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The Sun's wrath: economic effects of sunspot volatility

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Abstract

We provide empirical evidence on the negative relationship between sunspot volatility and GDP in OECD countries. Among the different sectors, we find that the information and communication sector is the most adversely affected by space weather.

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"Finally, we shall place the Sun himself at the center of the Universe."

Nicolaus Copernicus

1. Introduction

Space weather describes the way in which the Sun, and conditions in outer space more generally, impact human activity. The European Space Agency (2018) defines space weather in terms of the "environmental conditions in Earth's magnetosphere, ionosphere and thermosphere due to the Sun and the solar wind that can influence the functioning and reliability of spaceborne and ground-based systems and services or endanger property or human health." It is now well understood that extreme space weather phenomena such as geomagnetic storms represent a significant risk to infrastructures (e.g., telecommunications, broadcasting, navigation, power distribution), especially at northern latitudes. While the study of space weather is a rapidly growing field, academic work to assess its overall social and economic impacts appears to be in its infancy. Our objective in this study, therefore, is to provide initial estimates of the impact of space weather on economic variables. To the best of our knowledge, we are the first to use econometric methods to study the impacts of space weather on economic activity.

It is well-understood that solar activity tends to be more intense the larger the groups of sunspots are. Thus, we use the volatility in sunspot frequency as our measure of solar activity. The evidence we present shows a small but statistically significant effect of solar activity in OECD countries: on average, GDP decreases by at least 0.06 percent for every 1 percent increase in solar activity. Furthermore, this negative effect is amplified for countries in higher latitudes. The qualitative features of these estimates are insensitive to the presence of country fixed effects, year fixed effects, additional control variables, and first differencing. Among different production sectors in OECD economies, the information and communication sector appear to be the most significantly affected by space weather. Precisely, a one percentage point increase in solar activity lowers production in the information and communication sector by 1.07 percentage points.

Our study contributes to the larger empirical literature on the social and economic effects of geophysical and meteorological phenomena (e.g., Dell, et al., 2012; Hsiang and Narita, 2012; Cavallo, et al., 2013; Felbermayr and Gröschl, 2014). More directly relevant for our study is Eastwood, et al. (2017) where they reviewed documented impacts of space weather phenomena across sectors and examined attempts to quantify its economic consequences. What makes our study distinct from Eastwood, et al. (2017) is that we provide direct estimates of the economic cost of extreme space weather phenomena.

2. Space weather and its effects

Throughout this study, we use the volatility of sunspots as our measure of solar activity. Sunspots are temporary phenomena on the Sun's photosphere that appear darker than the surrounding areas. Indicating intense magnetic activity, sunspots accompany secondary phenomena such as bursts of electromagnetic radiation (flares) and eruptions of material (coronal mass ejections, CMEs) accompanied by solar energetic particles (SEPs). A solar flare is a sudden release of energy from the Sun, while a CME shoots hot plasma from the Sun into space. The precise mechanisms that trigger flares and CMEs are still being debated, but the bigger the group of sunspots, the more intense such solar activity tends to be. In this study, we use the publicly-available Sunspot Index and Long-term Solar Observations (SILSO) dataset published by the Royal Observatory of Belgium. The data on the frequency of sunspots (annual) from 1759 to 2017 is shown in Fig. 1. We can clearly see that solar activity follows a cyclical pattern, known as the solar cycle, lasting about 10-12 years each. Also shown in the figure is the volatility of sunspot activity. Volatility was computed from the standard deviation in sunspot frequency via a rolling window of 10 years which roughly corresponds to each solar cycle. We find that there is a cyclical pattern in the volatility of solar activity, with peak volatility occurring in 1963.

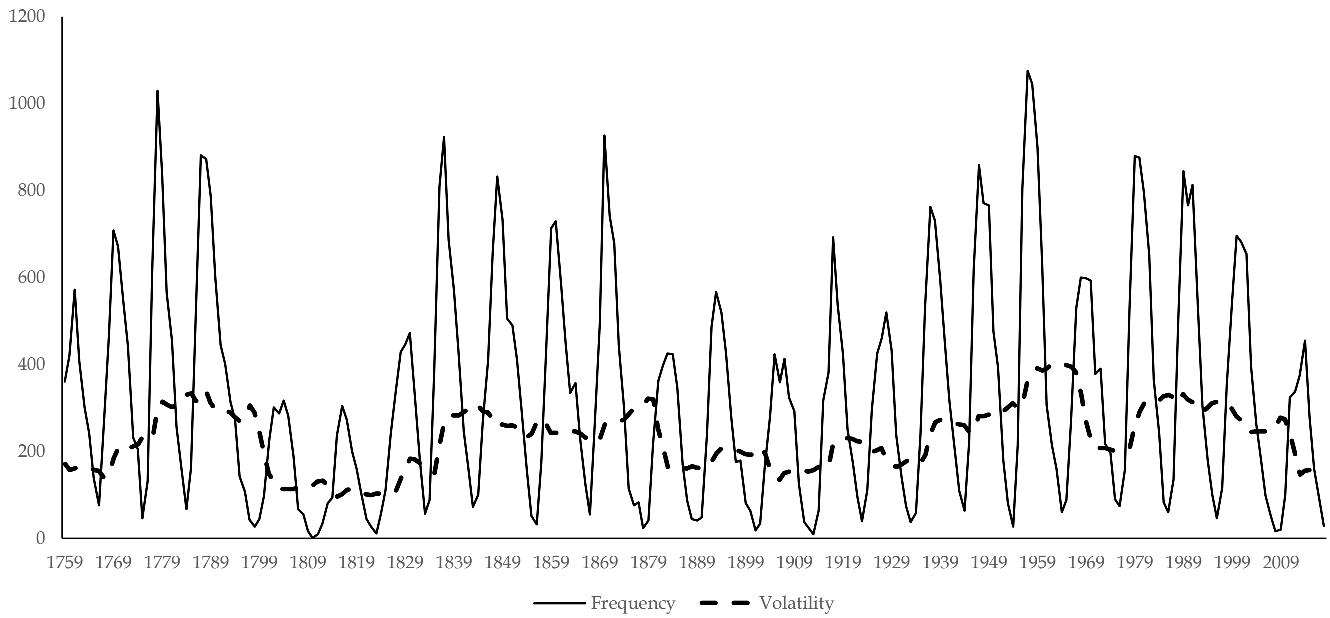

Figure 1: Frequency and volatility of sunspots from 1749 to 2017.

Flares and CMEs send enormous amounts of energy and charged particles hurtling into collision with the Earth's atmosphere, where they can cause geomagnetic storms. According to Eastwood, et al. (2017), these storms produce numerous effects such as voltage disruptions leading to power outages, changes in oil pipeline to soil voltage that drive enhanced corrosion, disruption in satellite, radio, and cellular communications networks, exposure to elevated levels of radiation, or reduced flights in polar routes. The adverse economic impacts of solar activity on the North American power grid has been well-documented. For instance, 4% of the power disturbances between 1992 and 2010 reported to the U.S. Department of Energy are attributable to strong geomagnetic activity (Schrijver, et al., 2013) . Interestingly, the effects of geomagnetic storms are not restricted to high latitudes and have been documented in the United Kingdom, Finland, Sweden, Spain, the United States and Canada, South Africa, Japan, China, and Brazil (Eastwood, et al., 2017).

3. Empirical results

Our identification strategy exploits the fact that the variation in solar activity is entirely exogenous, driven by the solar cycles. The geographical location of the country, and more specifically its latitude, is also important: the effects of intense solar activity are hypothesized to be stronger in higher latitudes. We can implement this identification strategy by estimating the following equation:

$$y_{i,t} = \beta solar\_activity_{t-1} + \gamma solar\_activity_{t-1} \times latitude_i + \kappa_i + \tau_t + \varepsilon_{i,t}. \quad (1)$$

The subscript *i* indexes the country and *j* the year. The variable *y* is an economic outcome variable (measured annually). The variable $solar\_activity$ is the log of the computed volatility in sunspot frequency (measured annually) lagged one period), our proxy for solar activity. The variable *latitude* is the log absolute value of the latitude of the country (i.e., a measure of distance from the equator), scaled to take values between 0 and 100, where 0 is the equator. The parameters κ and τ are country and time fixed effects, respectively. For as long as we control for year and country fixed effects, we automatically control for any possible independent effects of solar activity and country latitude. We are then left with the variation due to the interaction of the two factors, and this is what we exploit. For the economic outcome variable, we consider a panel of GDP and value added from different sectors covering 1995-2017, all in logs, per capita, and expressed in constant 2010 prices, sourced from the OECD online database. The sectors considered are: Agriculture, forestry, and fishing; Industry, including energy; Manufacturing; Transport; Information and communication; and Other sectors.

Table 1 reports our regression results. Column (1) shows a bivariate regression of log real GDP capita on solar activity. We find that a one percentage point increase in sunspot volatility reduces real GDP per capita by 0.88 percentage points. Column (2) then includes country fixed effects, to control for factors that affect GDP and covaries with country latitude. We see a similar negative coefficient, implying that for a given country, years with intense solar activity display on average lower output. Column (3) includes year fixed effects instead, to control for determinants of GDP that also covary with the timing of solar activity. The estimated coefficient is smaller in magnitude, suggesting that focusing on the within-country variation if anything overestimates the true negative effect of intense solar activity. Column (4) then displays the specification which includes both year and country fixed effects. The estimate is again statistically significant, very similar in magnitude, and shows that intense solar activity has a negative effect on GDP. Column (5) reports the estimated effect with the interaction specification. The interaction term is negative and statistically significant suggesting that the negative effect of intense solar activity to GDP is amplified in higher latitudes. Column (6) displays the estimated effect with lagged unemployment rate as an additional control variable. The estimate remains negative, statistically significant, and similar in magnitude as in the other specifications. There is a statistical concern that the previous estimates are driven by non-stationarity of solar activity and GDP, thereby making these results spurious. Hence, we transform the variables to induce stationary by first differencing. Column (7) present the result with first differences and reassuringly we find a coefficient, although very small in magnitude (0.06), that is negative and statistically significant. In all, we find that the negative effect of intense solar activity to GDP is less than 1 percent, with a low of 0.06 to a high of 0.875. Table 2 reports the regression results for sectoral production. Among the different sectors, we find that the information and communication sector as the most affected by solar weather. Our results

Table 1: The effects of solar activity in OECD countries.

Dependent variable.: Real GDP per capita (2010 prices)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Levels						First difference
Solar activity (t-1)	--- 0.875***	--- 0.875***	-0.862***	-0.862***	-0.580***	-0.854***	-0.059***
	(0. 062)	(0.029)	(0.049)	(0.050)	(0.122)	(0.049)	(0.010)
Solar activity (t-1) × Latitude					-0.005**		
					(0.002)		
Unemployment rate (t-1)						-0.022	
						(0.014)	
Observations	756	756	756	756	714	756	720
R squared	0. 185	0.853	0.291	0.953	0.843	0.956	0.024
Country FE	No	Yes	No	Yes	Yes	Yes	No
Year FE	No	No	Yes	Yes	No	Yes	No
Standardized effect	-0.430	-0.430	-0.424	-0.424	N/A	-0.670	-0.155

Notes: Robust standard errors in parentheses, clustered at the country level. *** p < .01, ** p < .05, * p < .1.

Table 2: The effects of solar activity across production sectors in OECD countries.

Production sectors	Marginal effect of solar activity	Standardized effect of solar activity	R squared	Observations
Agriculture, forestry, and fishing	-0.321*** (0.067)	-0.154	0.913	738
Industry, including energy	-0.709*** (0.069	-0.371	0.912	738
Manufacturing	-0.620*** (0.077)	-0.318	0.903	738
Transportation	-0.891*** (0.063)	-0.498	0.935	738
Information and communication	-1.077*** (0.074)	-0.396	0.959	738
Other	-1.043*** (0.058)	-0.410	0.964	738

Notes: Robust standard errors in parentheses, clustered at the country level. All regressions include country and year fixed effects. *** p < .01, ** p < .05, * p < .1.

indicate production in the information and communication sector decreases by 1.07 percentage points for every one percentage increase in solar activity. In all regressions we obtain a negative and statistically significant marginal effect for solar activity, which is consistent with the idea that intense solar activity can produce adverse effects in the economy.

4. Conclusion

Using econometric methods, we were able to provide the first direct estimates of the economic impact of intense solar activity. We believe that our findings can be used to guide future theoretical and empirical research in further understanding the economic impacts of space weather.

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