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Does sunspot numbers cause global temperatures? A reconsideration using non-parametric causality tests[☆]

Hossein Hassani[a,*], Xu Huang[b], Rangan Gupta[c], Mansi Ghodsi[a]

[a] Institute for International Energy Studies (IIES), Tehran 1967743 711, Iran
[b] The Statistical Research Centre, Bournemouth University, UK
[c] Department of Economics, University of Pretoria, Pretoria, 0002, South Africa

HIGHLIGHTS

- A non-parametric Singular Spectrum Analysis based causality test is proposed.
- SSA-based causality test outperformed time and frequency domain causality tests.
- The new non-parametric technique can capture the possibly existing nonlinearities.
- Predictive ability is detected from sunspot numbers on global temperatures.

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ABSTRACT

In a recent paper, Gupta et al., (2015), analyzed whether sunspot numbers cause global temperatures based on monthly data covering the period 1880:1–2013:9. The authors find that standard time domain Granger causality test fails to reject the null hypothesis that sunspot numbers do not cause global temperatures for both full and sub-samples, namely 1880:1–1936:2, 1936:3–1986:11 and 1986:12–2013:9 (identified based on tests of structural breaks). However, frequency domain causality test detects predictability for the full-sample at short (2–2.6 months) cycle lengths, but not the sub-samples. But since, full-sample causality cannot be relied upon due to structural breaks, Gupta et al., (2015) conclude that the evidence of causality running from sunspot numbers to global temperatures is weak and inconclusive. Given the importance of the issue of global warming, our current paper aims to revisit this issue of whether sunspot numbers cause global temperatures, using the same data set and sub-samples used by Gupta et al., (2015), based on an nonparametric Singular Spectrum Analysis (SSA)-based causality test. Based on this test, we however, show that sunspot numbers have predictive ability for global temperatures for the three sub-samples, over and above the full-sample. Thus, generally speaking, our non-parametric SSA-based causality test outperformed both time domain and frequency domain causality tests and highlighted that sunspot numbers have always been important in predicting global temperatures.

1. Introduction

Global warming, i.e., rising temperature of the earth's surface, is undoubtedly the biggest topic of research amongst researchers working on environment. While, analyzing the impact of global warming cannot be ignored, but what factors

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* Corresponding author.
E-mail address: hassani.stat@gmail.com (H. Hassani).

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drive it is perhaps more important, as it not only allows us to predict global warming, but also takes measures to control it. It is quite well-accepted that global warming is due to greenhouse gases, additionally, there is a large literature[1] that relates the same with solar activity. However, the evidence from this literature is, at best, mixed. While there are studies (see for example, Refs. [3–11]) that find significant relationships between solar radiation and global temperatures, one hand. On the other hand, there are some authors who claim that the two variables are unrelated (see for example, Refs. [12–16]). Thus, there is no clear-cut consensus about the possibility of a relationship between solar irradiance and global temperatures [17].

Against this backdrop, using sunspot numbers as a proxy for solar activity, Gupta et al. [2], recently analyzed whether sunspot numbers cause global temperatures based on monthly data covering the period 1880:1–2013:9. However, at this stage, it is important to point out, as indicated by Scafetta [18], sunspot numbers can only be considered as a ''partial proxy'' for solar activity. This is because time intervals between major solar flares, cosmic ray records, ACRIM composite of total solar irradiance satellite measurement, multi-scale thermal models of several total solar irradiances, and solar and astronomical oscillations are also possible, and perhaps, better proxies for solar activity than sunspot numbers. In addition, one must be cautious in suggesting that sunspot numbers are linearly and positively related to solar activity due to the intrinsic complexity of solar dynamics and of its multiple coupled phenomena, as discussed in detail in Ref. [18]. Gupta et al. [2] find that standard time domain Granger causality test fails to reject the null hypothesis that sunspot numbers do not cause global temperatures for both full and sub-samples, namely 1880:1–1936:2, 1936:3–1986:11 and 1986:12–2013:9 (identified based on tests of structural breaks). However, frequency domain causality test detects predictability for the full-sample at short (2–2.6 months) cycle lengths. Interestingly however, the study could not detect any causality for the sub-samples. Gupta et al. [2] thus, highlight the importance of analyzing causality using the frequency domain tests, which, unlike the time domain Granger causality test, allows one to decompose causality by different time horizons, and hence, possibly detect predictability at certain cycle lengths even when the time domain causality test might fail to pick up any causality. However, given that there exist structural breaks in the sample, Gupta et al. [2], suggest that the relationship could be spurious based on a full-sample analysis, since a full-sample analysis assumes stability of the parameters of a VAR, which is clearly not the case in the presence of breaks, and which is also vindicated by the fact that there is no evidence of causality over the sub-samples.

Given the importance of the issue of global warming, and more importantly the lack of evidence in favor of sunspot numbers leading to global temperatures in linear models, our current paper aims to revisit this issue of whether sunspot numbers cause global temperatures, using the same data set and sub-samples used by Gupta et al. [2], based on Singular Spectrum Analysis (SSA) technique, which is a new nonparametric technique known for both time series analysis and forecasting (as discussed further in Refs. [19–25]). The reason behind using a nonparametric technique is to capture possible nonlinearities that could exist in the data generating processes of the global temperatures and sunspots individually [18], as well as, in the relationship between global temperatures and sunspot activity, for instance due to the structural breaks detected by Gupta et al. [2]. The SSA being a nonparametric method captures the possible nonlinearities using a data-driven approach, without specifying any known functional nonlinear model to the relationship, which in turn, could be incorrectly specified in the first place, just like the linear model, on which time domain and frequency domain Granger causality tests are based on. Further, as pointed out by Aguirre et al. [26], the difficulties encountered in modeling sunspot numbers and global temperature data are due to the apparent nonstationarity property of the series and the complex dynamic fluctuations in the cycle amplitude of the sunspot number series. In other words, these complexities could be driving the mixed results discussed above in terms of the relationship between these two variables. In light of this, the importance of the nonparametric SSA-based causality cannot be underestimated, which besides being a nonlinear data-driven approach, also does not require pretesting to ensure that the variables under consideration are stationary [19–25].

The paper is structured as follows: Given that time and frequency domain causality tests were already discussed in Ref. [2], the details of the frequency domain causality test have been relegated to Appendix for the sake of completeness, with Section 2 introducing the SSA-based causality test (following the works of Hassani and Mahmoudvand [25]). Section 3 presents the data and empirical results. Finally, Section 4 concludes.

2. Methodology: the SSA-based causality test (MSSA)

Multivariate singular spectrum analysis (MSSA) is an extension of the standard Singular Spectrum Analysis (SSA) to the case of multivariate time series [19,20], in which SSA is a relatively new nonparametric technique known for both time series analysis and forecasting, detailed description can be found in Ref. [19]. After Broomhead and King [27] theoretically proposed the MSSA technique in the context of nonlinear dynamics for the first time, it has been widely applied on a range of different fields and a multitude of fairly precise results proved it as powerful and applicable technique, numerous applications and examples can be found in Refs. [19,21–24,28,20,25,29]. From the perspective of MSSA, two main concerns that make the problem more complex are: (i) similarity and orthogonality among series play an important rule for selecting the window length L and the number of eigenvalues r, and (ii) MSSA deals with a block trajectory Hankel matrix with special features rather than one simple Hankel matrix [25]. Briefly descriptions of MSSA and causality criteria are listed in following subsections.

1 The reader is referred to Gray et al. [1] and Gupta et al. [2] for further details.