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A multivariate causality test of carbon dioxide emissions, energy consumption and economic growth in China

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ABSTRACT

This paper uses multivariate co-integration Granger causality tests to investigate the correlations between carbon dioxide emissions, energy consumption and economic growth in China. Some researchers have argued that the adoption of a reduction in carbon dioxide emissions and energy consumption as a long term policy goal will result in a closed-form relationship, to the detriment of the economy. Therefore, a perspective that can make allowances for the fact that the exclusive pursuit of economic growth will increase energy consumption and CO_2 emissions is required; to the extent that such growth will have adverse effects with regard to global climate change.

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1. Introduction

Among the world's developed and developing countries, China is the major producer of carbon dioxide emissions and the greatest consumer of energy, and a trend of consistent exponential growth has become apparent in recent years. In 1980, China's carbon dioxide emissions amounted to 1405 million metric tons (MMT), equivalent to 7.78% of the world's total carbon dioxide emissions. By 2006, this amount had nearly tripled to 5607 MMT, accounting for 20.02% of the world's total carbon dioxide emissions. Energy consumption in terms of oil accounted for 1694 MMT of carbon dioxide emissions in China in 1980 and 7530 MMT in 2006, almost 3.45 times increase. In addition, according to reports from the Energy International Administration, total global consumption of coal has increased significantly in recent years. Moreover, China is now the leading coal consumer and the second leading consumer of electricity, accounting for 28.74% and 16.67% of the world's total consumption, respectively, in 2007. In addition, China's economy is continuing to expand rapidly, and over the last 30 years it has averaged a remarkable 8% growth in gross domestic product (GDP) per annum, with the levels of energy consumption and carbon dioxide emissions increasing commensurate with this.

Xiangzhao and Ji [1] examined the CO_2 trends in China and concluded that economic development is the main factor contributing to increased emissions. Zhang et al. [2] studied the decomposition of energy-related CO_2 emissions over the period of 1991–2006 in China, and also found that economic activity has the largest positive effect on emissions. Based on these studies, it can be concluded that GDP growth is indissociable from increases in both energy consumption and CO_2 emissions.

Han and Wei [3] investigated the relationship between Chinese GDP and energy consumption and concluded that both variables produced feedback causality. Independent verification of this conclusion can be found in the work of Wolde-Rufael [4], which studied industrial energy consumption and GDP in Shanghai. Shiu and Lam [5] and Yuan et al. [6] studied electricity consumption and economic growth and found that China manifests unidirectional Granger causality, running from electricity consumption to real GDP. Yu et al. [7] studied the dynamic relationship between economic growth and China's energy consumption through co-integration analysis and impulse response function, and ultimately concluded that the growth of GDP is a forceful driver in increased energy consumption.

Erol and Yu [8] studied the relationship between electricity and income for industrialized countries, and found that consumption of the former was positively correlated with economic growth. Cheng [9] likewise discovered in a study of Brazil that energy consumption caused economic growth. Masih and Masih [10,11] examined the relationship between energy consumption and real income, as well as economic growth, and concluded that energy consumption was influenced by economic activities in India, Pakistan, Korea and Taiwan. Stern [12,13] studied the role of energy in the US and used a multivariate vector autoregression (VAR) model of GDP, energy use, capital, and labor inputs to examine the macroeconomic conditions, and confirmed that energy use causes economic growth with energy use taken as a quality-adjusted index of energy input. Hondroyiannis et al. [14] investigated the causality of energy con-

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sumption and economic growth in Greece and found those two variables instigated feedback causality. Soytas and Sari [15] studied the causality between energy consumption and GDP in the G-7 and emerging markets, and concluded that increased energy consumption facilitated economic growth in France, Germany, Japan, Argentina and Turkey. Yemane [16] examined the relationship between industrial energy consumption and GDP in a case study of Shanghai and concluded that GDP growth was induced by more energy consumption. Paul and Bhattacharya [17] found bi-directional causality from energy consumption to economic growth in India. Finally, Lee [18] studied energy consumption and GDP in 18 developing countries, and found that energy consumption causes GDP growth.

The majority of the studies mentioned above confirm the existence of a close relationship between economic growth and energy consumption or carbon dioxide emissions and economic growth in most places around the world. The majority of these papers studied causality with two variables, economic growth and energy consumption, or carbon dioxide emissions and economic growth. This study investigates the causality with a multivariate co-integration test of carbon dioxide emissions and energy consumption associated with the growth of GDP in China; in addition, the level of energy consumption from sources such as crude oil, natural gas, coal, and electricity generation is also considered.

The rest of this research paper is divided into three sections: Section 2 features the methodology of co-integration and vector error correction model. Section 3 contains the empirical components of the study, which also include the intensity of carbon dioxide emissions and energy consumption. Lastly, this paper ends with conclusions drawn from the research findings.

2. Methodology

This section will first introduce the methodology of multivariate co-integration and then the vector error correction model will be described.

3. Multivariate co-integration test

According to Granger [19], the causal relationship test is valid provided the variables are not co-integrated. Stationary tests using the unit root test are run to identify the order appropriate for each variable. The advantage of the Phillips and Perron (PP) [20] test is that it is robust for a variety of serial correlations and time-dependent heteroskedasticities [21]. If a variable is found to be non-stationary, then the difference should be taken and the causality test applied with differenced data.

The concept of co-integration can be defined as a common stochastic trend among two or more economic variables over the long run. The trace test and maximum eigenvalue test are used to ascertain the existence of co-integration, and whether the method of estimation used is the ordinary least squares (OLS) or maximum likelihood, both return the same results [22]. If the results show evidence of a co-integrating relationship within the variables, this indicates that the research variables enact a systematic co-movement in the long run. Such a long run causality relationship requires testing by a vector error correction model (VECM).

3.1. Vector error correction model

The VECM was introduced by Sargan [23] and popularized by Engle and Granger [24] and Granger [25], and later refined by Hendry and Juselius' [26] emphasis on the importance of correct specification. Granger [25] argues that if variables are non-stationary, but become stationary after the difference, and are co-integrated, it becomes necessary to estimate a VECM for the Multivariate causality test. The VECMs for this test can be specified accordingly as:

$$\Delta(CO_2)_t = \beta_{30}\sum_{i=1}^{p}\beta_{31i}\Delta(CO_2)_{t-i} + \sum_{i=1}^{p}\beta_{32i}GDP_{t-i} + \sum\nolimits_{i=1}^{p}\beta_{33i}\Delta(\mathrm{En\_con})_{t-i} + \beta_{34}\epsilon_{t-1} + v_{3t} \quad (1)$$

$$\Delta(\mathrm{En\_con})_t = \beta_{20} + \sum_{i=1}^{p}\beta_{21i}\Delta(\mathrm{En\_con})_{t-i} + \sum_{i=1}^{p}\beta_{22i}\Delta GDP_{t-i} + \sum\nolimits_{i=1}^{p}\beta_{23i}\Delta(CO_2)_{t-i} + \beta_{24}\varepsilon_{t-1} + v_{2t} \quad (2)$$

$$\Delta GDP_t = \beta_{10} + \sum_{i=1}^{p}\beta_{11i}\Delta GDP_{t-i} + \sum_{i=1}^{p}\beta_{12i}\Delta(\mathrm{En\_con})_{t-i} + \sum\nolimits_{i=1}^{p}\beta_{13i}\Delta(CO_2)_{t-i} + \beta_{14}\varepsilon_{t-1} + v_{1t} \quad (3)$$

where GDP refers to China's gross domestic product, En_con includes the consumption of crude oil, natural gas, coal, and electricity, while CO_2 is denotes carbon dioxide emissions. Individual energy consumption equations are omitted and represented in aggregate terms. Δ is the difference operator, β's are the parameters to be estimated, v_t's are the serially uncorrelated error terms, p's are the number of lags and ε_{t-1} is the vector error correction term (VECM), which is derived from the long run co-integration relationship, $y_t = \alpha_0 + a_1x_t + \varepsilon_t$, where a's are parameters to be estimated and ε_t is a stationary series. There are two-steps involved in obtaining a VECM. Firstly, the Phillips–Perron (PP) tests of unit root are used to check the residuals are stationary after co-integration. Secondly, the residuals are incorporated into the model (VECM).

The null hypothesis is $H_0{:}\beta_{11i} = 0$ for all i in Eq. (1) or $H_0{:}\beta_{21i} = 0$ for all i in Eq. (2) or $H_0{:}\beta_{31i} = 0$ for all i in Eq. (3). This paper evaluates Granger causality through a pairwise Granger causality test as 'short run' causality in the sense that dependent variables give short-term shocks to the stochastic environment.

4. Empirical analysis

In this section we will first conduct a descriptive analysis of the data set. Then the unit roots and co-integration test will be determined, in addition to the vector error correction model as well as the intensity of carbon dioxide emissions and energy consumption.

4.1. Data analysis

The primary sources of energy are fossil fuels, nuclear power and renewable energy. This paper addresses the relation between the primary energy consumption and GDP, and uses fossil fuels as the primary energy sources.

The Energy Information Administration undertakes the annual collection of data about the consumption of petroleum products and the direct combustion of crude oil, measured at the rate of a 1000 barrels per day (Cr_con). For coal, the relevant variable is a million short tons (Coal_con), while natural gas is measured in a billion cubic feet (NG_con). In addition, electricity is quantified in terms of a billion kilowatt hours (Elec_con), with carbon dioxide emissions measured by a million metric tons (CO_2). Gross domestic product data, as measured in billions of US dollars (GDP), was collected from the World Bank. All data was collected for the period spanning between 1981 and 2006. Table 1 illustrates the descriptive statistical analysis, which reveals that GDP was more volatile than the other variables according to the value of the coefficient of variation (CV), whereas coal consumption was markedly less so. All data are skewed to the right and the fluctuations can be leptokurtic (CO_2), NG_con, Coal_con and Elec_con) and platkurtic

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