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Analysis

Energy consumption, carbon emissions, and economic growth in China

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ABSTRACT

This paper investigates the existence and direction of Granger causality between economic growth, energy consumption, and carbon emissions in China, applying a multivariate model of economic growth, energy use, carbon emissions, capital and urban population. Empirical results for China over the period 1960–2007 suggest a unidirectional Granger causality running from GDP to energy consumption, and a unidirectional Granger causality running from energy consumption to carbon emissions in the long run. Evidence shows that neither carbon emissions nor energy consumption leads economic growth. Therefore, the government of China can purse conservative energy policy and carbon emissions reduction policy in the long run without impeding economic growth.

1. Introduction

Global warming has been one of the most important environmental problems of our ages. The ever increasing amount of carbon dioxide (CO_2), the dominant contributor to the greenhouse effect, seems to be aggravating this problem. Academics and practitioner alike have been debating about reducing greenhouse gas (GHG) emissions to alleviate global warming.

There seems to be basically three research strands in literature on the relationship between economic growth and environmental pollutants. The first strand focuses on the environmental pollutants and economic growth nexus. It is closely related to testing the validity of the so-called environmental Kuznets curve (EKC) hypothesis, which postulates an inverted U-shaped relationship between the level of environmental degradation and income growth. That is to say, environmental degradation increases with per capita income during the early stages of economic growth, and then declines with per capita income after arriving at a threshold. Ever since the original empirical study of Grossman and Krueger (1991), an increasing body of literature has tested the economic growth and environmental pollution nexus.[1] However, the empirical results appear to be controversial. The EKC model is severely criticized for lack of feedback from environmental pollutants to economic output as income is assumed to be an exogenous variable (see Arrow et al., 1995; Stern, 2004; Hung and Shaw, 2002; among others). Hill and Magnani (2002), Stern (2004), and Dinda (2004) provided extensive reviews of this EKC research.

The second strand concentrates on the link between economic output and energy consumption, since the emissions are mainly caused by burning fossil fuels. Following the seminal study of Kraft and Kraft (1978), an increasing number of studies has assessed the empirical evidence employing Granger causality and cointegration model. The earlier studies mostly apply a bivariate model and fail to get consensus results. The bivariate model is criticized in many econometric issues, especially the omitted variables bias. Stern (1993) argued that bivariate tests may fail to detect causality because of the substitution effects that may occur between energy and other inputs. Employing a multivariate model with energy consumption, gross domestic product (GDP), capital, and labor force, Stern (1993) found Granger causality running from energy use to GDP for the USA. Following Stern (1993), a considerable number of studies[2] has tested the causal relationship between the energy consumption and economic output in a multivariate context. However, the multivariate studies also produce conflicting results. Huang et al. (2008) provided a good review on the empirical results from causality tests.

An assessment of the existing literature indicates that most studies focus on the nexus of output-energy or output-pollution. Only recently, a combined approach of those two methods has emerged which is implied to investigate the inter-temporal links in the energy–environment–income nexus. Appling a multivariate model with income, energy

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[1] See, e.g. de Bruyn and Opschoor (1997), Unruh and Moomaw (1998), Heil and Selden (1999), Taskin and Zaim (2000), Friedl and Getzner (2003), Coondoo and Dinda (2008), and Managi and Jena (2008).

[2] See, e.g., Masih and Masih (1998);Asafu-Adjaye (2000);Stern (2000);Ghali and El-Sakka (2004);Oh and Lee (2004); Lee (2005).

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consumption, carbon emissions, gross fixed capital formation, and labor force, Soytas et al. (2007) found no Granger causality between income and carbon emissions, and no Granger causality between energy use and income in the US. But energy consumption Granger causes the carbon emissions in the long run. Using the same approaches and variables as that of Soytas et al. (2007), Soytas and Sari (2009) found the same link between income and carbon emissions in Turkey. However, the carbon emissions Granger cause the energy consumption in the long run. The lack of a long run Granger causality between income and carbon emissions provides evidence that both the US and Turkey reduce carbon emissions without forgoing economic growth. Applying the bounds testing to cointegration procedure in a multivariate model with carbon emissions, energy use, income, and foreign trade, Halicioglu (2009) found that there is a bi-directional Granger causality (both in short and long run) between the carbon emissions and income in Turkey. This result is conflicting with that of Soytas and Sari (2009). Ang (2008) found that output growth Granger causes energy consumption in Malaysia. However, weak evidence of causality running from carbon emissions to income in the long run, but no feedback link is observed.

In the first two research strands, there are even a more limited number of examples that examine the nexus between economic growth and environmental degradation in China. Song et al. (2008) investigated the relationship between environmental pollution and economic growth in China based on the EKC hypothesis using Chinese provincial data. It is found that there is a long run cointegration relationship between per capita emissions of three pollutants (waste gas, waste water, and solid wastes) and per capita GDP. Furthermore, the results showed that all three pollutants are inverse U-shaped in China. Soytas and Sari (2006) found that there is no Granger causality between income and energy use in China. The empirical study of Yuan et al. (2008) showed there is a bilateral Granger causality between GDP and energy use in the long run, and unidirectional Granger causality from GDP to energy use in the short run in China. The causality results of previous studies for China are summarized in Appendix A. The empirical studies using the same country data also failed to achieve unanimous conclusions. To the best of our knowledge, no study has been conducted to examine the relationship between economic growth, energy use, and pollutant emissions under the same framework in China. As such, this is one of our major contributions.

The choice of China is also motivated by the fact that China has been the second largest energy consumer and energy-related CO_2 emitter in the world. As a developing country, China is one of the highest growth economies in the world, and it has experienced a significant rise in energy consumption and carbon emissions in recent decades. During the period 1980–2007, the average annual growth rate of GDP is more than 9%, the primary energy consumption increased by about 340%, and carbon dioxide emissions sharply increased by about 352%. The Kyoto Protocol is severely criticized for lack of inclusion of emission reduction obligations for developing countries, as Pittel and Rübbelke (2008) points out: “Due to the rising importance of developing countries' contribution to climate change, their participation in an international problem–solution approach becomes crucial.”[3] China should make effective policies in reducing CO_2 emissions to alleviate global warming, although its per capita emissions are very low. Therefore, we examine the inter-temporal relationship in income–energy–environment nexus, which has good policy implications for China to reduce CO_2 emissions.

The remainder of this paper is organized as follows: the next section describes the econometric methodology used in the study; Section 3 discuses data used and unit root tests; the fourth section presents Granger causality results; Section 5 presents generalized impulse responses, followed by conclusion and policy analysis in Section 6.

[3] China, India, and other developing countries are not included in any numerical limits under the treaty.

2. Methodology

Vector autoregression (VAR) and error correction model (ECM) are often used to examine the Granger causality among variables. To that respect one could conduct a VAR in first-order differences of the variables if variables were known to be $I(1)$ (integrated of order one) with no cointegration, and one could conduct an ECM if the variables were known as to be cointegrated. Hence, whether the variables are integrated, cointegrated, or (trend) stationary is usually pre-tested. Toda (1995) showed that the pre-tests for cointegration ranks in Johansen-type ECM are very sensitive to the values of the nuisance parameters in finite sample. Hence causality inference in ECM may suffer from severe pretest biases. If the system contains unit roots, standard Wald statistics based on ordinary least-squares (OLS) estimation of level VAR model for testing coefficient restrictions have non-standard asymptotic distributions that may involve nuisance parameters (see, e.g., Sims et al., 1990; Toda and Phillips, 1993). The augmented VAR approach proposed by Toda and Yamamoto (1995) (thereafter TY), on the other hand, has much practical appeal because it can be applied for any arbitrary level of integration. Zapata and Rambaldi (1997) pointed, the TY procedure has a high power of the test in moderate to large samples; If there is uncertainty as to whether the variables are $I(0)$ or $I(1)$, the TY procedure is being performed on the safe side. Yamada and Toda (1998) showed, the FM-VAR (proposed by Phillips, 1995) and ECM procedures are more powerful than TY procedure. However, the actual size of the TY procedure based test is stable for sample sizes that are typical for economic time series data, and the FM-VAR and ECM procedures tend to have larger size distortion than TY procedure. The serious size distortion may not be acceptable, and therefore the TY procedure is appealing for its small size distortion. Following Soytas et al. (2007) and Soytas and Sari (2009), we apply TY procedure to examine the income–energy–environment nexus in China. The TY procedure steps are as follows:

(i) Find the maximal order of integration d of variables by conducting unit root tests.
(ii) Determine the optimum lag length p of a VAR. Since the true lag length p is rarely known in practice, we can estimate it by several criteria.
(iii) Estimate the lag-augmented VAR($p+d$) model:

$$\mathrm{V}_t = \boldsymbol{\alpha} + \boldsymbol{\beta}_1\mathrm{V}_{t-1} + \boldsymbol{\beta}_2\mathrm{V}_{t-2} + \ldots + \boldsymbol{\beta}_p\mathrm{V}_{t-p} + \cdots + \boldsymbol{\beta}_{p+d}\mathrm{V}_{t-p-d} + \varepsilon_t$$

where, $\boldsymbol{\alpha}$ is a vector of constant, $\boldsymbol{\beta}_t$ is coefficient matrix, and $\boldsymbol{\varepsilon}_t$ is white noise residuals.
(iv) Check robustness of augment VAR($p+d$) by diagnostic tests.
(v) A Wald test is conducted on the first p parameters instead of on all parameters in the augment VAR($p+d$) model, and the statistics follows an asymptotic Chi-square distribution with p degrees of freedom (For more on Wald statistics, see Toda and Yamamoto, 1995; Zapata and Rambaldi, 1997). The null hypothesis is that the row i, column j element in $\boldsymbol{\beta}_k$ equals zero for $k=1,2,\cdots,p$. The jth element of $\mathbf{V}_t$ does not Granger-cause the ith element of $\mathbf{V}_t$ if and only if the null hypothesis is true.

3. Data and unit root tests

3.1. Data and discussions

In a single country study, dividing by population number only scales the variable down (Soytas et al., 2007). Friedl and Getzner (2003) argued that the Kyoto Protocol calls for a reduction in the percentage of emissions and they suggested the use of total rather than per capita emissions. Therefore, total data but not per capita data are used in this paper.