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Energy consumption, carbon emissions, and economic growth in India: Evidence from directed acyclic graphs

Zihui Yang [a,*], Yongliang Zhao [b]

[a] Lingnan College, Sun Yat-Sen University, 135 Xingang Xi Road, Guangzhou 510275, People's Republic of China
[b] College of Economics, Jinan University, No. 601, Huangpu Avenue West, Tianhe, Guangzhou 510632, People's Republic of China

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ABSTRACT

This study investigates the temporal linkages among economic growth, energy consumption, and carbon emissions for India during the period 1970–2008 using recently developed methods of out-of-sample Granger causality tests and directed acyclic graphs (DAG). Building on the data-driven DAG representation, we uncover the contemporaneous causal patterns between economic activities and environmental pollutants, which is first documented in the literature and could further improve the investigation of the dynamic linkage pattern. The results show that energy consumption uni-directionally Granger causes carbon emissions and economic growth, while there is a bidirectional causality between carbon emissions and economic growth. We also find that trade openness is one of the important determinants of energy consumption and carbon emissions. Some important policy implications are also discussed.

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1. Introduction

With increasing concern over global warming and growing carbon dioxide (CO_2) emissions in developing countries like India, associations between environmental pollutants and economic activities in developing countries have received more and more attention in the literature. Unfortunately, despite the abundance of research on this topic, the empirical literature has not yet reached a consensus about whether economic growth is the cause or effect of energy consumption, and whether economic growth is the solution or source of environmental pollution problem (known as EKC hypothesis). Thus, further investigation of the relationship between energy consumption, carbon emissions, and economic growth appears warranted.

In a brief review of the empirical literature, we find three different groups of studies on the relationship between economic activities and environmental pollutants. The first one considers those studies that explore the economic growth–environmental pollutant nexus. In particular, this strand of research examines the environmental Kuznets curve (EKC) hypothesis, which states that there exists an inverted U-shaped relationship between environmental degradation and economic growth. Since the seminal work of Grossman and Krueger (1991) who proposes and tests the EKC hypothesis, there has been a vast body of EKC literature exploring the linear (e.g., de Bruyn et al., 1998; Shafik, 1994), quadratic (e.g., Holtz-Eakin and Selden, 1995; Roberts and Grimes, 1997) and cubic (e.g., Grossman and Krueger, 1995; Harbaugh et al., 2002) reduce-form relationships between CO_2 emissions and per capital income. However, as summarized in the survey of Dinda (2004), Stern (2004) and Kijima et al. (2010), the EKC model is subjected to criticism including omitted variables bias (Stern and Common, 2001), as well as no feedback from environmental damage to economic production (Coondoo and Dinda, 2002).

The second bulk of studies is related to examine the causal relationship between the energy consumption and economic growth. Starting from the initial pioneering work of Kraft and Kraft (1978) who find a unidirectional causality running from economic growth to energy consumption in the U.S., researchers have paid considerable attention to the economical growth–energy consumption nexus. However, mixed and conflicting evidences are often found in extant literature. For example, Abosedra and Baghestani (1989), Cheng and Lai (1997), Yemane (2004), Lee (2005), among others, find unidirectional causality either from energy consumption to economical growth or vice versa, while Yu and Hwang (1984), Hwang and Gum (1992), Yang (2000), Glasure (2002), Hondroyiannis et al. (2002) and Oh and Lee (2004) find bidirectional causality or no causality. More, existing empirical studies are often conducted in a bivariate framework using Granger-causality test and may thus suffer from the problem of omitted variables bias (see Stern, 1993, 2000).

The third group of empirical studies has emerged in the recent literature which has sought to combine the above two strands of empirical literature and investigate the dynamic causal relationships between environmental pollutants, energy consumption and economic growth

* Corresponding author. Tel.: +86 20 84039466; fax: +86 20 84114823.
E-mail addresses: yzh2016@gmail.com (Z. Yang), ericjue@sohu.com (Y. Zhao).

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within the same framework. Soytas et al. (2007), Ang (2008), Soytas and Sari (2009), Zhang and Cheng (2009) and Halicioglu (2009) are some of the contributions to this recently developed area. In particular, this new strand of the literature utilizes time series techniques to investigate the inter-temporal links in the energy–environment–growth nexus for different countries, but again finds mixed and inconclusive results.

The purpose of this paper is to empirically investigate the relationships among energy consumption, CO_2 emissions and economic growth in India in the same multivariate framework. The contributions of our study to the existing literature are as follows. First, unlike most pervious research that relies on traditional in-sample Granger causality tests, this study employs multivariate out-of-sample Granger causality tests to investigate the relationship among energy consumption, economic growth, and carbon emissions. Recent research argues that out-of-sample Granger causality test based on forecasting performance is more in the spirit of the original definition of causality proposed by Granger (1969) and may be more powerful than the standard in-sample test. However, these important insights have not received proper attention it merits until recently Chao et al. (2001) and Corradi and Swanson (2002), among others, advocate using out-of-sample forecast comparisons to test Granger causality. As pointed out by Ashley et al. (1980), "a sound and natural approach to such [Granger causality] test must rely on the out-of-sample forecasting performance of models relating the original (non-prewhitened) series of interest". According to Chao et al. (2001), the choice of out-of-sample versus in-sample Granger causality tests can impact causal inference significantly. As documented in Chen (2005), out-of-sample tests may provide better information about causality than in-sample tests when time series are characterized by discrete structural breaks. More, Clark (2004) provides Monte Carlo evidence suggesting that out-of-sample tests are less subject to overfitting. In light of these reasons, we use several newly developed out-of-sample Granger causality tests to infer Granger causality inference.

Second, and more importantly, we apply the directed acyclic graph (DAG) technique (Pearl, 2000; Spirtes et al., 2000; Swanson and Granger, 1997) to explore the important contemporaneous causal pattern among energy consumption, economic growth, and carbon emissions, which is used to conduct a data-determined structural decomposition of the VAR analysis. The conventional VAR analysis (i.e. forecast error variance decomposition) widely relies on a Cholesky decomposition to achieve a just-identified system in contemporaneous time, which is severely criticized for imposing a rather restrict and somewhat unrealistic assumption of a recursive contemporaneous causal structure (see, for example, Bernanke, 1986; Cooley and LeRoy, 1985; Swanson and Granger, 1997, among others). The application of this relatively new technique, which has not been previously used in the energy economics literature, not only provides evidence previously unavailable on contemporaneous causal relationships in income–energy–environment nexus, but also offers a specific and data-determined pattern for the structure decomposition of VAR residuals and further improves VAR innovation accounting analysis.

Third, we attempt to extend the above multivariate framework by taking the impacts of trade openness on energy consumption and CO_2 emissions into account. According to Wyckoff and Roop (1994), about 13% of the total carbon emissions of the six largest OECD countries are embodied in their imports of manufactured goods. Schaeffer and Leal de Sa (1996) reveal that the liberalization of international trade facilitates the increasing transfer of CO_2 emissions from developed countries to developing countries. In a recent study on the dynamic relationships between CO_2 emissions, energy consumption, income and foreign trade in Turkey, Halicioglu (2009) confirms that impact of foreign trade on CO_2 emissions seems to be noticeable. In light of these findings, this study aims to enrich the existing literature by incorporating trade openness in the energy–environment–growth nexus to shed new light to its influence on energy consumption and CO_2 emissions.

Investigation of the relationship among energy consumption, CO_2 emissions and economic growth in India is important given that India is one of the fastest growing economies and the second most populous country in the world with more than one billion people, which means that its energy consumption and CO_2 emissions will continue to rise in the future. The choice of this country is also motivated by the fact that India has been the world's fourth largest energy consumer (EIA, 2011), and the world's third biggest emitter of CO_2 that accounts for more than 5% of global CO_2 emissions (IEA, 2011). What's more, India's primary energy supply will increase by at least 3 to 4 times by 2031 with respect to the base financial year 2003 (Ghosh, 2010), and the most carbon-intensive of fossil fuel — coal is projected to continue to remain its dominating position in order to make energy price affordable. Clearly, exploring the intertemporal relationship between energy consumption, CO_2 emissions and economic growth in India helps to design effective energy and environmental policies.

The organization of the remainder of this paper is as follows. The next section briefly describes the empirical methodology employed. Section 3 describes the data and analyzes the main empirical findings. Finally, the summary and the policy implications of our findings are outlined in Section 4.

2. Methodology

To the best of the authors' knowledge, this is the first study that applies recently developed methods of out-of-sample Granger causality tests and directed acyclic graphs to investigate linkages among economic growth, energy consumption, and carbon emissions. Below a brief discussion of the methods will be provided.

2.1. Out-of-sample Granger causality tests

As mentioned above, out-of-sample Granger causality tests are conducted based on forecasting performance and more closely aligned with the spirit of the original concept of Granger causality, and could provide the best information bearing on hypothesis about causation (Ashley et al., 1980, p.1149). To see this, let us start with the following nested model:

$$z_t = a_1 + \beta_{11} z_{t-1} + \mu_{1t} \tag{1}$$

$$z_t = a_2 + \beta_{11} z_{t-1} + \beta_{21} w_{t-1} + \mu_{2t}. \tag{2}$$

The series w_t Granger causes z_t if the past of w_t contains additional information on future values of z_t after controlling for the past of z_t. Therefore, it appears to be in keeping with the spirit of definition to carry out Granger causality tests by comparing the out-of-sample forecasting performance of these two nested models. Specifically, to implement the out-of-sample forecast, we divide the sample of T observations into in-sample and out-sample portions. The number of in-sample and out-of-sample observations is denoted by R and P, respectively, and $R + P = T$. We adopt a recursive scheme for forecasting, where as forecasting moves forward in time, forecasting models are re-estimated with more data. The one-step-ahead recursive forecasts of z_t are generated for the P observations, and the corresponding forecast errors series from the unrestricted model (2) and the restricted model (1) are denoted as $\hat{e}_{2,t}$ and $\hat{e}_{1,t}$, respectively. If the unrestricted model (2) forecasts are significantly superior to the restricted model (1) forecasts, i.e. if $\hat{e}_{2,t}$ is smaller than $\hat{e}_{1,t}$, then w_t Granger-causes z_t in an out-of-sample sense.

In order to evaluate the out-of-sample forecasting performance of these two models and test the null hypothesis of no Granger causality, in our study four test statistics are performed. Of these four statistics, Diebold and Mariano (1995) *MSE–t* statistic and the McCracken (2007) *MSE–F* statistic are based on forecast accuracy, while Harvey

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