Consequently, the U.S. economy spent nearly half the time in recessions during the period 1856-1933 (corresponding to solar cycles 10-16). This compares to only 15 percent of the time in recession during 1933-2008 (solar cycles 17-23).

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 toward minimizing the chances of recessions and alleviating and shortening them. In practice, it meant that many random shocks, such as bank runs or stock market crushes, were either pre-empted (for example, through timely bank resolution) or no longer resulted in economy-wide recessions. And if a recession occurred, after all, the government rushed to apply powerful economic stimulus to re-start growth as quickly as possible. This was not the case in the XIX or even early XX century.

Switching attention from recession starts to recession length, between 1933 and 2008 the U.S. economy was in recession most often within about 3 years after the solar maximums. Over this period, from the month of the solar maximum to 36 months afterward, the U.S. economy spent more than 34 percent of its time in recession. In about 1 year in the middle of this range, from 12 to 24 months after the solar maximums, the "recession" indicator averaged 44 percent. Furthermore, in the very middle of this range, 1½ years after the solar maximums, there were two months when the “recession” indicator averaged 57 percent. In other words, the U.S. economy was in recession more often than not 1½ years after a solar maximum, which is much more often than in any other time across the solar cycle (Figure 5). Statistically validating this pattern, monthly series of U.S. recessions (with 1 for recession months and 0 for no recession) has a correlation of as high as 0.21 with the sunspot series (with the lag of 18 months) over 1933-2008 (Table 4). However, this correlation loses significance once we extend the sample to 1901 and then to 1855, the same as for recession starts.

Recessions in G7 Countries

The Economic Cycle Research Institute (ECRI) provides consistent dating of economic recessions for all G7 countries from 1965. This year corresponds neatly to the beginning of the 20th solar cycle. Using NBER recession dating for the U.S. and ECRI dating for the other six countries, we can expand to G7 the analysis of recession and solar cycle links done above for the U.S.

Our analysis indicates that during 1965-2008, recessions in G7 countries occurred much more often in the 3 years around and after solar maximums. Out of the total of 36 recessions that began in 1965-2008 in the G7 countries, 21 recessions started in the period from 5 months before the solar maximum to 33 months after it. Thus, about 3/5 of recessions started in the 3 years around and after the solar maximums. This is remarkably close to the same proportion for the U.S. for 1933-2008 (8 out of 13 recessions), though in the case of the U.S. the time period was shorter (about 2 years around and after sunspot maximums). Correlation between the monthly G7 recession starts series (with 1 or 2 for months when recessions started in one or two countries and 0 for all other months) and sunspots is nearly 0.08 for 1965-2008, which is on the border of statistical significance (Table 5).

Turning from the recession starts to recession length, during 1965-2008 G7 countries found themselves in recession most often in the 1 to 3 years after the solar maximum. During this period, on average, about 3 out of 7 countries were in recession, which is much more often than in any other point of the solar cycle (Figure 6). Monthly series of the G7 recessions (that count the number of G7 countries being in recession each month) has a correlation of as high as 0.22 with the sunspot series, which is highly significant. Moreover, this correlation rises to as high as 0.44 if we take sunspot series with the lag of 18 months, to account for the fact that the G7 recessions peak 1-3 years after the sunspot maximum (Table 5).

Other Indicators of Business Cycle

Once we established that recessions in the U.S. and G7 countries occurred more often around and after solar maximums, it is reasonable to expect that economic indicators fluctuating with the business cycle would deteriorate around the same period as well. In particular, we can expect it from aggregate measures of business activity such as composite leading indicators (CLIs) compiled by the Organisation for Economic Co-operation and Development (OECD). The OECD CLI system was developed, specifically, to predict cycles in a reference series and give early signals of turning points of economic activity (OECD, 2012).

And indeed, CLIs for the U.S. and other G7 economies exhibit negative correlation with the solar cycle. In the U.S. over the period 1955-2008 (corresponding to solar cycles 19-23), the CLI took a dip (signaling deteriorating business conditions), on average, in the 3 years around and after the solar maximum, reaching its lowest point about 2½ years after it (Figure 7). Over the period 1955-2014, the CLI series had a statistically significant negative correlation of -0.15 with the sunspot series with a lag of 24 months (Table 6). The similar pattern is observed for all other G7 countries (Figures 8-10). The CLIs for these countries all have negative correlations with the sunspot series with the lag of 24 months, which is highly statistically significant for all countries but Japan. Moreover, the same pattern and statistically significant correlations are observed for aggregate CLIs for all G7 countries, for the entire OECD, and for OECD plus six “non-market economies” (Brazil, China, India, Indonesia, Russia and South Africa).

For the U.S., the results for the CLI are corroborated by similar findings for the Aruoba-Diebold-Scotti (ADS) business conditions index. The ADS index is designed to track real business conditions at high frequency. It blends high- and low-frequency information and stock and flow data: jobless claims, payroll employment, industrial production, personal income, manufacturing and trade sales, and GDP (Aruoba et al., 2009). During 1964-2008, the ADS index had low negative values in the 3 years after the solar maximums, which indicated worse-than-average business conditions (Figure 11). And the index had a highly statistically significant negative correlation with the sunspot series (Table 7).

The U.S. unemployment rate exhibits even stronger correlation with the solar cycle. Consistent monthly U.S. unemployment data is available from 1948 on. In the 66 years from 1948 to 2014, all 6 sunspot maximums overlapped closely with minimums of the U.S. unemployment rate. Moreover, each time the dynamics of unemployment changed from a declining trend to a rapid increase, with the unemployment rate peaking 2-3 years after the sunspot maximums (Figures 12, 13). Consequently, the unemployment rate exhibited highly significant correlation with the sunspot series with a lag of 24 months. This apparent link with the solar cycle is particularly important in view of the role given to the unemployment rate in dating U.S. business cycles.

Furthermore, the G7 unemployment rate shows the same correlation with the solar cycle. During the period 1956-2014, all five sunspot maximums overlapped closely with minimums in the G7 unemployment rate, followed by its increase to a peak a few years later (Figures 14, 15). Moreover, the unemployment rate for the entire group of advanced economies[2] follows the same pattern.

However, the relation between unemployment and the solar cycle was not uniform across G7 economies. On the one hand, the data for Canada exhibit very much the same correlation as in the U.S. On the other hand, the long-term monthly data for Japan did not confirm the existence of such a strong link. 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 indicate a relatively weak link between

[2] Countries classified as “advanced economies” in the IMF World Economic Outlook (WEO).

sunspots and unemployment. This can be explained in part by the lack of uniform unemployment data. For example, the available data for the UK suggested that the unemployment rate bottomed out before the sunspot maximum and increased sharply after it, but the relatively short data span covering only two solar cycles did not allow to claim that this was a reliable pattern.

Not surprisingly, the U.S. GDP also takes a dip in the years after solar maximums. During 1954-2008 (corresponding to solar cycles 19-23), on average, low GDP growth rates were observed for 3 years after the solar maximum (Figure 16). The same pattern is observed for the aggregate growth rate of all G7 countries, of all advanced economies, and in the GDP growth series for the entire world (Figure 17).

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

Our study documented that the cyclical maximums of solar activity have been associated with recessions in the U.S. and other G7 economies. For the past 100 years, each solar maximum overlapped closely with a U.S. recession. And from 1965 on, for which time consistent recession dating is available for all G7 countries, about 3/5 of recessions started in the 3 years around and after sunspot maximums. In view of this fascinating coincidence, can we expect that the next solar activity maximum will be followed closely by another U.S. recession and recessions in other G7 countries?

According to NASA estimates, the 24th solar cycle reached its maximum in April 2014. This estimate can be updated and subject to further developments (for example, in the summer of

2012 NASA projected the solar maximum to be in early to middle 2013). On the annual basis, it appears that 2014 will see the highest number of sunspots unless something unexpected happens with solar activity and it increases further in 2015 instead of the currently expected slowdown. Using these current NASA projections, we can compare the actual and projected dynamics of economic indicators for the 24th solar cycle with the averages of the previous cycles.

For the U.S. economy, our analysis points to elevated risk of a recession start from early 2014 to end-2015 (Figure 1). At the time this article was drafted, we know that there was no recession up to end-2014, and the consensus forecast for 2015 does not point to high recession risks. However, the U.S. economy contracted quite unexpectedly by 2.1 percent in annualized terms in Q1 2014. Many professional forecasters downplayed this episode as a one-off glitch caused by extreme weather conditions in the winter of 2013/14. However, let us note that this was one of the deepest single-quarter GDP declines outside of recession in the entire span of quarterly GDP statistics from 1947 on. Moreover, it was only the third such single-quarter contraction that did not trigger full-scale recession in the last 30 years. This suggests that the same forces that triggered U.S. recessions after previous solar maximums might have been at work in Q1 2014. However, FED's highly accommodative monetary policy (including its "quantitative easing" operations) and other stimulus measures deployed by the U.S. government in 2014 could have prevented these forces from triggering a full-scale recession.

G7 countries as a group entered the 3-year period of elevated recession risk at the end of 2013 (Figures 2, 6). Averaging historical data across previous solar cycles suggests that 3 or even 4 out of 7 countries could fall into recession within 1 to 3 years after the solar maximum. In Q2-Q4 2014, two of the G7 countries – Italy and Japan – were in recession. Remarkably, Japan fell into recession in 2014 quite unexpectedly for most professional forecasters. Moreover, two other G7 countries, France and Germany, appear to be at high risk of tipping into recession.

In particular, the dynamics of CLI for Germany appears to resemble most closely the average pattern of this indicator in previous solar cycles (Figure 9). This is broadly consistent with the analysis of the World Economic Outlook (WEO, 2014) published by the IMF in October 2014, which estimated the chances of the entire euro area falling into recession in 2015 at close to 40 percent.

Even as our analysis points to elevated risks of recession ahead, the available medium-term economic forecasts for 2015 and subsequent years do not seem to factor in such risks. For example, we can see that the IMF WEO published in October 2014 projected further reduction in world unemployment in 2015-19, while the average of historical observation across previous solar cycles suggests that it can increase after the solar maximum (Figure 14). In the same vein, the IMF WEO projects increasing world economic growth in 2015-19, while the experience of the previous solar cycles points to elevated risks of slowdown (Figure 17). As the actual developments unfold, it will be interesting to see if the calculations based on the solar cycle pattern could be helpful in forecasting the economic trends.

In any case, the U.S. experience suggests that concerted policy actions could shape the dynamics of economic variables against the unfavorable odds driven by the solar cycle. In particular, the “quantitative easing” monetary policy was very effective in engineering the persistent decline in unemployment rate from late 2009 to end-2014. Unemployment kept declining in 2014 even as our previous analysis based on the solar cycle pattern pointed to risks of its rising in this period (Gorbanev, 2012). Moreover, the accommodative policy could have averted a new recession in early 2014, by limiting GDP contraction to the first quarter of the year. However, by end-2014 the U.S. authorities wound down the “quantitative easing” operations, consistent with the brisk economic expansion in 2014 and generally upbeat forecasts for 2015. Over the next year we will see whether the downside risks associated with elevated solar activity are relevant for the U.S. economy in the absence of powerful stimulus measures.

VI. Conclusions and Prospects for Further Research

Our results imply that we can project recessions, at least some of them. The solar cycles follow a more or less regular 11-year pattern. Solar cycle projections—including projections for the solar maximums—are available from several reliable sources. The results reported above indicate that we can use these projections to forecast periods of elevated recession risks in the U.S. and other economies.

Because of space and time constraints, in this paper we focused on solar cycle links with only a few selected economic time series. Beyond them, there are other series for the U.S. and other countries that seem to follow the patterns of solar cycles. The research scope could be widened to cover consumer confidence, labor productivity, capacity utilization, purchasing manager's indices (PMI), and other indicators that broadly follow the business cycle pattern.

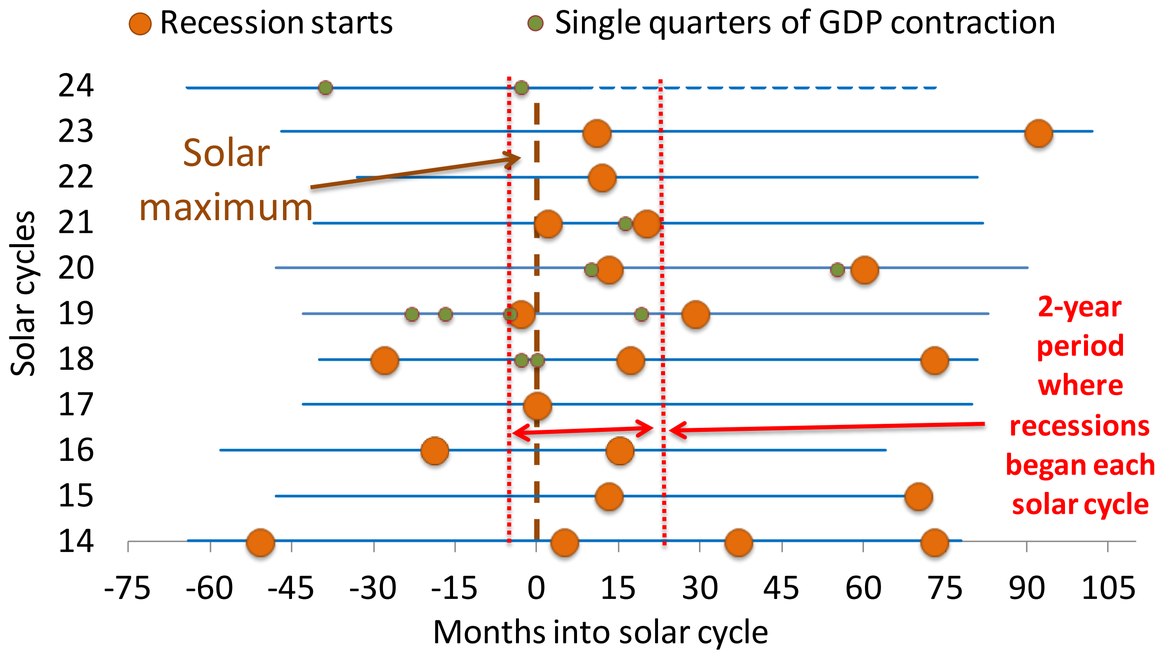
Another implication of this research is the possibility of classifying recessions as those which overlap with solar maximums and those falling between them. Are there fundamental differences between these two groups of recessions? Can we say that the recessions closely following solar maximums are triggered by factors related to solar activity, while those occurring during other phases of the solar cycle are caused by shocks of earthly nature such as banking and financial panics? What are the properties of recessions that overlap with solar *minimums*, including the Great Recession of 2007-09? Does it imply that the counter-cyclical economic policies should be designed eyeing the solar cycle phase?

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

Above all, a closer look at a broader range of indicators of solar activity could help identify the exact channels of its influence on the economy and society. Correlation of certain economic time series with the solar cycle documented in this paper and other studies tells us little about the nature of the relation between them, leaving it open to criticism that the link is purely coincidental. But what if a strong correlation with the sunspot number series could be confirmed by an even stronger correlation with another indicator of the solar activity directly affecting Earth, such as the intensity of solar flares or CMEs? This would point to the possible channel of solar impact propagation and pave the way for further research on verifying and documenting the exact nature of the impact.

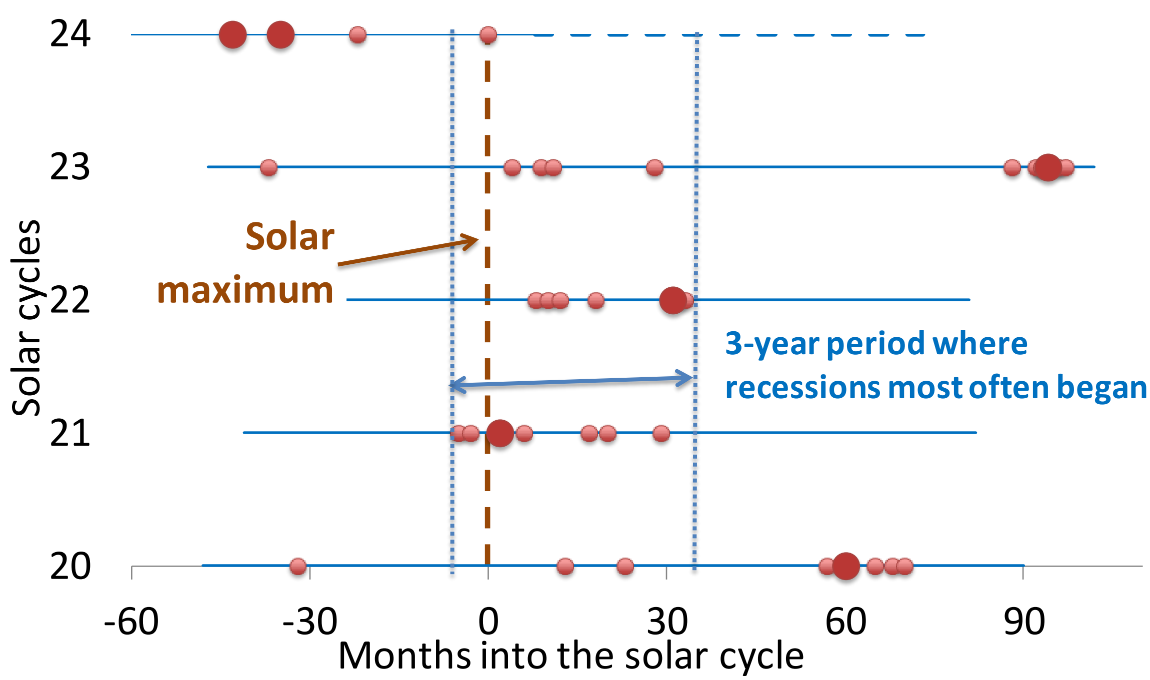
Research in the nexus of solar activity, recessions and revolutions looks particularly promising. Even as it might be difficult to believe that solar maximums increase the risk of economic recessions, what about Chizhevsky's claim that solar maximums increase the chances of *revolutions*? Can we prove that major revolutions overlapping with peaks of solar activity—such as the revolution of 1917 in Russia that brought communists to power and a chain of revolutions in 1989-91 that led to the collapse of the USSR and Soviet Bloc—was not a coincidence? As with recessions, we have obtained results confirming that revolutions do occur more frequently in the years around and after solar maximums. Further research in this area can lead to remarkable discoveries about solar activity influence on human life and behavior.

Figure 1. US Recession Starts in 1901-2014
(Solar cycles 14-24 centered on solar maximums)



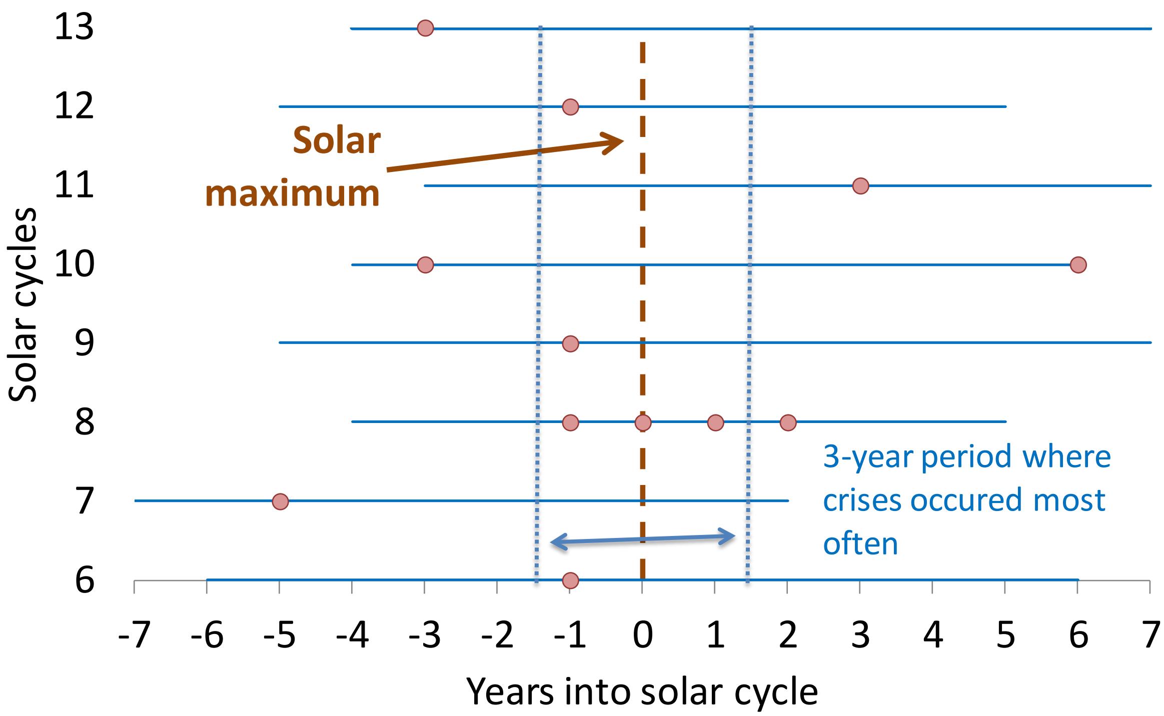
Sources: NBER; FRED; NASA; and author's calculations.

Figure 2. G7 Recession Starts in 1965-2014
(Solar cycles 20-24 centered on solar maximums. Larger markers for months when recession began in two countries)



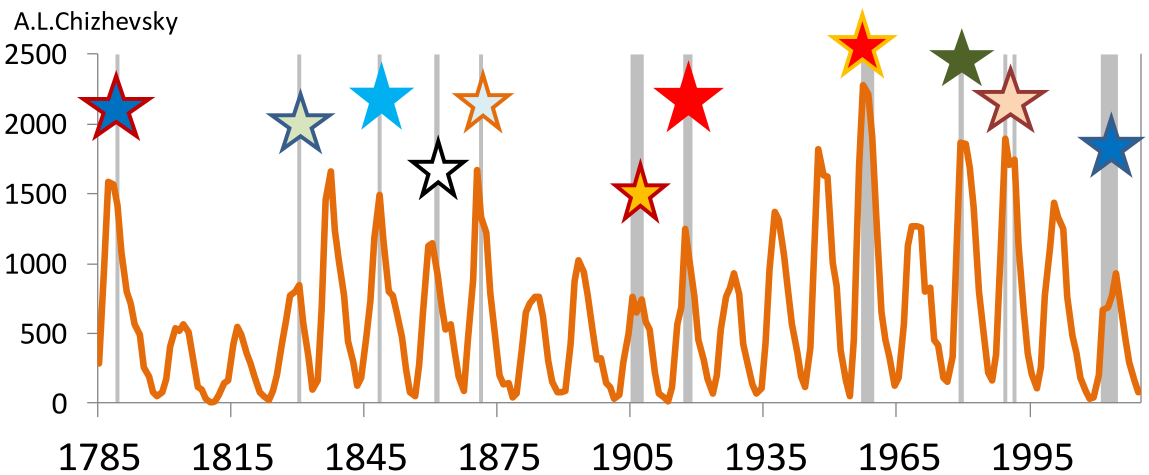
Source: NBER; ECRI; NASA; and author's calculations.

Figure 3. Commercial Crises in the XIX Century
(Solar cycles 6-13 centered on the years of maximums)



Sources: Hyndman (1892); NASA; and author's calculations.

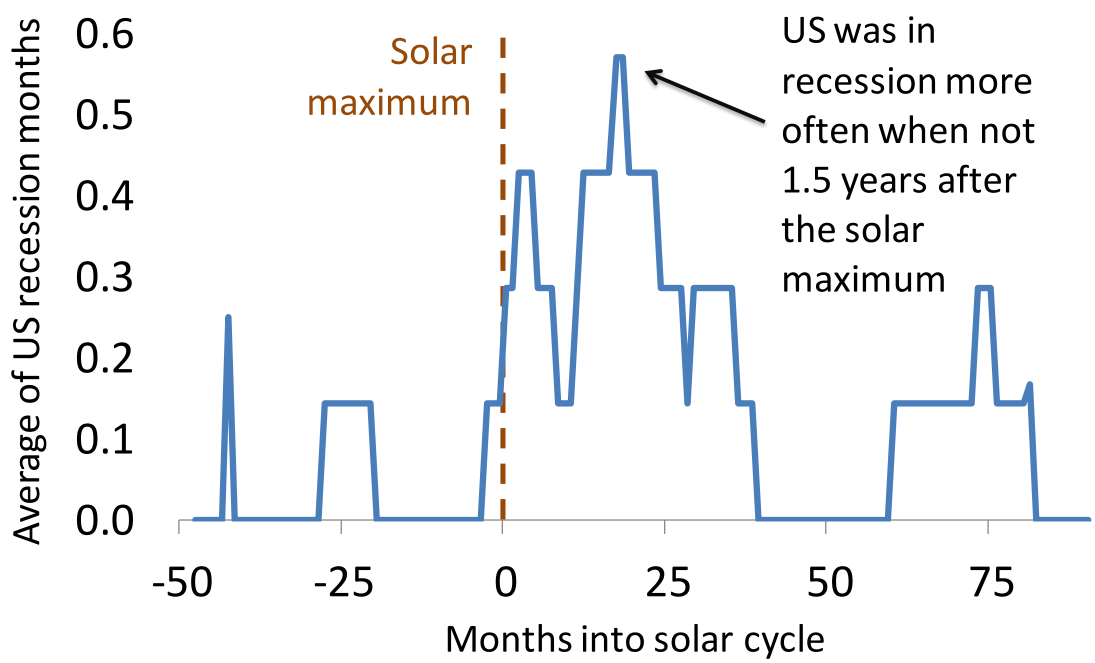
Figure 4. Selected Revolutions that Overlapped with Solar Maximums, 1785-2014



	Years	Events
	1789	Great French Revolution
	1830	Revolutions in Europe (France, Poland, Germany, Italy, Greece)
	1848	Revolutions in Europe (Italy, France, Germany, Austria, etc.)
	1861	Secession of 13 southern US states that formed the C.S.A.
	1871	Uprising in Paris "Paris Commune"
	1905-07	Revolution of 1905-07 in the Russian Empire
	1917 1918	February Revolution, Great October Socialist Revolution in Russia Revolution in Germany, collapse of the Austro-Hungarian Empire
	1957-59	Revolution in Cuba
	1979	Islamic Revolution in Iran
	1989 1991	Fall of Berlin Wall, collapse of communism in Eastern Europe Collapse of Soviet Union and Yugoslavia
	2010-13 2013-14	"Arab Spring": Revolutions in Egypt, Libya, Syria, Yemen, Tunisia, etc. Revolution in Ukraine

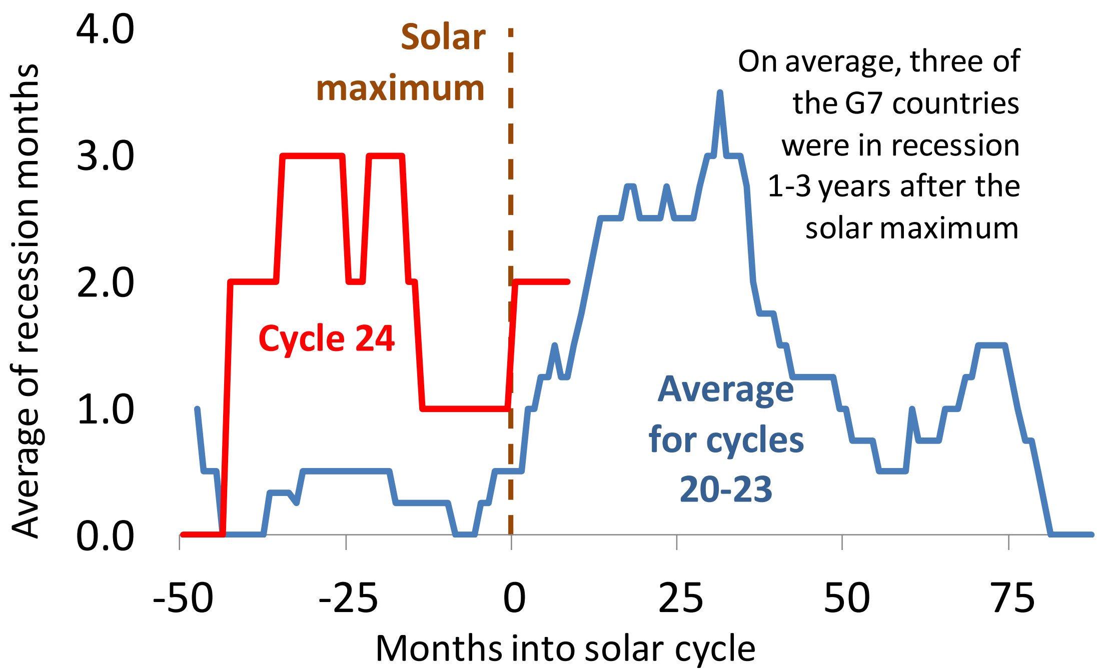
Sources: Chizhevsky (1924, 1976); NASA; history textbooks.

Figure 5. Average of US Recession Months in 1933-2008
(Solar cycles 17-23, centered along solar maximums)



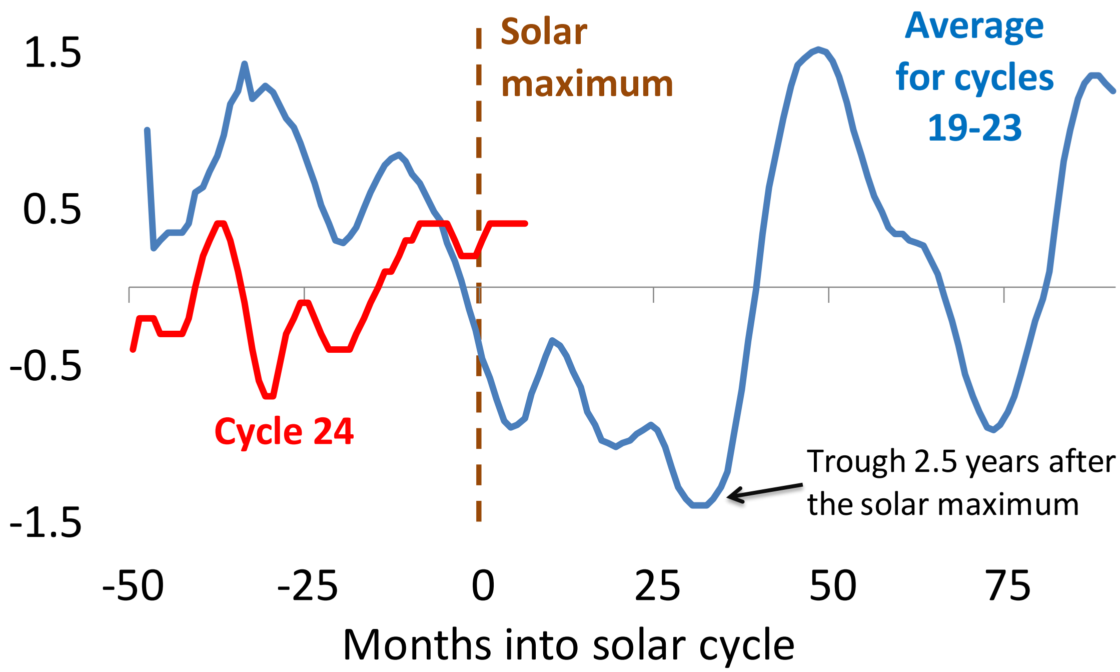
Source: NBER; FRED; NASA; and author's calculations.

Figure 6. Average of G7 Recession Months in 1965-2014
(Solar cycles 20-24 centered along solar maximums)



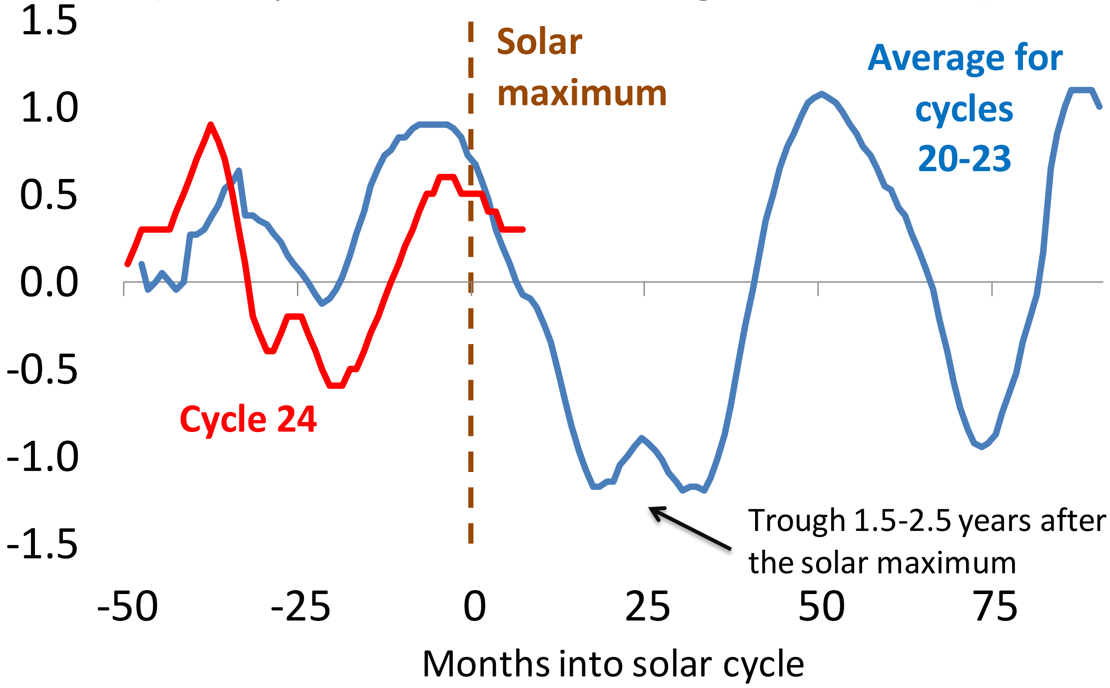
Source: NBER; FRED; ECRI; NASA; and author's estimates.

Figure 7. US CLI in 1955-2014
(Solar cycles 19-24 centered along solar maximum)



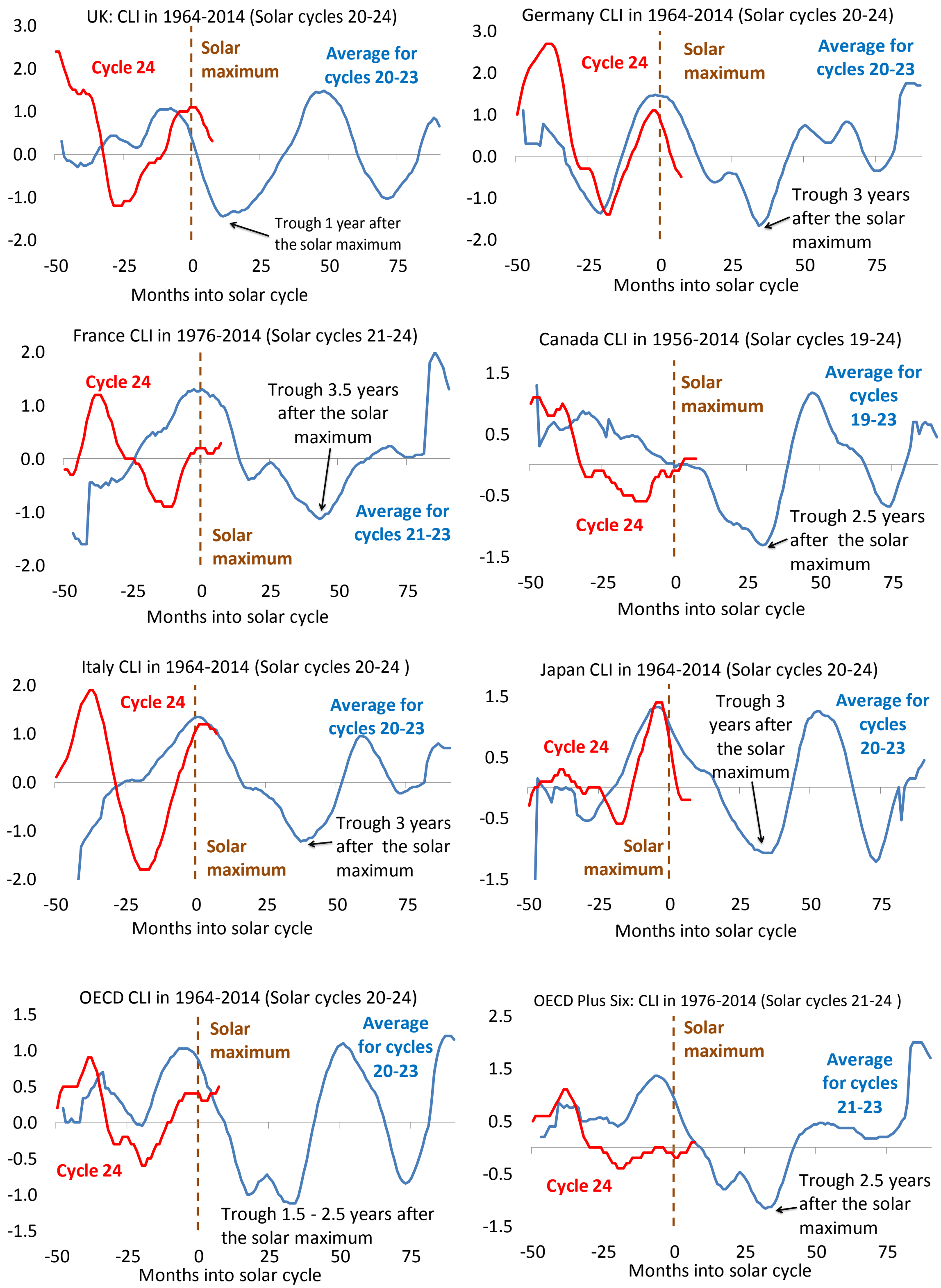
Source: OECD; NASA; and author's calculations.

Figure 8. G7 Average CLI in 1964-2014
(Solar cycles 19-24 centered along solar maximum)



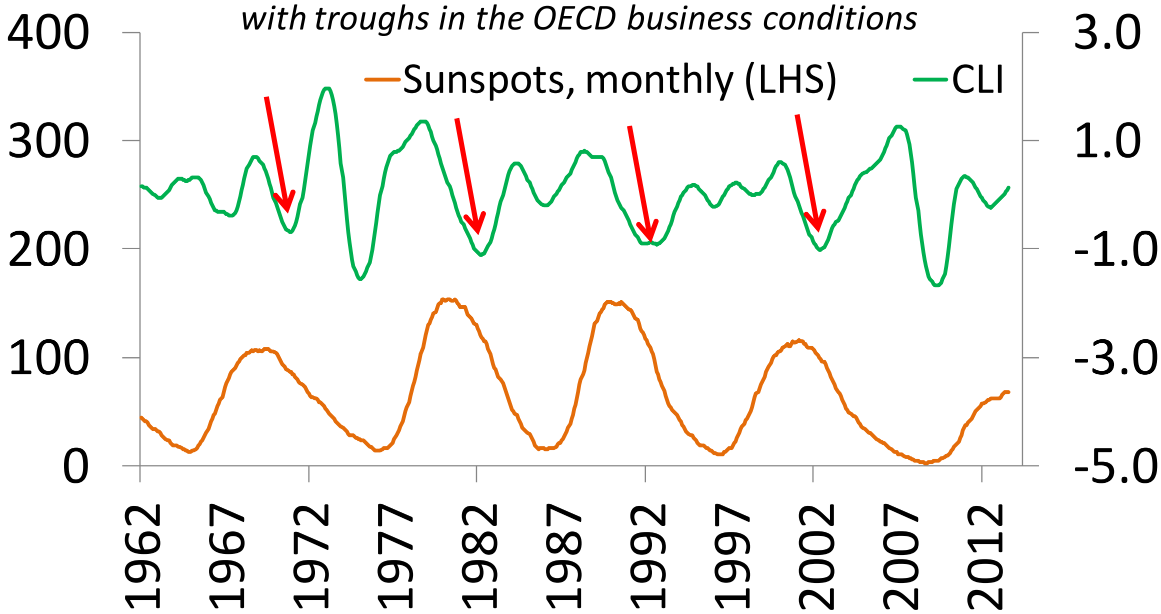
Source: OECD; NASA; and author's calculations.

Figure 9. G7 and OECD Countries: Sunspots and CLIs in 1956-2014
(Solar cycles 19-24 centered along solar maximums)



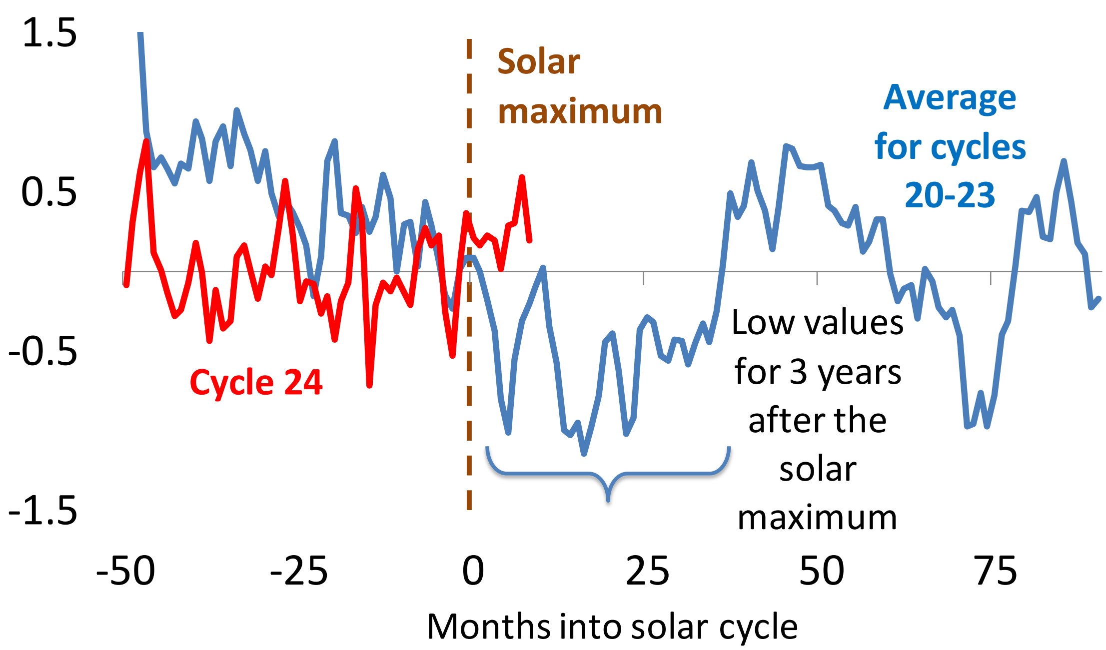
Source: OECD; NASA; and author's calculations.

Figure 10. Solar Cycle and OECD CLI, 1962 - 2013
(Smoothed with 25 months moving average)
All four maximums of solar activity overlapped closely with troughs in the OECD business conditions



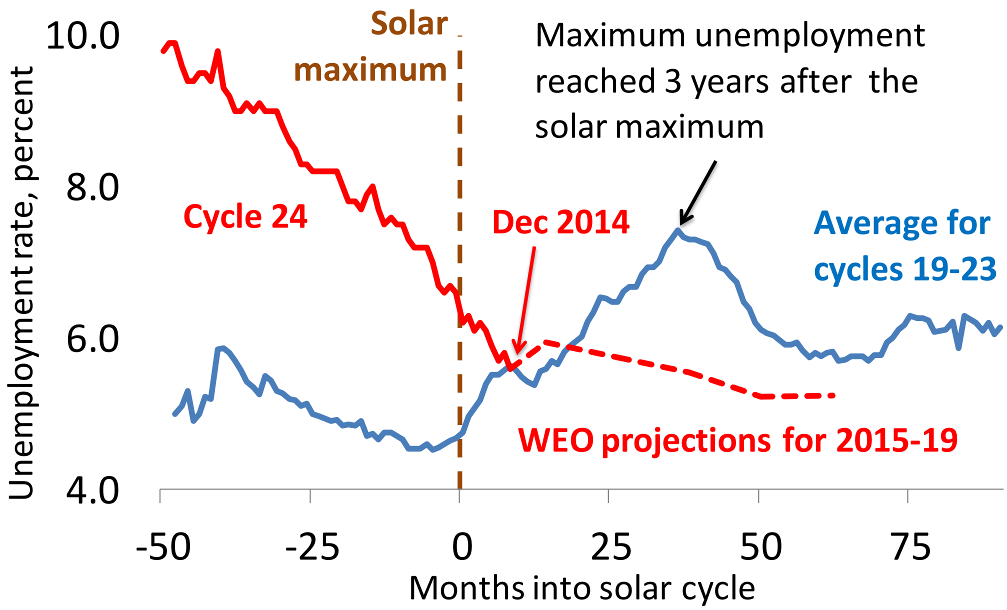
Sources: OECD; NASA; author's calculations.

Figure 11. US ADS in 1964-2014
(Solar cycles 20-24 centered along solar maximum)



Source: US FED ; NASA; and author's calculations.

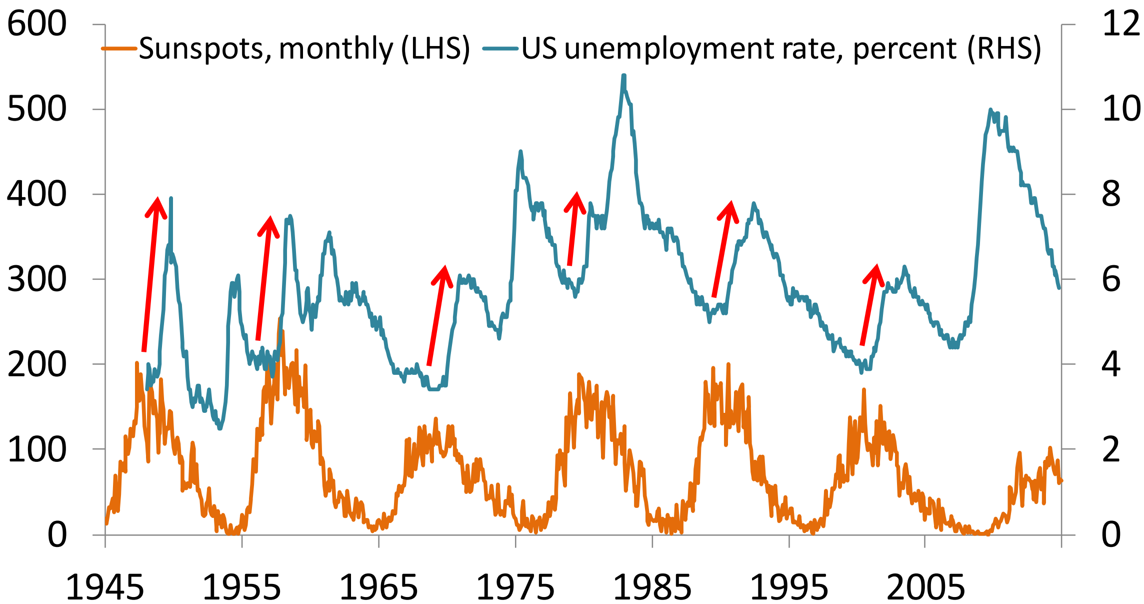
Figure 12. US Unemployment in 1954-2019
(Solar cycles 19-24 centered along solar maximum)



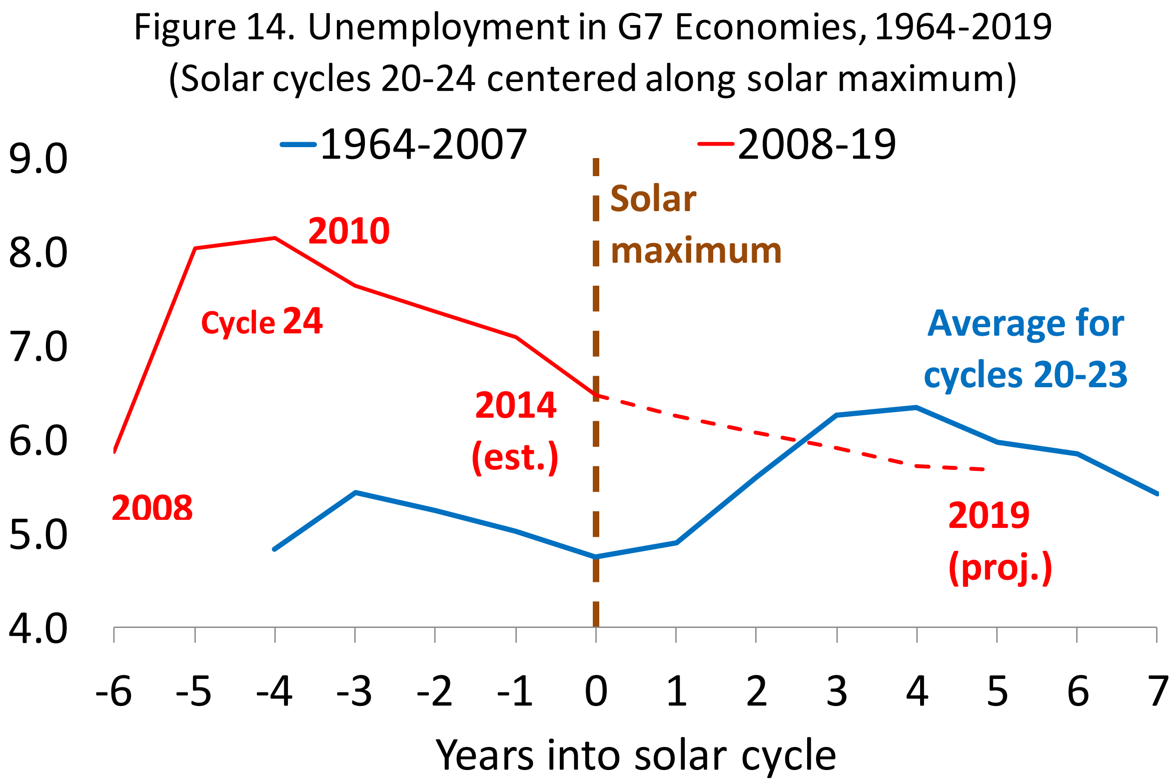
Source: FRED ; NASA; IMF *WEO (October 2014)*; and author's calculations.

Figure 13. Solar Cycle and US Unemployment, 1948-2014

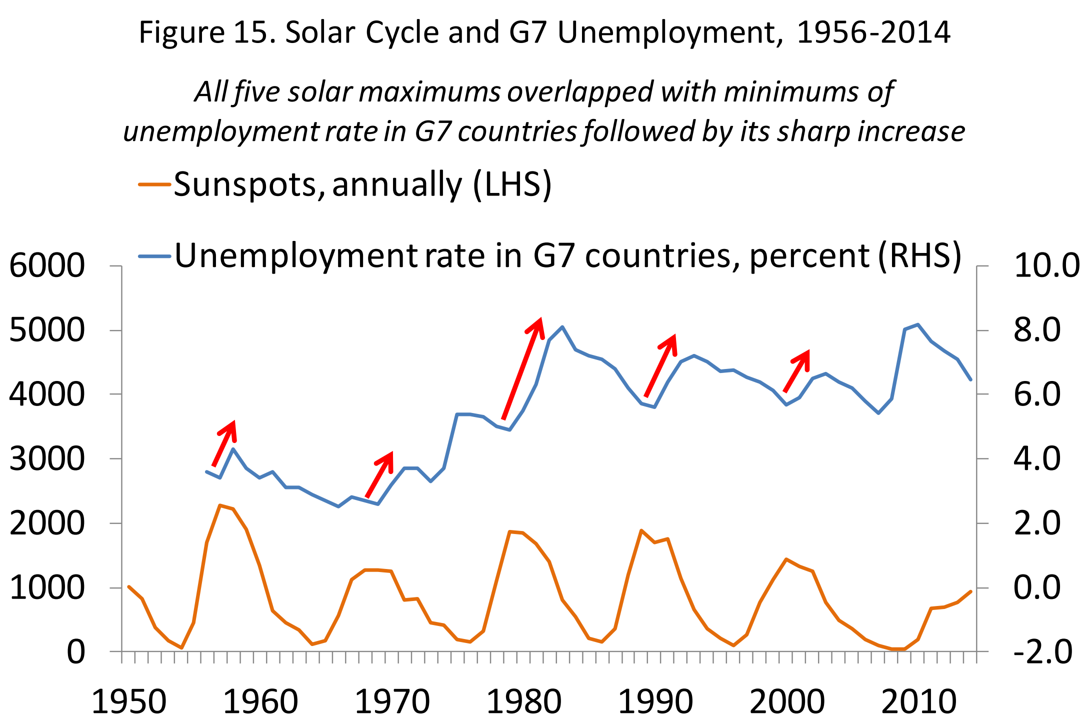
All six solar maximums overlapped with minimums of the US unemployment rate followed by its sharp increase



Sources: US Bureau of Labor Statistics; FRED; NASA.

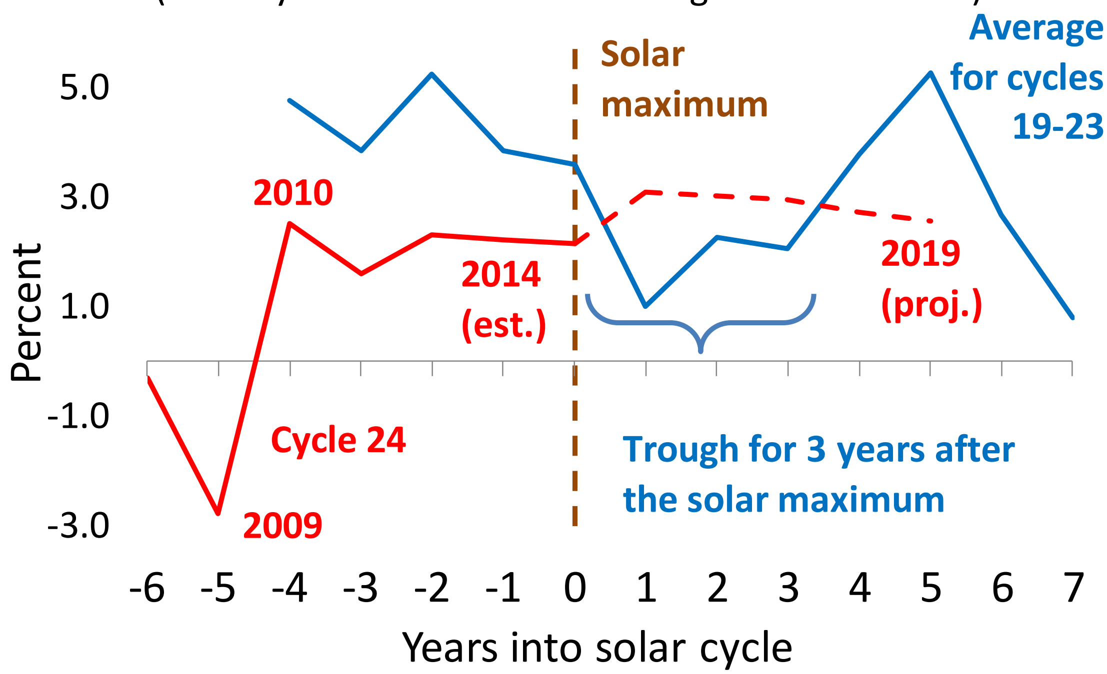


Source: IMF *WEO (October 2014);* OECD; NASA; and author's calculations.



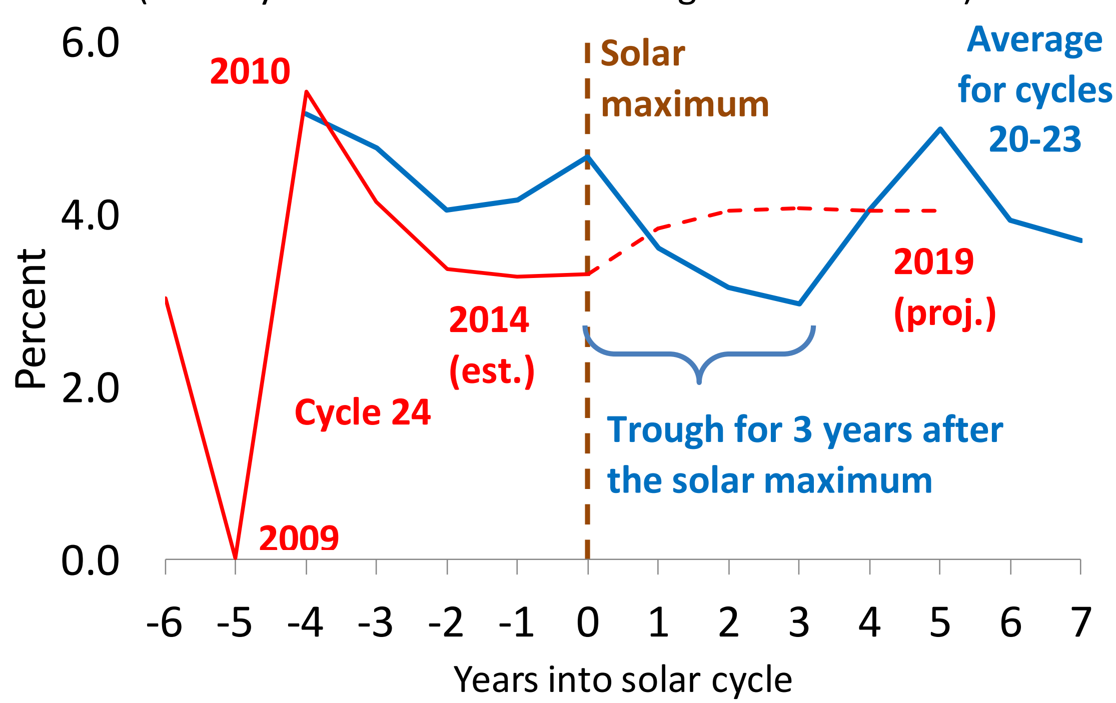
Sources: OECD; IMF *WEO (October 2014)*; NASA.

Figure 16. US GDP Growth in 1954-2014
(Solar cycles 19-24 centered along solar maximum)



Source: Bureau of Economic Analysis; IMF *WEO (October 2014)* ; NASA; and author's calculations.

Figure 17. World GDP Growth in 1964-2014
(Solar cycles 20-24 centered along solar maximum)



Source: IMF *WEO (October 2014)* ; NASA; and author's calculations.

Table 1. Sunspots and Commercial Crises of the XIX Century

Source	Time period	Crisis years	Correlation	Significance*
Hyndman (1892)	1801-1900	1815, 1825, 1836-39, 1847, 1857, 1866, 1873, 1882, 1890	**0.24**	Very high (**P=0.02**)
Hyndman (1892)	1801-1900	Crisis of 1836-39 treated as one event in 1837	0.08	Not significant
Conant (1915): Banking and financial crises	1798-1912	1810, 1814-19, 1825, 1837-39, 1847, 1857, 1864-66, 1873-79, 1882-84, 1890, 1893, 1907	0.05	Not significant

Source: Conant (1915); Hyndman (1892); and author's estimates.

* In this and other tables, significance is based on t-statistic probability distribution, with lower probability **P** standing for higher significance of the correlation. We describe the significance of correlations characterized by probabilities of up to **0.0005** as "Extremely high"; by probabilities around **0.01-0.02** as "Very high"; by probabilities on the magnitude of **0.05-0.08** as "Satisfactory"; by probabilities about **0.1** as "Low"; and by probabilities above it as "Not significant".

Table 2. US Recession Starts and Sunspots

Source	Time period	Correlation	Significance
NBER	Nov.1933-Nov.2008	**0.088**	Very high (**P=0.01**)
NBER	Sep.1901-Nov.2008	0.050	Satisfactory (P=0.07)
NBER	Jan.1855-Nov.2008	0.036	Low (P=0.12)

Source: NBER; FRED; NASA; and author's estimates.

Table 3. US Recessions in 1856-2008

(Before and after the Great Depression of 1929-33)

Time period	Jan 1856 - Oct 1933	Nov 1933 - Nov 2008
Corresponding solar cycles	10 to 16	17 to 23
Months in recession	934	901
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.

Table 4. US Recession Periods and Sunspots
(With the lag of 18 months)

Source	Time period	Correlation	Significance
NBER	Nov.1933-Nov.2008	**0.21**	Extremely high (**P<0.0001**)
NBER	Sep.1901-Nov.2008	0.04	Not significant
NBER	Jan.1955-Nov.2008	-0.02	Not significant

Source: NBER; FRED; NASA; and author's estimates.

Table 5. G7 Recessions and Sunspots

	Source	Time period	Correlation	Significance
Recession starts	NBER, ECRI	Dec.1964-Nov.2008	0.08	Satisfactory (P=0.08)
Recession length	NBER, ECRI	Dec.1964-Nov.2008	**0.22**	Extremely high (**P<0.0001**)
With 18 month lag	NBER, ECRI	Dec.1964-Nov.2008	**0.44**	Extremely high (**P<0.0001**)

Source: NBER; FRED; ECRI; NASA; and author's estimates.

Table 6. OECD CLIs and Sunspots
(With 24 months lag)

Countries	Time period	Correlation	Significance
US	Jan.1955-Aug.2014	**-0.15**	Extremely high (**P<0.0001**)
Canada	Jan.1956-Aug.2014	**-0.18**	Extremely high (**P<0.0001**)
France	Jan.1970-Aug.2014	**-0.16**	Extremely high (**P=0.0003**)
UK	Dec.1957-Aug.2014	**-0.11**	Very high (**P=0.01**)
Germany	Jan.1961-Aug.2014	**-0.10**	Very high (**P=0.01**)
Italy	Jan.1962-Aug.2014	**-0.10**	Very high (**P=0.01**)
Japan	Jan.1959-Aug.2014	-0.04	Not significant
G7	Jan.1959-Aug.2014	**-0.09**	Very high (**P=0.02**)
OECD	Jan.1961-Aug.2014	**-0.18**	Extremely high (**P<0.0001**)
OECD+6*	Jan.1970-Aug.2014	**-0.20**	Extremely high (**P<0.0001**)

Source: NBER; FRED; ECRI; NASA; and author's estimates.

*OECD plus Brazil, China, India, Indonesia, Russia and South Africa.

Table 7. US ADS, Unemployment and Sunspots
(With 24 months lag)

	Source	Time period	Correlation	Significance
ADS	US FED*	Mar.1960-Oct.2014	**-0.16**	Extremely high (**P<0.0001**)
Unemployment	Bureau of Labor Statistics	Jan.1948-Oct.2014	**0.12**	Very high (**P=0.0006**)

Source: NBER; FRED; ECRI; NASA; and author's estimates.

* Published by Federal Reserve Bank of Philadelphia.

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