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RESEARCH ON RELATIONSHIP BETWEEN CARBON DIOXIDE EMISSIONS, IMPORTS, EXPORTS, AND POPULATION IN CHINA

Empirical relationships between carbon dioxide emission, imports, exports, and population have been investigated. An empirical model with carbon dioxide emissions, structure and scale of import and exports, populations was built. Using ridge regression analysis and observed data from 1985 to 2006 in China, we examined the relationship between each part of carbon dioxide emission and corresponding coefficients, including *GIV* (gross imports value), *GXV* (gross exports value), and *P* (populations). The results have shown that the increasing trend in *TCOE* (total carbon dioxide emissions) was determined by the exports, while its standard level is determined by population. Increasing the imports may reduce *TCOE*. Considering working to expand economy, the best ways for China to reduce *TCOE* are to introduce advanced technology and take actions to guarantee strict execution of cut-emission policy. Although the increasing imports also can reduce *TCOE*, it is not reasonable for the global cut-emission policy. To control population is not applicable as the immense population base, so government's publicity for low-carbon live is a necessary and feasible way to reduce carbon dioxide emission.

1. INTRODUCTION

Global awareness on climate change has created much interest in analyzing the trends of world energy use and carbon dioxide emissions [1]. A number of studies focus on the relationship among carbon dioxide emission, economy development, and energy consumption. It is well known that carbon dioxide emissions are linearly related to the amounts of fuel consumed [2]. After studying eleven countries of the Commonwealth of Independent States, Apergis and Payne [3] found that energy consumption has a positive and statistically significant impact on carbon dioxide emissions while real output follows

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an inverted U-shape pattern associated with the Environmental Kuznets Curve (EKC) hypothesis in the long-run. The short-run dynamics indicate unidirectional causality from energy consumption and real output, respectively, to carbon dioxide emissions along with bidirectional causality between energy consumption and real output [3].

One perspective suggests that global trade flows have shifted pollution associated with manufacturing from developed to developing nations [4]. While the concept of global trade flows has been applied to various types of pollution, it has been most widely applied to carbon dioxide pollution [5–7]. It was found that 10.03–26.54% of China's annual carbon dioxide emissions are produced during the manufacture of export goods destined for foreign consumers, while the carbon emissions embodied in China's imports accounted for only 4.40% (1997) and 9.05% (2007) [11].

Moreover, no carbon dioxide studies have specifically addressed whether carbon dioxide emissions are influenced by significant trading relationship or consumption effects. It is well known that advanced industrial nations impact carbon dioxide emissions because of the demand these nations place on developing nations for natural resources, and especially energy resources. Among highly industrialized nations, however, it is plausible that one nation may have a greater impact on carbon dioxide production due to its high levels of demand for energy related resources and other consumption practices [8].

Thus, the purpose of this study is to explore carbon dioxide emissions originating from population, imports, and exports. Firstly, a brief review of the current status of the carbon dioxide emission, economy, and population was made. Then, a decomposition models to discuss the relationship between carbon dioxide emission, imports, exports, and population were proposed. Thirdly, the results of ordinary least square (OLS) regression were described, and model validity and accuracy were discussed. Lastly, the previous work has been summarized.

2. DATA

As carbon dioxide emission is directly related to domestic goods and services, we use real gross domestic product (*GDP*) as for this analysis. In this study, gross imports value (*GIV*), gross exports value (*GXV*), gross domestic product (*GDP*), populations (*P*), and total carbon dioxide emissions (*TCOE*) between 1980 and 2007 were selected as variants. The data such as *GIV*, *GXV*, and *GDP* are compiled from the *China Statistical Yearbook* (1981–2008). *P* and *TCOE* are obtained from the International Energy Administration (EIA). We examined each of these variants below.

2.1. CARBON DIOXIDE EMISSIONS IN CHINA

Carbon dioxide emissions are highly related to the energy consumptions such as the total energy demand and energy constructor [9]. Since China initiated its economic reform program in 1978, it has become the second largest energy consumer in the world, second only to the US in 2005 [10]. Meanwhile, *TCOE* increased from 1460 million tons (in 1980) to 6246 million tons (in 2007) with the annual average growth rate of 11.71% [11]. *TCOE* were raised perpendicularly except during 1997 to 2001 when abnormal situations exist.

2.2. POPULATIONS IN CHINA

China is the most populous country in the world with the population of 1.3 billion, which makes up approximate one fifth of the world population in 2008 [12]. From 1980 to 2008, China's population increased from about 0.98 billion to 1.33 billion with its annualized growth rate about 1.21%. Meanwhile, world's populations increased from 4.45 billion to 6.69 billion with the annualized growth rate about 1.73% [13]. Generally speaking, the increase of population in China is highly correlated with that in the world. But, since China carried out the policy of "family planning", the annualized growth rate of China's population declined faster than that of the world's one. After 2002, the annualized growth rate of China's population remained about 0.6% [14].

2.3. ECONOMY AND TRADE IN CHINA

GDP growth relates the carbon dioxide emissions after studying the relationship between carbon dioxide emissions and *GDP* growth using the date envelopment analysis [15]. Import and export are thought as partially responsible for elevated CO_2 emissions [16].

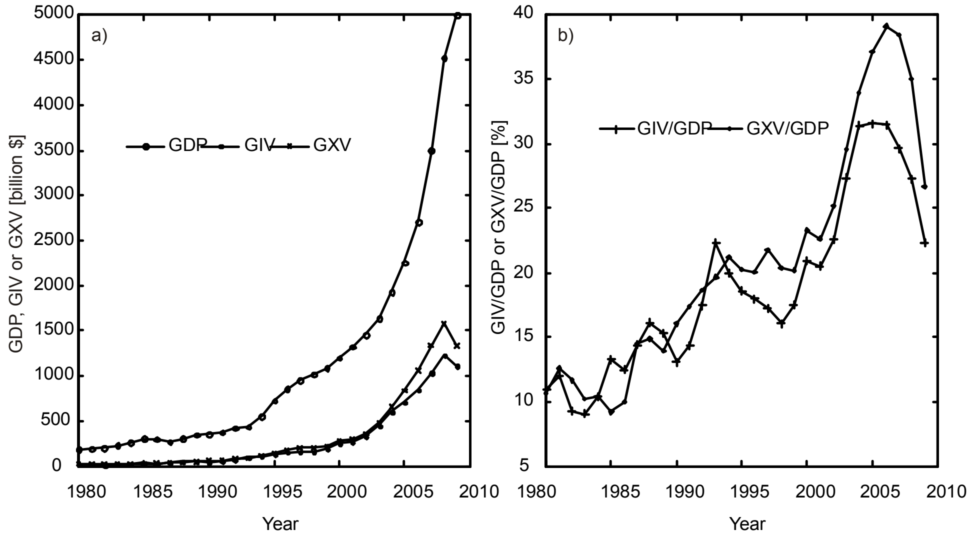

Fig. 1. The Chinese economy and trade from 1980 to 2007

Figure 1a shows Chinese economy and trade from 1980 to 2007. The *GDP* increased from 189.40 billion $ in 1980 to 3494.06 billion $ in 2007, which corresponds to 18.45-fold increase in 29 years. Meanwhile *GIV* increased from 20.86 billion $ to 1034.73 billion $ (49.61-fold increase), and *GXV* increased from 20.17 billion $ to 1342.21 billion $ with the annual average growth rate of 2.29%. Figure 1b shows the changes in proportion of *GIV*, *GXV* from 1980 to 2007. In 2007, *GIV* constituted the 29.61% of *GDP*, 18.60% less than in 1980. Meanwhile, *GXV* accounted for 38.41% of *GDP*, 27.77% less than in 1980. The general trend of *GIV* and *GXV* was increasing and represented abnormal behavior from 1996 to 2000. The ratio of *GXV* to *GIV* fluctuated around 1 overall the period. Before 1994, the average ratio was 0.95, and there was an excess of imports over exports. While it was 1.08, and there was an excess of exports over imports after 1995.

2.4. DECOMPOSITION MODEL OF CARBON DIOXIDE EMISSION

Several variants of the index decomposition analysis (IDA) approach have been developed. However, to a large extent, selection of the method seems to be arbitrary, and there is little consensus on which method is the superior one [17]. Each decomposition method can be applied in a panel or time series data analysis. A time series analysis compares indices on a year-by-year basis and when annual data are available; time series decomposition is preferred and adopted in the current study.

TCOE are decomposed into three parts: carbon dioxide emissions by exports (*COEX*), carbon dioxide emissions by imports (*COEI*), and carbon dioxide emissions by population (*COEP*):

$$TCOE = COEX + COEI + COEP \tag{1}$$

The following reasonable assumptions about *COEX*, *COEI*, and *COEP* are made [18]. Firstly, each of them has some relationship with corresponding *GDP*; secondly, *COEX* and *COEI* are mainly determined by the technology; thirdly, technology level has a positive relationship with economic level.

According to the assumptions above, it is apparent that *COEX*/*GXV*, *COEI*/*GIV*, and *COEP*/*P* should decrease with the economy growth. While the technology is advanced enough, *COEX*/*GXV*, *COEI*/*GIV*, and *COEP*/*P* are tending towards stability. *COEP* is determined by the population and the technology in production [19]. The CO_2 emitted by each person (*COEP/P*) is defined as *PCOEP*:

$$PCOEP = \frac{COEP}{P} = \frac{k_1}{GDP} + b_1 \tag{2}$$

CO_2 emitted by per *GIV* (*COEX*/*GIV*) or per *GXV* (*COEI*/*GXV*) is defined as *PCOEX* and *PCOEI*, respectively

$$PCOEX = \frac{COEX}{GXV} = \frac{k_2}{GDP} + b_2 \tag{3}$$

$$PCOEI = \frac{COEI}{GIV} = \frac{k_3}{GDP} + b_3 \tag{4}$$

k_1, k_2, k_3, b_1, b_2, and b_3 in Eqs. (1)–(3) represent the model parameters. Equations (5)–(7) are introduced to express *COEP*, *COEX*, and *COEI*, respectively:

$$COEP = \left(\frac{k_1}{GDP} + b_1 \right) P \tag{5}$$

$$COEX = \left(\frac{k_3}{GDP} + b_3 \right) GXV \tag{6}$$

$$COEI = \left(\frac{k_2}{GDP} + b_2 \right) GIV \tag{7}$$

If *COEP*, *COEX*, and *COEI* in Eq. (1) are replaced by those resulting from Eqs. (5)–(7), *TCOE* may be expressed as:

$$TCOE = k_1 \frac{P}{GDP} + k_2 \frac{GXV}{GDP} + k_3 \frac{GIV}{GDP} + b_1 P + b_2 GXV + b_3 GIV \tag{8}$$

GXV/*GDP* and *GIV*/*GDP* stand for China's exports and imports as a share of *GDP*. Given that *GDP*/*P* represents the average income, *P*/*GDP* is the inverse of this value. In the process of economic development, *GXV*/*GDP* and *GIV*/*GDP* both changed within a fixed scope and influenced the fluctuation of *TCOE*. Meanwhile *GDP*/*P*, *GXV*, and *GIV* increased with economic development and determined the trend in *TCOE*. The trend in *P* is different, as composition of population changes and transforms in different countries; therefore, the influence of *P* is uncertain.

From the analysis above, we know that *TCOE* is not only influenced by the parameters k_1, k_2, k_3, b_1, b_2, and b_3 but also by the proportion of *GEV/GDP*, *GIV/GDP*, *GDP/NP*, *GEV*, *GIV*, and *P*.

3. RESULTS AND DISCUSSION

3.1. REGRESSION ANALYSIS METHOD

Panel data is widely used and refers to data that are collected from many different places in the same period [20]. Alternatively, data reflects changes over time are referred to as time series data. It has been suggested that the nature of the time series has a profound impact on the modeling work, and the analysis of time series data can provide many new insights relevant to modeling work or policy development [21].

In the OLS regression, an equation is developed by an optimized process which minimizes the sum of the squared distances between the sample's data points and the values predicted by the equation. Assumptions in OLS regression include [22]: (1) regression coefficients are linearly related, (2) all predictors must have a constant variance, (3) residuals shall not correlate with each other (serial correlation), (4) residuals have a constant variance. (5) No predictor variable is perfectly correlated with one another (to avoid multi-collinearity), (6) residuals are normally distributed.

3.2. REGRESS ANALYSIS RESULTS AND DISCUSSION

In this section, data from 1980 to 2007 are used to estimate the parameters of Eq. (8), using the ordinary least square regression (OLS). Table 1 shows the results of OLS regression computed by the software of Matlab 10. Parameter b_1, b_3, k_1, and k_3 passed the t-test at a significance level of 0.01. Parameters k_2 and b_2 passed the t-test at the significance level of 0.025. Equation (8) passed the F-test at the significance level of 0.01. The results of the regression analysis were applied to Eqs. (2)–(7), and each part of the carbon dioxide emissions has been calculated and shown in Fig. 2.

Table 1

Regression analysis and test results

Parameter	Parameter value	t-test value
k_1, million tons	372.84	1.9798[a]
k_2, million tons	385.99	1.6255[b]
k_3, million tons	3177.13	15.9085[a]
b_1, million tons per million $	13.34	2.7309[a]
b_2, million tons per million $	–0.01	1.5104[b]
b_3, million tons per million $	0.035	6.3759[a]
R^2	0.99	
F-test value	271.77	
P-value	3.70×10^{-14}	

[a]Refer to 0.01% levels of significance.
[b]Refer to 0.025% levels of significance.

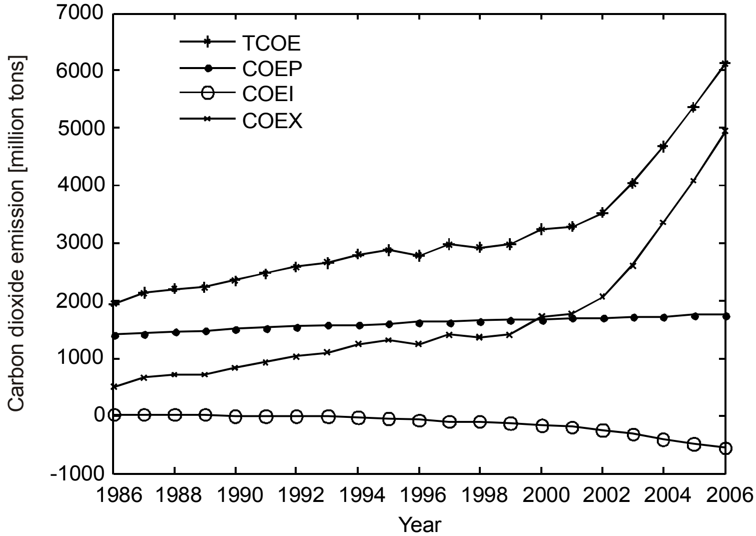

Fig. 2. Carbon dioxide emission influenced by *GXV*, *GIV*, and *P*

The value of b_1GIV increased as an exponential curve during the study period, and b_2GXV decreased as an inverted exponential curve following the *GXV* growth. Meanwhile, b_3P increased as the population increased.

Figure 2 clearly shows the change of *TCOE*, *COEP*, *COEI*, and *COEX* between 1986 and 2006. Every variation exerts a different influence on each part of the carbon dioxide emissions. The expression $k_1(P/GDP)$ and $k_2(GIV/GDP)$ fluctuated around zeros, they have no contribution to *TCOE*. Meanwhile, k_3 (*GXV*/*GDP*) which is influenced by the *GXV*/*GDP*, has increased from 372.88 million tons (1986) to 1261.90 (2006) million tons. It has increased by 3.38 times. b_1P fluctuated between 1422.88 million tons and 1748.63 million tons from 1986 to 2006. b_2GIV decreased from –54.80 million tons (1986) to –663.45 (2006) million tons. It can decrease the *TCOE* to increase imports. Meanwhile, b_3GXV increased from 121.17 million tons (1986) to 3680.57 (2006) million tons.

From the results above, we can conclude that imports increasing or exports decreasing can decrease the *TCOE*. During the study period, population has the greatest contribution to the *TCOE*, and the contribution of *GXV* to *TCOE* is the swiftest rise. The import has negative contribution to *TCOE*.

As is seen in Fig. 3, *COEX* increased during the entire period while the *COEI* was decreasing. *COEP* increased smoothly as a straight line. The trend of *TCOE* was steadily upwards except in 1997. The trend of *TCOE* was similar to that of *COEX*. In summary, the trend of *TCOE* was mainly determined by the *GXV* in China. *COEP* is another unneglectable factor determines the *TCOE*. As the economy grows, not only is the technology more advanced, but also constructer of consumption is changed. *COEI* declined sharply because the import increasing can result in the production of goods decreasing. It can reduce China's carbon emission. *COEI* increased like an exponential curve as the contrary reasons. *COEP* almost has nothing change because of following reasons. One is that technological innovation makes the $k_1(P/GDP)$ to fluctuate about zeros, and the other one is that the scale of production makes the b_1P increase.

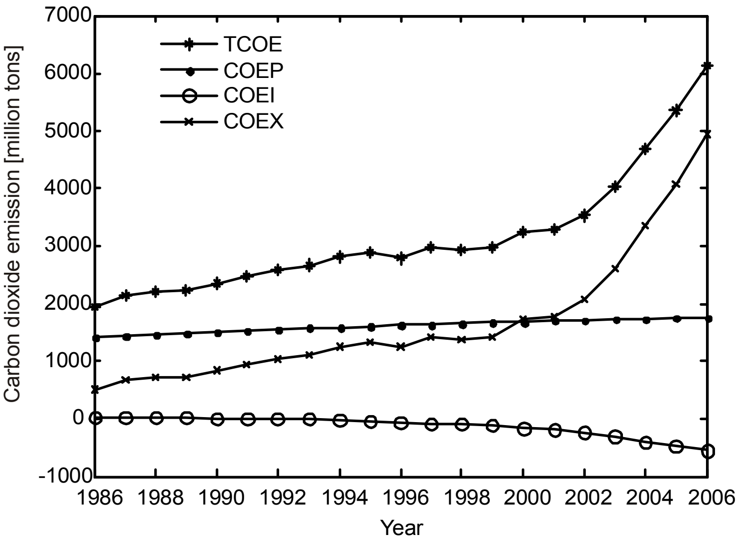

Fig. 3. Carbon dioxide emitted by *GXV*, *GIV*, and *P*

There are several possible reasons for the above results. First, *COEP* mainly affects factors such as population, living standards, the procedure of production, the ways of consumption etc. The population and living levels determine trend of *COEP* jointly. Living standards determine the CO_2 emissions by one person while the population determines the scale of production. The qualities of consumers and the ability of management only affect fluctuations in *COEP*. If consumers' quality and management's ability are higher, *COEP* are lower; the inverse is also true. Technology affects *COEP* temporarily, which is determined by the cycle of technology innovations. Therefore, *COEP* is determined by the s*cop*es of *P* and the parameter b_1.

Secondly, *COEX* and *COEI* are influenced not only by *GXV*, *GIV*, *GXV*/*GDP*, and *GIV*/*GDP* but also by b_2 and b_3. When *GIV* or *GXV* increases, *COEX* and *COEI* are affected naturally. The influence of *GIV* or *GXV* is determined by the constructors of imports or exports. If the exports with high carbon dioxide emission account for the large proportion of imports, *COEX* will increase with *GXV* growing. On the other hand is in adverse. And for the same reason, *COEI* will decrease with *GIV* growing.

3.3. POLICIES SUGGESTION FOR CHINA

The following policy recommendations are proposed according to the above scenario and sensitivity analysis results of the model.

Firstly, bring the low carbon emission equipments in the international marketplace such as energy, transportation, telecommunication, petroleum, chemicals, raw material, and some high-tech areas such as switchboards, microelectronics, aircraft manufacturing, space technology, and nuclear energy [23]. From 1978 to 1998, China signed 27 875 contracts (104.97 billion $) for the technology imports. Only in 1998, 6000 contracts were signed (6.5 billion $). Although the overall technical level of its industry has been greatly improved in line with the developments in science and technology since the Reform and Open Policy in 1978, China's energy efficiency is the lowest among the major industrialized countries in high energy consumption industries such as Iron and Steel, nonferrous metal industry, coal industry, power sector, and chemical industry. If it doesn't bring in advanced technology and key equipment, China's position in international trade will be a "world factory" [11].

Secondly, optimize the constructors in trade. Exports and imports determine the trend of carbon dioxide emissions in China. Meanwhile, the products for exporting, which emit less carbon dioxide emissions in production, are considered firstly [24].

Thirdly, elevate living standards and control population. The living standards and population determine the standard level of *TCOE* commonly. When the population grows, the needs for products are increasing. The scales of production will be larger than before [25].

At last, tap new resources of energy, which have no carbon dioxide emission such as solar power, hydroelectricity, and wind power. In many countries, exploring the new energy is an important way to decline the carbon dioxide emission [26].

4. CONCLUSIONS

In China, the *TCOE* increased over three times from 1987.45 (1986) million tons to 6017.69 (2006) million tons. The increasing trend in *TCOE* was determined by the exports, while its standard level is determined by population. Increasing the imports may reduce *TCOE*. The following policies are suggested to reduce *TCOE* though the way of trade:

Considering working to expand economy, the best ways for China to reduce *TCOE* are to introduce advanced technology and take actions to guarantee the strict execution of cut-emission policy. Although the increasing imports can also reduce *TCOE*, it is not reasonable for the global cut-emission policy. To control population is not applicable as the immense population base, so government's publicity for low-carbon live is a necessary and feasible way to reduce carbon dioxide emission.

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