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CO_2 emissions and economic development: China's 12th five-year plan

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ABSTRACT

For the period of the 12th Five-Year Plan (2011–2015), the Chinese government has decided to reconsider and adjust its policies on economic development because of the pressures of CO_2 emissions and fossil energy consumption. The current paper adopts the logarithmic Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model to simulate the relationship between CO_2 emissions and other economic development factors in China. Three groups of outliers are found using samples from 1989 to 2008 and the Partial Least Square (PLS) regularity test method. The outlier analysis reveals three important areas for CO_2 reduction: (a) decreasing the share of coal to the total energy consumption and replacing it with non-fossil energies; (b) controlling vehicles used in the cities as well as (c) adjusting industrial structure. Furthermore, based on the social and economic realities of China, the current paper designs six feasible development scenarios for the period covered by the 12th Five-Year Plan and predicts the values of each factor in each scenario. The values can test the implementation of China's CO_2 control development concept. The experiences obtained by outlier analysis can be of significant reference value for realizing the predicted scenarios.

1. Introduction

In the past two decades (1989–2008), the average annual growth rate of China's real GDP has been nearly 10.91%. At the same time, total energy consumption has also increased from 969.34 to 2850 million tons of Standard Coal Equivalent (SCE). The major portion of the China's energy consumption is in non-renewable resources. In 2008, fossil energies accounted for over 91% of the total energy consumption, of which over 68% came from coal (NBSC, 2009). The combustion of fossil fuels has emitted large amounts of CO_2. Since 2007, China has become the largest CO_2 emitter in the world, accounting for over 25% of the world's total emissions in 2009 (EIA, 2011). According to trend analysis, China's CO_2 emissions will further increase rapidly in the next several years (Meng and Niu, 2011a). The consumption of fossil energy has affected China's living environment (Wang, 2010). More importantly, CO_2 emitted from the combustion of fossil fuels is mainly responsible for the greenhouse effect, which has far-reaching effects on our lives (Liu, 2007). China's sustainability will become increasingly difficult if it maintains the development mode it has employed in the past. Many researchers have studied China's energy consumption and CO_2 emissions to search for possible measures to improve its emission intensity (He et al., 2010; Donglan et al., 2010; Duan, 2010; Tan et al., 2011; Feng et al., 2011; Zhou et al., 2011; Yi et al., 2011). They have advanced many valuable measures but have not considered the periodical characteristics of China's macro-policy.

China has reconsidered and adjusted its development policies in every fifth year since 1953, except for the years 1963–1965. This management system is called the Five-Year Plan. As a socialist country, the Chinese government has the powerful capability to control its socio-economic development. The Five-Year Plans have greatly affected China's economic growth rate, energy consumption structure, investment orientation, and so on. Since the 11th Five-Year Plan, China has paid close attention to its energy intensity, energy saving targets, and use of renewable energy (Lin et al., 2008; Wang and Chen, 2010), but the effects of CO_2 emissions control have not been satisfactory. 2011 is the first year of the 12th Five-Year Plan. With the increasing number of environmental disasters as well as the emission pressures both at home and abroad, the Central Committee of the Chinese Communist Party has decided to implement more effective measures to control China's CO_2 emissions. Energy policy, especially how to adjust the relationship between economic growth and CO_2 emissions, is one of the most important parts of the plan.

At present, three main models can be used to decompose CO_2 emissions. First is the Divisia decomposition approach, which decomposes the variation of CO_2 emissions into the influences of industrial structure adjustment and technological innovation. Second is the DEA and Malmquist productivity index model, which decomposes the variation of CO_2 emissions into the

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influence of efficiency change, pure technical efficiency change, and scale efficiency change. Third are the environmental Impact, Population, Affluence, and Technology (IPAT) and Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) models, which decompose the variation of CO_2 emissions into the influences of population, affluence, and technology. Compared with the former two models, the decomposition results of IPAT and STIRPAT are more easily measured by statistical data and are more convenient for use in policy adjustment. Therefore, we selected the IPAT and STIRPAT models to find the quantitative relationship between CO_2 emissions and their influencing factors.

Ehrlich and Holdren (1971, 1972) were the first to advance the IPAT model, known as $I=PAT$, to decompose quantitatively human impact on the environment into the factors of population, affluence, and technology. As a follow-up study, Waggoner and Ausubel (2002) further decomposed the T in IPAT into consumption per unit of GDP (C) and impact per unit of consumption (T). Hence, their model was written as $I=PACT$ and called ImPACT. IPAT, ImPACT, and other similar models have no essential difference; they have been widely used in analyzing energy consumption and economy development (Geoffrey and Hammond, 2004; Ma and Stern, 2008; Saikku et al., 2008; Feng et al., 2009; Gao et al., 2010; Di et al., 2011). However, as a common premise, the aforementioned models assume that each factor has the same influence on the decomposed impact. This premise has been considered the fatal limitation of these models (Dietz and Rosa, 1994; Fan et al., 2006). To overcome this limitation, Dietz and Rosa (1994) advanced the STIRPAT model, which has been successfully used to model statistically non-proportionate impacts of variables on the environment (Dietz and Rosa, 1997; York et al., 2003; Lin et al., 2009; Squalli, 2010; Martínez-Zarzoso and Maruotti, 2011).

The STIRPAT model can be rewritten as a linear model by computing a logarithm. Estimating the parameters of the linear model is inevitable if we want to obtain the quantitative equation. Variables of the linear STIRPAT model often have extreme multicollinearity, as influenced by the common social and economic environment. In this situation, parameters obtained with the traditional Ordinary Least Square (OLS) algorithm would be very unstable. Wold et al. (1983) advanced the Partial Least Square (PLS) method to overcome this problem. Compared with OLS, PLS has the ability to find hyperplanes of maximum variance between the response and independent variables. Chin and Newsted (1999) proved the ability of PLS to find the regression parameters using few observations with multicollinearity. This ability has also been verified by many researchers (e.g., Lee et al., 2008; Siitonen et al., 2010; Meng and Niu, 2011b).

The current paper is organized as follows. Section 2 briefly introduces the main models used: the STIRPAT model, the PLS and Outlier Test model, and the grey model. Section 3 examines China's historical data from 1989 to 2008 to obtain the linear model. It tests the outliers and reveals three important areas for CO_2 reduction. This section designs six scenarios for China's 12th Five-Year Plan and predicts the development factors of each variable in each scenario. Section 4 provides the summary and conclusions based on the results of the previous sections.

2. Methodologies

2.1. STIRPAT model

In the present study, the STIRPAT equation (Dietz and Rosa, 1994) is written as

$$I_i = aP_i^b A_i^c T_i^d e_i \tag{1}$$

where I is the value of CO_2 emissions; P is the population; A is the annual disposable income per capita; T is the CO_2 emissions per unit of GDP; a, b, c, and d are the parameters; e is the error term; and i is the ith sample.

Eq. (1) keeps the multiplicative logic of the IPAT model. By computing the logarithm, it becomes the following form:

$$\ln I_i = \ln(a) + b\ln(P_i) + c\ln(A_i) + d\ln(T_i) + \ln(e_i) \tag{2}$$

Compared with Eq. (1), Eq. (2) obtains the parameters more easily; therefore, it is used in the present paper to simulate the relationship between CO_2 emissions and economic development factors.

2.2. PLS and outlier test method

The PLS algorithm is selected to obtain the parameters of Eq. (2) to diminish the influence of multicollinearity. Furthermore, the following outlier test method offers many useful experiences of China's CO_2 emission control.

Define the contribution rate of the ith sample to all components as

$$T_i^2 = \frac{1}{(n-1)} \sum_{h=1}^{m} \frac{t_{hi}^2}{\operatorname{var}(t_h)} \tag{3}$$

where t_{hi} is the ith value in the hth extracted component (vector) in PLS modeling; m is the number of extracted components; and n is the number of samples.

The value T_i^2 reflects the influence of the ith sample. If it is too large, then the impact of the ith sample to the regression curve is considerable; the ith sample is then called an outlier.

To test the outliers, Tracy et al. (1992) constructed an F test statistic:

$$\frac{n^2(n-m)}{m(n^2-1)} T_i^2 \sim F(m, n-m) \tag{4}$$

If

$$T_i^2 \geq \frac{m(n^2-1)}{n^2(n-m)} F_a(m, n-m) \tag{5}$$

the ith sample is considered an outlier at a confidence level of $1-\alpha$.

If there are two components ($m=2$), Eq. (3) is written further as follows:

$$T_i^2 = \frac{1}{(n-1)} \left(\frac{t_{1i}^2}{\operatorname{var}(t_1)} + \frac{t_{2i}^2}{\operatorname{var}(t_2)} \right) \tag{6}$$

and Eq. (5) is written as

$$\left(\frac{t_{1i}^2}{s_1^2} + \frac{t_{2i}^2}{s_2^2} \right) \geq \frac{2(n-1)(n^2-1)}{n^2(n-2)} F_\alpha(2, n-2) \tag{7}$$

If the equal sign in Eq. (7) holds true, the boundary line of the outliers is an ellipse. Using t_1 and t_2 as axes, we draw the ellipse and points for each sample on a two-dimensional surface. According to Eq. (7), samples outside the ellipse are considered outliers.

The PLS can obtain the most stable parameters of Eq. (2). As a further development of PLS, the outlier test algorithm can tell us which samples are different from others. Further analyses of these outliers will obtain many effective experiences.

2.3. Grey model

China has maintained a stable population policy since the 1980s. The annual rate of population increase has fallen smoothly in the past few years. The figure of the change rate of population is an exponential decrease curve. There has been no sign that China will significantly change its population policy in the next