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Impact of Regional Development on Carbon Emission: Empirical Evidence Across Countries

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Abstract: Global warming is recently an urgent issue worldwide. The increase of carbon emissions induced by human economic activities has become a major driving force behind global climate change. Thus, as a matter of social responsibility, reasonable carbon constraints should be implemented to ensure environmental security and sustainable development for every country. Based on a summary of studies that examined the relationship between carbon emissions and regional development, this paper shows that human activity-led carbon emission is caused by the combination of several influencing factors, including population size, income level, and technical progress. Thus, a quantitative model derived from IPAT-ImPACT-Kaya series and STIRPAT models was established. Empirical analysis using multivariate nonlinear regression demonstrated that the origins of growing global carbon emission included the increasing influencing elasticity of the population size and the declining negative effect of technical progress. Meanwhile, in context of classification of country groups at different income levels, according to the comparison of fluctuating patterns of the influencing elasticity, technical progress was found as the main factor influencing carbon emission levels in high-income countries, and population size might be the controlling factor in middle-income countries. However, for low-income countries, the nonlinear relationship between carbon emission and its influencing factors was not significant, whereas population growth was identified as an important potential driving force in future carbon emissions. This study can therefore provide a reference for the formulation of policies on carbon constraints, especially to develop more efficient carbon mitigating policies for countries at different income levels.

Keywords: carbon emission; regional development; population size; income level; technical progress

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1 Introduction

Global warming is a direct consequence of increasing CO_2 concentration in the atmosphere, which is caused by the abnormal increase in carbon emission levels and is a significant threat to the safety of global living conditions (IPCC, 2007). Carbon emission has increased rapidly with the emergence of the industrial revolution and has caused a corresponding increase in the global average temperature. Many studies had proven that the increase in carbon emission in the past 100 years was mainly caused by human activities (IPCC, 2000; Stern, 2003). Energy combustion, as a human economic activity, is the most critical cause of the rapid increase in carbon emission (Nordhaus, 1977). CO_2 concentration before the pre-industrial times was 280 ppm and increased rapidly since the 19th century with a growth rate of up to 2.0 ppm/yr from 2000 to 2009 (Nordhaus, 2007). By 2009, the concentration of CO_2 was 39% higher than that during the pre-industrial times (http://www.globalcarbonproject.org/carbonbudget/09/hl-full.htm/Carbon Budget 2009 Highlights). The trend of growth

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is similar to that of human industrialization and is also consistent with the process of continuous excavation and use of fossil energy.

This paper will review related studies on the relationship between human-induced carbon emission and regional development, based on which to select a proper combination of influencing factors and determine the form of the model. We will then establish the theoretical quantitative model of carbon emission and focus on the fluctuation of elasticity of the given factors that impact carbon emission, both on a global scale and in countries grouped according to income level. Using the historical data from all countries and regions, an empirical analysis based on the model was carried out. The historical analysis will provide a useful tool to explain the growth trend of carbon emission levels. Furthermore, determining the controlling factor of different countries can offer the basis for future policies on regional emission constraints.

2 Literature Review

2.1 Factors influencing carbon emission

Studies on the relationship between regional development and carbon emission growth had been ongoing for more than four decades and had achieved findings on theoretical research, qualitative estimation, and quantitative simulation. Currently, five factors of regional development are commonly being studied. First is population size. Numerous results had illustrated that the rapid growth of population had a significant impact on increasing carbon emission levels and the prevalence of global warming (Houghton *et al*., 1996; International Energy Agency, 1996). Ehrlich and Holdren (1969) emphasized that problems on food security, water pollution, energy, and overcrowded traffic conditions caused by population growth negatively affected the environment and natural resources. The strength of the impact from population growth might be associated with the level of regional development, which necessitated further study. According to Ehrlich and Holdren (1971), population size had a relatively less impact on carbon emission levels in high-income countries. However, the factor of population size remains an important indicator and independent from the other factors of the regional economy.

Second is income level. A large number of empirical studies since the 1990s have demonstrated that various environmental indicators, including greenhouse gases (GHG) emission, have an inverted U-shaped relationship with the income level, namely, gross domestic product (GDP) per capita. This is also known as Environmental Kuznets Curves (EKC) (Grossman and Krueger, 1993; Selden and Song, 1994; Shafik and Bandyopadhyay, 1992; Zou *et al*., 2009). The empirical study of Holtz-Eakin and Selden (1992) had provided proof of this reversed U-shaped relationship, but the inflection point was at an extremely high level of income. This theoretical precondition posed many problems in several other empirical analyses. Taking CO_2 emission as an example, the studies by Shafik (1994) and Tucker (1995) showed that carbon emission per capita increased monotonically as the income level increased. Based on these empirical analyses, a number of scholars believed that an extension exists in the relationship between carbon emission and regional GDP per capita, such as an N-shaped relationship (Sengupta, 1996). Many studies at present have attempted to reveal the relationship between carbon emission and income level; however, the variance among the empirical analyses based on the different scales and methods showed the theoretical deficiencies of EKC, which was a challenge in determining the occurrence of the inflection point of EKC (Arrow *et al*., 1995; Moomaw and Unruh, 1997).

Third is technical progress, which is an economic indicator that has an indispensable impact on carbon emission. On one hand, technology is a basic tool in the intensive consumption of natural resources and the environment. Thus, technical progress can directly represent the fundamental characteristics of regional development. On the other hand, in contrast to the logical relationship between population size and carbon emission, technical progress is the most important factor to induce the reduction of carbon emission (Duro *et al*., 2010; Sun, 2002). A large number of studies had proven that the difference in technical progress among regions was the most critical factor contributing to the efficiency of energy utilization and directly to differences in carbon emission levels (Duro and Padilla, 2006). Therefore, technical progress is also a key factor influencing carbon emission, which can not be neglected.

Fourth is the origin of carbon emission. The dynamic relationship between carbon emission and human activity is fairly complicated, with EKC being limited as stated earlier. Many studies had to focus on human activities that directly result in CO_2 emission to establish and explain the fundamental relationship. With this perspective in consideration, the production chain in economic activities is the fundamental source of carbon emission. Human production activities that may directly result in carbon emission include agriculture, fossil-fuel combustion, industrial processes, land-use changes, and land clearing (Raupach *et al.*, 2007). Several studies had been conducted on energy input and consumption, with the aim to establish a reasonable relationship between the production chain and carbon emissions. Nordhaus (1977) mentioned that human activities with the strongest impact on climate change were agriculture and energy utilization, with the latter having a stronger impact than the former. In energy utilization, fossil-fuel combustion critically contributed to the continuous growth of carbon emission (Siddiqi, 1995; China Climate Change Group, 2000). These studies attempted to explain the increase in emission in accordance to the producing process of carbon emission. However, the factors to be considered were overly complicated, and a large number of estimation based on physical and chemical mechanisms were involved in the studies conducted, leading to the low operability of the model.

The last factor is economic structure. An increasing number of studies had emphasized the impact of economic structure on carbon emission. Studies by Zhang (2003), Friedl and Getzner (2003) showed that economic or industrial structures were important factors that affected carbon emission. Specifically, the share of service industry in an economy was significantly correlated with carbon emission. Meanwhile, energy structure was also an influencing factor in controlling carbon emission based on the empirical analysis studies regarded the structure of energy consumption and demanding as the primary objectives (Ang and Zhang, 2000; Casler and Rose, 1998). Moreover, the effect of the alternative process of new energy to obtain power-wasting and non-clean energy was greater than the effect of GDP growth in achieving the carbon reduction target (Xu *et al.*, 2006). However, these factors were dependent apparently on income level or on technical progress factors, which can lead to a significant autocorrelation effect (Wu *et al.*, 2013). In addition, the models derived from these factors were commonly highly difficult to interpret.

Therefore, according to the current review of the studies on the relationship between carbon emission and specific indicators, among the five factors mentioned above, population size, income level and technical progress have underwent a number of modifications and improvement processes, being reasonable and matured ties to connect regional development with carbon emission. Meanwhile, economic performance indicators should not be used simultaneously to establish the logical relationship between regional development and carbon emission because carbon emission exists in all economic chains in the form as flux, and the autocorrelation between indicators is inevitable. Thus, under the premise that the factor of income level has been selected, the economic structure indicator should be disregarded.

2.2 Models

2.2.1 Theoretical models

Based on the influencing factors summarized above, the models established by these specific indicators were examined in numerous empirical studies, and then the relationship between carbon emission and regional development could be studied quantitatively. A large number of quantitative models used for estimating the environmental impact of carbon emission caused by human activities have been created, and some classical models have been widely used, such as IPAT, ImPACT, Kaya, and STIRPAT. According to IPAT identity, motivators of environmental degradation mainly consist of Population (*P*), Affluence (*A*), and Technology (*T*) (Ehrlich and Holdren, 1970; Commoner *et al.*, 1971). IPAT identity, which is not limited to GHG emissions, can be applied to determine the technology factor and economic efficiency in the process of regional development. Based on the IPAT identity, ImPACT model adds energy consumption per unit of GDP (energy intensity) as influencing factor and embodies *A* factor in GDP per capita (Waggoner and Ausubel, 2002). The well-known model of Kaya is essentially consistent with ImPACT, and the basic formula is as follows.

$$Impact(\mathrm{CO_2}) = P \cdot \frac{GDP}{P} \cdot \frac{E}{GDP} \cdot \frac{\mathrm{CO_2}}{E}$$

where P is the population size and E represents the primary energy consumption. In terms of convenience and flexibility, the IPAT-ImPACT-Kaya series simply measures the relationship among regional carbon emission, economic development, and energy efficiency (Lozano and Gutierrez, 2008). Specifically, this series can be used to analyze the relative intensity of factors that affect the amount of CO_2 emission and its pattern of variation over time. Meanwhile, the model can also estimate future carbon emission levels after identifying all impact factors. However, the IPAT-ImPACT-Kaya series assumes that the index of each influencing factor is the same. Thus, the STIRPAT model was developed:

$$I_i = a \cdot P_i^b \cdot A_i^c \cdot e_i = a \cdot P_i^b \cdot A_i^c \cdot IS_i^d \cdot C_i^f \cdot ES_i^g \cdot T_i^h$$

where I_i is the environmental impact in region i; P_i^b is the total population in region i with an index of b; and A_i^c is the GDP per capita in region i with an index of c; e_i is the residue term of technology in region i; IS_i^d is the industrial structure in region i with an index of d; C_i^f is the energy intensity in region i with an index of f; ES_i^g is the energy structure in region i with an index of g; T_i^h is the technology in region i with an index of h; a is the coefficient. Each index is usually understood as influencing elasticity and determined by an empirical analysis based on ordinary least squares regression (OLS).

2.2.2 Application of models

The IPAT-ImPACT-Kaya series and STIRPAT models are the most widely applied in studies estimating carbon emission induced by human activities. Based on a large number of empirical studies examining historical data from regions at different scales and with various kinds of aims on numerous issues, these quantitative models have underwent a long process of correction and improvement.

Comparison of the influencing intensities of *Population*, *Affluence*, and *Technology* is the first issue discussed in the application of the IPAT-ImPACT-Kaya series. Commoner *et al.* (1971) and Commoner (1972a; 1972b) developed the IPAT model into a concept as follows:

$$I = Population \cdot \frac{(Economic\ good)}{Population} \cdot \frac{Pollutant}{(Economic\ good)}$$

where I is the environmental impact of any kind of GHG, which is represented as *Pollutant* in the model, and the *Economic good* represents affluence. Carbon emission is the only pollutant applied in the empirical analysis based on this model. These studies demonstrated that the impact of population size and affluence (*Economic good / Population*) was relatively small, but the technology (*Pollutant / Economic good*) was the most important factor in the environmental evolution. However, the definition of I here was not clear, and the geographical scope in the empirical analysis was small. Meanwhile, the model focused excessively on pollution sources, rendering the complexity of *Economic good*. Ehrlich and Holdren (1970; 1971; 1972a; 1972b) subsequently revised the model as the population became a function of the impact of emission, and the key conclusions were as follows: 1) *Population* and impact per capita were relatively independent; 2) impact per capita had a certain feedback on *Population*, but whether it was negative or positive is unclear; and 3) *Population* was the most important controlling factor in the environmental evolution. However, these studies lacked analysis on space or time and underestimated the negative feedback of the decline in the quality of the environment. Intergovernmental Panel on Climate Change (IPCC) frequently applied models of the IPAT-ImPACT-Kaya series to distinguish the influencing intensity, that was, the elasticity of the factors. Based on the equation, the IPCC reported that the growth rate of population size and income level had exceeded and would continue to exceed the decline of energy intensity. Meanwhile, inhibition from the reduction of carbon emission per energy supply gradually weakened. The most important point stated was that global energy use and supply were highly significant factors in the growth of emission (IPCC, 2000; 2007).

Second, the influencing elasticity of particular factors gradually became the hotspot in the researches on carbon emission, including population size and income level. Dietz and Rosa (1997) and Rosa and Dietz (1998) improved the equation by using the STIRPAT model and by adding the index as the influencing elasticity for the different factors. The basic model is as followed:

$$I_i = a \cdot Population_i^b \cdot (\frac{GDP}{Population})_i^c \cdot T^d \cdot e_i$$

where I_i is the environmental impact in region i; $Population_i^b$ is the population in region i with an index of b;

$(GDP/Population)_i^c$ is the GDP per capita in region i with an index of c; T^d is the technical factor with an index of d; a is the coefficient, and e_i is the error term in region i. This formula could show the influencing intensity more precisely. Furthermore, these studies revealed that the influencing elasticity of population size reflected a non-linear change, and the influencing elasticity of income level had limitations (when GDP per unit reached about 10 000 dollar USD), thus an inverted U shape appeared. Stern (2003) and Arrow *et al.* (1995) forwarded a new model as a logarithmic function. They found that the growth of emissions and income level had an inverted U-shaped relationship, namely EKC. However, the Kuznets curve could not adapt to the empirical analysis of the existing emissions as stated earlier. Meanwhile, the problems showed that the model did not fully reflect various factors and no analysis of countries with different income levels were conducted. Thus, the analysis was limited in application.

Third, the influencing elasticity of technical progress was given significant focus in recent years because this factor is the only efficient approach toward emission constraints. Heaton *et al.* (1991) and Chertow (2000) adopted the IPAT equation and proved that technical progress is the core factor in restricting the emissions. However, the equation still lacked estimation on the influencing intensity of existing technologies.

Fourth, more effort has been exerted on the integration of the influencing factors and in enhancing the explanatory ability of the model since 2000. Waggoner and Ausubel (2002) reintegrated the IPAT equation, especially the modified equation, and determined the specific indicator for each factor, which gradually became a routine for the model afterwards. This study introduced the influencing factor C (energy consumption per unit of GDP) to reflect the nature of production and consumption, but ignored the significant autocorrelation between C and income level. Technical progress was decomposed into multiple sub-factors in this paper, while its reduction represented the preference of greater energy consumption. Furthermore, York *et al.* (2003) improved the method and introduced ecological flexibility (*EE*) to improve the accuracy of the model. Therefore, the impact of population size turned into a linear growth, namely, the influencing elasticity was constant, but the impact of income level was monotonically increasing while its influencing elasticity gradually reduced.

Therefore, the progress of the quantitative relationship between carbon emission and regional development can be divided into three stages. The models obtained considerable progress in two aspects, namely, model form and variables. In the first stage, most models began from a qualitative perspective to study the growth of carbon emission led by human activity. The influencing factors only have two aspects, namely, population size and technical progress. In the second stage, the models focused on the effect of income level on carbon emission growth and probed into quantitative analysis methods. Meanwhile, technical progress, as a residual variable, is yet to be integrated with other factors. Cases based on the different income levels of different countries occurred in the empirical studies from this stage, representing future research direction of studies on regional development influencing carbon emission. In the third stage, models introduced new influencing economic or social factors and sought a suitable model form. The application of economic methodology continuously improved the model structure, resulting in the emergence of a number of empirical studies. The quantitative shift in the relationship between carbon emission and its influencing factors was observed in this stage. Population size and income level monotonically increased with the growth of carbon emission, but the specific characteristics were different. Technical progress and consumption structure were negatively correlated with carbon emission, but their specific forms remained controversial. In addition, consumption always had significant autocorrelation with income level, which must be avoided.

3 Empirical Study

3.1 Data sources and methods

Based on historical studies on carbon emission dominated by regional development, the main factors controlling regional carbon emission in this paper will include population size, income level, and technical progress. These three factors, which involve the main aspects controlling carbon emission independently, can express regional development directly and enhance the explanatory ability of the model significantly. Meanwhile, the form of the model in this paper originated from the STIRPAT Model. Under the premise that the relative indices of all the influencing factors in the

IPAT-ImPACT-Kaya series model are the same, this series can not show the influencing elasticity of the factors impacting carbon emission and may lose a large amount of information. In other words, this paper aims to explore the fluctuating patterns and the impacting intensities of the influencing factors, so the model must introduce the influencing elasticity factor: α, β, γ. Overall, the model is determined by:

$$I(CO_2)=P^{\alpha} \cdot A^{\beta} \cdot T^{\gamma} \quad (1)$$

where I (CO_2) is the environmental impact of carbon emission which is referred by CO_2 emission (10^6 t); P is population size which is referred by total population (persons); A is income level which if referred by GDP per capita (current US dollar); T is technical progress which is referred by GDP per unit of energy use (USD per kg of oil equivalent); and α, β and γ are the indices, namely, the influencing elasticity of each factor. To maximize the number of the sample size and stabilize the sample quality, this analysis only takes nations with no missing indicator values from 1992 to 2008 as the valid sample, and the total number of samples is 120 each year. Data were obtained from World Bank Database (http://data.worldbank.org/).

This study conducts empirical regression based on the above model. Carbon emission, as a dependent variable, is examined in terms of the impact of population size, income level, and technical progress in the regression, based on which the indices of each independent variable are determined, *i.e.*, the influencing elasticity and its fluctuating features of the three factors. The empirical analysis utilized data from 1992 to 2008 and the multiple nonlinear regressions were implemented in SPSS. Based on the distribution pattern of the scatter graph of the original data, the initial values of the elasticity selected in all regressions were $\alpha = 0.5$, $\beta = 0.5$ and $\gamma = -0.5$.

3.2 Results

3.2.1 Variation of influencing elasticity under a global scale

In context of the continuous growth of the absolute value of global carbon emission and the three independent variables, the change of the influencing elasticity of each factor has its own characteristic (Fig. 1).

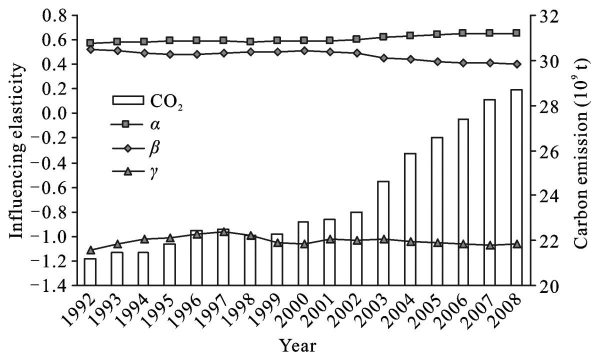

Fig. 1 Variation of influencing elasticity (global data, 1992–2008)

First, the elasticity of P, i.e., α, is positive and relatively stable. The absolute value of α was approximately 0.6, with a gradual increase from 1992 to 2008, indicating a positive relation to carbon emission. Second, the elasticity of income level, i.e., β, is a positive value, with an absolute value mainly from 0.4 to 0.5, demonstrating the income level has a positive relation with carbon emission and a generally stable declining trend. Third, the elasticity of technical progress, i.e., γ, is negative, showing negative relation with carbon emission and indicating technology being possibly similar to carbon sink. The absolute value of γ is approximately 1.1 with a slight fluctuation and overall gradually decreases. No monotonic trend of γ is in accordance with the contingency of the technological revolution.

The data are not normalized. Thus, the absolute values of α, β, and γ do not have practical significance. However, the trends and characteristics of their fluctuation still play an important role in the indication. The slow increase of α illustrates the gradual strengthening of the positive effect of the population size for carbon emission. Meanwhile, the population size is keeping growing, which causing that the influence of the population size essentially increases. The decline of β illustrated that the positive effect of income level on carbon emission gradually weakens with the growth of value of this factor. This observation agrees with the trend shown in the Environmental Kuznets Curve. Technical progress is the most critical factor in inhibiting carbon emission. However, γ is not stable, further indicating that the innovation of low-carbon technologies is accidental. In addition, the standard errors of α and β demonstrate that the correlations between carbon emission and P, A are significant, but the standard error of γ is relatively higher because of the fluctuation of the data (Table 1). Therefore, based on the overview on the fluctuations of the influencing elasticity of all the factors on a global scale from 1992 to 2008, the reasons behind the growth in global carbon emission include the increase in the elasticity of the population size and the decline of the negative effects of technical progress. Considering the income level still contributes the positive effect on carbon emission with population size, the technical progress as the unique negative effect may be more influential on the global carbon emission.

3.2.2 Variation of influencing elasticity of countries with different income levels

(1) Variation of influencing elasticity of high-income and middle-income countries

The countries at different income levels in this paper are divided into three levels based on GDP per capita: high-income, middle-income, and low-income countries. This criterion is mainly based on the number of samples and the requirements of measuring operations. Meanwhile, considering the growth of the world economy and inflation factors, the specific boundaries are changing over time (Table 2).

Table 1 Results of multiple nonlinear regression

Year	α	β	γ	Standard error		
				α	β	γ
1992	0.569	0.525	–1.114	0.010	0.030	0.102
1993	0.578	0.508	–1.057	0.011	0.030	0.103
1994	0.582	0.496	–1.018	0.011	0.031	0.107
1995	0.587	0.485	–1.015	0.011	0.032	0.112
1996	0.589	0.477	–0.978	0.011	0.031	0.111
1997	0.587	0.487	–0.958	0.011	0.032	0.114
1998	0.585	0.500	–0.995	0.011	0.031	0.112
1999	0.588	0.505	–1.048	0.010	0.030	0.116
2000	0.589	0.509	–1.066	0.010	0.029	0.113
2001	0.594	0.497	–1.021	0.010	0.028	0.113
2002	0.596	0.496	–1.027	0.009	0.028	0.116
2003	0.617	0.455	–1.017	0.009	0.029	0.126
2004	0.627	0.440	–1.045	0.009	0.031	0.132
2005	0.637	0.425	–1.054	0.010	0.032	0.137
2006	0.646	0.413	–1.064	0.010	0.033	0.140
2007	0.651	0.408	–1.070	0.010	0.034	0.142
2008	0.652	0.403	–1.058	0.011	0.035	0.141

Table 2 Criteria of classification of countries with different income levels

Type	GDP per capita (current USD, 1992–2000)	GDP per capita (current USD, 2001–2008)
High income	>8000	>10000
Middle income	1800–8000	2000–10000
Low income	<1800	<2000

Based on the classification of income levels, global carbon emission is split, and thus the influencing factors demonstrate a number of new features. Carbon emissions of high-income and middle-income countries indicate an increasing overall trend, as illustrated in Fig. 2. Particularly, carbon emission of high-income countries has been over 1.1×10^{10} t since 1994, while that of middle-income countries has rapidly increased from less than 4×10^9 t in 1992 to 1.1×10^{10} t in 2008. Thus, the carbon emissions of both country groups have become increasingly closer after 2006. Carbon emission of middle-income countries increased sharply in 2006, which is potentially caused by the change of the dividing boundaries of income levels. Specifically, the total carbon emission of each country group is the sum of the emission of each country at its own income level. Hence, the changes in dividing boundaries may influence the carbon emission of different country groups.

For high-income countries, the influencing elasticity of all factors on carbon emission is unstable. The elasticity α is distributed mainly within the ranges of 1 to 1.5. The elasticity β and γ fluctuate significantly and distribute mainly from –1 to 0 and –2 to –1, respectively (Fig. 2). The features of these results have shown abundant critical information. The elasticity of income level is negative, indicating that the income level in high-income countries is the same as carbon sink, which means that high-income countries may have entered the decline phase of the Environmental Kuznets Curve. However, several standard error values of β are not significant (Table 3). Meanwhile, the elasticity of population size is not synchronous with the carbon emission in the growth trend, but the elasticity γ gradually increases suggesting the negative effect of technical progress on carbon emission is weakened. These results indicate that the growth of carbon emission in high-income countries is mainly controlled by technical progress. Based on the income level divisions of the World Bank, of which high-income and upper middle-income countries are basically analogous with high-income and middle-income countries, respectively, as stated in this paper. The value of the technical progress indicator of high-income countries constantly exceeds that of the world level (Fig. 3). This value further proves that the slow growth of carbon emission in high-income countries is chiefly affected by the high level of low-carbon technologies.

For middle-income countries, the elasticity of all influencing factors of carbon emission is relatively stable. The elasticity α and β are overall positive, mainly ranging from 0.5 to 1 and from 0 to 0.5, respectively; whereas the elasticity γ is negative with apparent fluctuation. Compared with high-income countries, the positive value and the declining trend of the influencing elasticity β indicate that middle-income countries are still in the increasing phase of the Environmental Kuznets Curve and enter the declining phase in 2008. This observation proves to a certain extent the existence of the inverted-U shaped relationship between carbon emission and income level. Meanwhile, β shows a weakened positive effect and γ indicates an overall strengthening negative effect on carbon emission; however, considering the carbon emission of middle-income countries is growing in general, so the gradually increasing α demonstrates that the population size is the most important factor controlling carbon emission in middle-income country.

Therefore, the controlling factor of emissions in high-income countries is technical progress, which may be related to the limited growth potential of the population and the increase of income level in both country groups. And the controlling factor of emissions in middle-income countries is population size, of which the effect might be enhanced by the constantly increasing in population. Nevertheless, on one hand, the influencing elasticity of income level in high-income countries on carbon emission has entered the descending phase of the Kuznets Curve. On the other hand, the carbon emissions of these country groups remain as a mainpart of

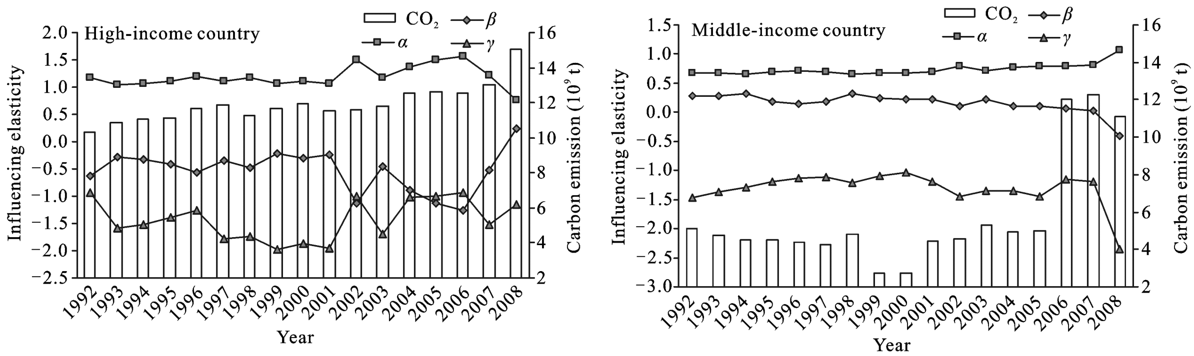

Fig. 2 Influencing elasticity of high-income and middle-income countries (1992–2008)

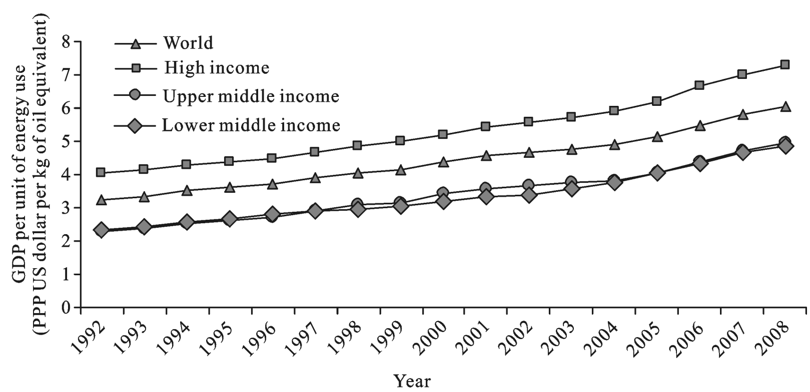

Fig. 3 Technical progress of high-income, upper middle- and lower middle-income countries (based on division of World Bank, 1992–2008, USD). PPP GDP is gross domestic product converted to current international dollars using purchasing power parity rates. An international dollar has the same purchasing power over GDP as a USD in the United States (Definition as World Bank)

Table 3 Results of multiple nonlinear regression of high- and middle-income levels

Year	*α*	*β*	*γ*	Standard error		
				α	*β*	*γ*
High-income countries						
1992	1.181	–0.632	–0.931	0.050	0.108	0.130
1993	1.037	–0.273	–1.595	0.075	0.159	0.229
1994	1.070	–0.335	–1.527	0.075	0.160	0.230
1995	1.104	–0.411	–1.381	0.073	0.159	0.243
1996	1.186	–0.575	–1.263	0.086	0.187	0.261
1997	1.112	–0.357	–1.792	0.089	0.184	0.256
1998	1.172	–0.468	–1.729	0.066	0.136	0.168
1999	1.056	–0.212	–1.979	0.093	0.193	0.297
2000	1.100	–0.302	–1.867	0.089	0.182	0.236
2001	1.072	–0.231	–1.951	0.087	0.173	0.220
2002	1.500	–1.130	–1.007	0.126	0.261	0.274
2003	1.176	–0.449	–1.690	0.083	0.172	0.225
2004	1.362	–0.888	–1.012	0.126	0.264	0.297
2005	1.500	–1.130	–1.007	0.126	0.261	0.274
2006	1.566	–1.252	–0.944	0.128	0.257	0.239
2007	1.224	–0.529	–1.519	0.077	0.150	0.197
2008	0.759	0.234	–1.152	0.051	0.118	0.273
Middle-income countries						
1992	0.678	0.275	–1.467	0.035	0.084	0.076
1993	0.666	0.290	–1.363	0.038	0.090	0.075
1994	0.649	0.315	–1.281	0.033	0.079	0.073
1995	0.702	0.184	–1.184	0.028	0.067	0.059
1996	0.715	0.148	–1.126	0.032	0.078	0.060
1997	0.703	0.181	–1.122	0.033	0.081	0.060
1998	0.650	0.318	–1.213	0.025	0.065	0.078
1999	0.679	0.235	–1.100	0.038	0.079	0.126
2000	0.681	0.222	–1.027	0.042	0.086	0.141
2001	0.703	0.220	–1.196	0.021	0.055	0.066
2002	0.784	0.108	–1.449	0.050	0.111	0.089
2003	0.718	0.219	–1.349	0.023	0.058	0.070
2004	0.775	0.097	–1.345	0.040	0.092	0.077
2005	0.784	0.108	–1.449	0.050	0.111	0.089
2006	0.792	0.058	–1.151	0.012	0.037	0.149
2007	0.812	0.030	–1.183	0.014	0.039	0.162
2008	1.059	–0.405	–2.349	0.054	0.121	0.376

global carbon emission. Therefore, inhibiting the emissions is particularly important. In summary, the further development of low-carbon technologies and the mitigation of the population size are ways to restrict carbon emission for high-income and middle-income countries.

(2) Variation of influencing elasticity of low-income countries

The carbon emission of low-income countries indicated an increase trend before 2005. However, in 2006, carbon emission declined sharply, which could have been caused by the change in the dividing boundaries of income levels and the sampling method. This situation is similar to that on middle-income countries mentioned previously. Thus, this part of emission still requires our attention. The variation of influencing elasticity of low-income countries is significantly different from the former two country groups. Both *β* and *γ* exhibit abnormal fluctuations and relatively high standard errors (Fig. 4 and Table 4), resulting in the difficulty of interpretation. Considering that low-income countries are mainly small countries with a small population size and delayed economic development, a comparison study is difficult to conduct on the development pattern between these countries and high-income or middle-income countries. Thus, the multiple linear regression models may not be able to explain the manner that carbon emission is influenced by regional development in low-income countries.

However, the elasticity of all factors may still have some implications. On one hand, the elasticity *α* is keeping positive, showing a stable trend and relatively significant standard error as compared with *β* and *γ* (Table 4). This information may indicate that population size is the primary controlling factor of carbon emission fluctuation in low-income countries. More importantly, the total population of low-income countries account for one-third of the world, and still continues growing at a dramatic speed. Thus, the positive effect of population size influencing carbon emission is

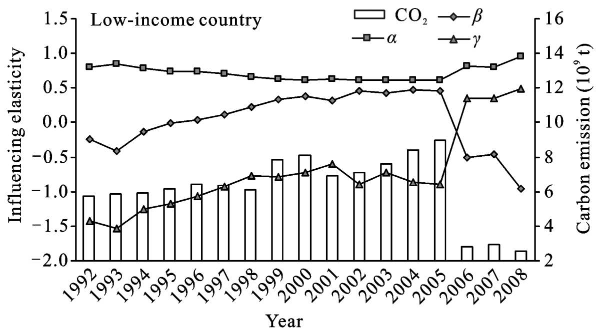

Fig. 4 Influencing elasticity of low-income countries (1992–2008)

Table 4 Results of multiple nonlinear regression of low-income countries

Year	α	β	γ	Standard error		
				α	β	γ
1992	0.795	–0.240	–1.429	0.039	0.134	0.174
1993	0.854	–0.411	–1.527	0.053	0.179	0.196
1994	0.778	–0.140	–1.253	0.045	0.146	0.188
1995	0.743	–0.010	–1.169	0.045	0.139	0.196
1996	0.732	0.033	–1.062	0.048	0.143	0.193
1997	0.705	0.109	–0.920	0.047	0.139	0.203
1998	0.664	0.222	–0.771	0.049	0.141	0.204
1999	0.632	0.333	–0.784	0.039	0.108	0.179
2000	0.616	0.381	–0.724	0.034	0.092	0.174
2001	0.630	0.319	–0.597	0.038	0.116	0.203
2002	0.617	0.458	–0.899	0.056	0.149	0.249
2003	0.608	0.433	–0.720	0.050	0.144	0.228
2004	0.606	0.476	–0.869	0.054	0.151	0.236
2005	0.617	0.458	–0.899	0.056	0.149	0.249
2006	0.814	–0.514	0.352	0.060	0.192	0.273
2007	0.802	–0.460	0.356	0.066	0.202	0.272
2008	0.958	–0.951	0.494	0.116	0.374	0.290

continuously magnified. On the other hand, the elasticity β fluctuates abnormally, but maintains a positive value when its standard errors are relatively low, demonstrating that low-income countries are also in the increasing part of the Environmental Kuznets Curve. However, considering that the regional development in low-income countries is relatively backward and the income is low, income level may not have significant impact on the carbon emission. Combined with the technical progress, which is lower than the world average, the rapid growth of carbon emission in low-income countries is expected mainly based on the higher value of α and the growth of the population. Overall, as population size increases continuously but technical progress remains low in low-income countries, the significant potential of growth of carbon emission in future should be given sufficient attention.

5 Conclusions

First, human economic activities drive the gradual growth of carbon emission, which are mainly controlled by the regional development in various countries and regions. According to numerous theoretical studies, the detailed logical frame adopts, population size, technical progress and certain indicators of economic performance to establish the influencing relationship. In addition, studies concerning the relationship between income level and carbon emission are abundant and underwent a large number of amendments. Therefore, the income level is the most matured parameter in numerous indicators of economic performance that can be related to carbon emission.

Second, many formulas and models are established to reveal the relationship between regional development and carbon emissions. Based on the systematic conclusion of this paper, the most influential and most widely applied models at present are the IPAT-ImPACT-Kaya series and STIRPAT models. The former is generally used to predict local carbon emission on the basis of empirical study, and the latter is primarily used to confirm the influencing factors of carbon emission and to probe into the influencing elasticity of all the factors. This paper found population size, income level, and technical progress from the IPAT-ImPACT-Kaya series as the most widely recognized influencing factors of carbon emission. The exponential form of the STIRPAT model is used to provide all factors with the concept of elasticity and to examine the features and patterns of the fluctuation of influencing factors.

Finally, based on the multiple nonlinear regressions of all factors of global development and carbon emission from 1992 to 2008, the continuous growth of global carbon emission is caused mainly by the increase in the elasticity of population size and more importantly by the reduction of the negative impact from technical progress. In the context of the classification of different income levels, this paper initially proves the existence of EKC between carbon emission and income level. Meanwhile, for high-income countries, the fluctuation of carbon emission is almost similar to that of technical progress, which is the key to controlling carbon emission. For middle-income countries, population size is the most convincing factor in controlling the carbon emission. For low-income countries, the nonlinear relationship between carbon emission and influencing factors is not significant. Nevertheless, population size may be a potentially important driving factor of carbon emission in low-income countries in the future.

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