

The Driving Factor Analysis of China's CO₂ Emissions Based on the STIRPAT Model

Shumei Feng

School of Economics, Jinan University, Guangzhou, China

Email: smei_feng@126.com

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Abstract

In recent years, China is facing unprecedented challenges in maintaining sustained economic growth, reducing CO₂ emissions and tackling climate change. Therefore, the analysis of China's CO₂ emissions driving factors is of great significance. This paper is based on the extension of the STIRPAT model. It decomposes three factors: the population, economy and technology, and makes a quantitative analysis on driving forces of China's CO₂ emissions about the total population, urbanization rate, real GDP per capita, the proportion of secondary industry, private car ownership, energy intensity, coal consumption and oil consumption. The result shows that the population is still one of the important factors affecting China's CO₂ emissions; the energy consumption structure, mainly coal consumer-oriented, has a big positive driving force on CO₂ emissions; real GDP per capita which represents the economic factor and the private car ownership has a bigger elasticity coefficient on CO₂ emissions. In order to control and reduce CO₂ emissions, we should control the population scale reasonably, improve the level of urbanization, optimize energy structure, improve the quality of economic growth and encourage residents' green consumption.

Keywords

CO₂ Emissions, STIRPAT Model, The Driving Factors

1. Introduction

In recent years, the joint efforts to deal with the global climate issues have achieved outstanding results. From the "Delhi declaration" in 2002, the "Bali roadmap" in 2007 to the international climate conference held in 2009 in Copenhagen, the above shows the human wisdom and efforts to solve the problem of global climate change. On September 23, 2014, the largest international conference—the UN climate summit was held in the United Nations headquarters,

which explores the improvement measures of air problems caused mainly by agriculture, oil, industrial, and transportation. On the climate conference in Paris in December 2015, through the unremitting efforts of all countries, the overall goal of global climate change was clearly put forward. Relative to pre-industrialization, the goal is to keep the range of the temperature rise within 1.5 degrees.

China is in development stage of industrialization. As of 2012, China's coal consumption reached 3.62 billion tons, and carbon emissions reached 8 billion tons, far more than the other countries and China has become the world's largest energy consumer and CO₂ emitter. China's economic development faces many problems, such as low level of urbanization, large population base, unreasonable energy consumption structure, excessive proportion of secondary industry, etc. The concern on Chinese economy is how to find the low carbon economy development mode that suits China's national conditions. The key to solve these problems is to construct the model of CO₂ emissions, arrive at the quantitative relationship between the driving factors on CO₂ emissions and find the emphasis of the low carbon economy development in China. Only in this way can we "suit the remedy to the case", solve the problem of environment better, and provide theoretical support for the low carbon economy development of China.

2. Summary of Related Research

At present, there is rich literature analyzing the influencing factors on CO₂ emissions at home and abroad. Richard (2003) [1] uses IPAT, IMPACT and STIRPAT model as a research tool, analyses the domestic CO₂ emissions factors and the mechanism of the environmental impact of economic development. He thinks that CO₂ emissions and energy consumption change are primarily influenced by affluence, industrialization, population and urbanization process. Long Aihua (2006) [2] and others use STIRPAT model to analyze the effect on China's water footprint by the total population, degree of prosperity and technical level since 2000. Wang Limeng (2006) [3] analyzes the time distribution of China's environmental pressure through the STIRPAT model. Taoyuan Wei (2011) [4] decomposes the main method of STIRPAT, under different functions using of different models, provides the basis of adding the model indexes. Liddle (2013) [5] analyzes the gross national product (GNP) and the urban population of impact on the environment pressure for developing and developed countries through the STIRPAT model.

Previous literature shows that, the standard STIRPAT model provides a simple decomposition of the environmental impact of human factors, thus we can analyze the impact of human driving factors on the environment. It has strong practicability. In the application of the model, the impact of demographic factors on carbon emissions research mainly focuses on the investigation of the total population for a long time, ignoring the urbanization rate of population structure. The population's influence on carbon emissions does not reflect the whole factors of demographic. In addition, in terms of selecting the index of technical level, previous scholars tend to adopt energy intensity, the selection of indicators

is not very rich and comprehensive. Therefore, this paper extends the traditional STRIPAT model, decomposes the three factors population, economy and technology into population size, urbanization rate, real GDP per capita, industrial structure, private car ownership, energy intensity, coal consumption and oil consumption, analyzes the eight driving forces of China's CO₂ emission, makes up for the conduct of ignoring the population structure but only focuses on the population in the past research. In addition, adds the coal consumption and oil consumption which represent energy consumption structure into the model. Indexes chosen by this essay are richer and more comprehensive than using only energy intensity on behalf of the technical level.

On the basis of previous theoretical studies using STIRPAT model, this paper established CO₂ emissions model of eight indexes about population, economy and technology, collected statistical data since 1985 in China, used empirical research on China's CO₂ emissions drivers. It concludes the quantitative relationship between CO₂ emissions and the driving factors; provides targeted, scientific and effective policy recommendations about CO₂ emissions control and low carbon economy development in China based on the driving factors on the impact of CO₂ emissions. This will be conducive to further studies of factors influencing the carbon emissions, of China in the future, helps save energy, protect the environment and reduce CO₂ emissions. It has important theoretical and practical instruction significance. In this paper, the research result will help find the correct development direction of low carbon economy in China and find a suitable low carbon economy development mode according to China's actual situation.

3. Model, Variables and Data Sources

3.1. The STIRPAT Model Building

STIRPAT model is widely used; scholars use it to solve the problem of environmental pressure; it is a random form of IPAT model. American ecologist Ehrlich and Commoner [6] propose the IPAT equation in the 1970s, their study concludes that there are three main factors affecting the environment I: population P, affluence A and technology T, and sets up the constant expression of the relationship between the three:

$$I = PAT \quad (1)$$

IPAT equation has the advantage of simple structure and easy operation, so it is widely applied to analyze the environmental change and human factors. The limitations of the model is, however, it considers only the influence factors of population, affluence and technology level, besides, there is a same proportional change among the three, so it necessarily not applies anymore in the current social environment. In order to overcome the defects of IPAT equation, the scholar Dietz [7] establishes STIRPAT model in 1994, which is based on IPAT equation, namely the random effects model of IPAT equation. Compared to the IPAT equation, STIRPAT model introduces the concept of index, which can be used to

study different proportional change of the influences. The specific expression is:

$$I = aP^b A^c T^d e \quad (2)$$

In this formula, a represents the constant term of proportion. The b , c and d represent respectively the elastic coefficients of the three variables- population scale P , affluence A as well as the technical level T . The e represents the random error of the model. In actual analysis, we generally use the logarithmic form of the model, namely,

$$\ln I = a + b(\ln P) + c(\ln A) + d(\ln T) + e \quad (3)$$

Compared to the IPAT model, STIRPAT model can select the index variables of population, affluence and technology as the estimated parameters. It also allows us to add, modify or decompose the related influencing factors. So, the scholars usually extend the STIRPAT model appropriately, based on different research purposes and requirements. This paper also adopts the extended STIRPAT model to carry out empirical research. The extended expression of STIRPAT model is as follow:

$$\begin{aligned} \ln I = \ln \alpha + \beta_1 (\ln P_1) + \beta_2 (\ln P_2) + \gamma_1 (\ln A_1) + \gamma_2 (\ln A_2) \\ + \gamma_3 (\ln A_3) + \lambda_1 (\ln T_1) + \lambda_2 (\ln T_2) + \lambda_3 (\ln T_3) + \ln u \end{aligned} \quad (4)$$

The variables in the model are shown in **Table 1**.

3.2. The Calculation of CO₂ Emissions and Data Sources

At present, in the study of CO₂ emissions, scholars usually refer to the National Greenhouse Gas Listing Guidance Method designated by the United Nations Intergovernmental Panel on Climate Change (IPCC) in 2006, namely Listing Method. The calculating formula of CO₂ emissions can be expressed as follow:

$$EC = \sum EC_i = \sum E_i * CC_i * CF_i * COF_i * (44/12) \quad (5)$$

where, EC represents the estimated amount of CO₂ emissions and i represents the type of energy, which includes coal, oil and gas. E_i is the consumption of energy i . CF_i is the net calorific value of energy i . CC_i is the coefficient of carbon

Table 1. Variables in the Model.

Variable	Index Meaning	Unit
I	CO ₂ emissions	Ten thousand tons
P1	Population size	Ten thousand people
P2	Population urbanization rate	%
A1	Real GDP per capita	Yuan
A2	The second industry	%
A3	Private car ownership	Thousands of cars
T1	Energy intensity	Tons of standard coal per ten thousand yuan
T2	Coal consumption	Ten thousand tons of standard coal
T3	Oil consumption	Ten thousand tons of standard coal

emissions of energy i which is provided by the IPCC (2006). COF_i is the carbon oxidation factor of energy i . $CF_i * CC_i * COF_i$ is the coefficient of carbon emissions of energy i . In 2009, Shiyi Chen [8] has calculated the CO_2 emissions coefficient of coal, oil and natural gas. The research result is of great academic recognition and is widely used. Therefore, this paper direct refers to the estimation data: the CO_2 emissions coefficients of coal, oil and gas respectively are 2.763, 2.145 and 1.642. The unit is kg per kg of standard coal.

This paper studies the time interval of 1985-1985. The data about the population, economic and technical all come from "China Compendium of Statistics, 1949-2008", "China Energy Statistical Yearbook 2009", "China Energy Statistical Yearbook 2015", "China Statistical Yearbook 2016" and the database of State Statistical Bureau.

4. The Empirical Analysis

4.1. Ridge Regression Analysis

The matrix form of multiple linear regression model is:

$$y = X\beta + \varepsilon \quad (6)$$

Among them, X is the design matrix of regression model. β is the unstandardized coefficient matrix of regression equation. ε represents the constant matrix. The formula for computing β in the OLS estimates is:

$$\hat{\beta} = (X'X)^{-1} X'y \quad (7)$$

When there is multicollinearity between the independent variables, $|X'X| \approx 0$. At this time, the OLS method is not effective, as it cannot for inverse matrix. Therefore, A.E. Hoerl [9] proposes the Ridge Regression Estimation (RR) in 1962. It is actually a biased estimation. The principle is to add a normal matrix kI ($k > 0$) to $X'X$, so, $|X'X + kI| \neq 0$.

We standardize data to solve the problem of different dimension, and X still represents the standardized design matrix. So, $\hat{\beta}(k) = (X'X + kI)^{-1} X'y$ is the ridge regression estimation of β . Among them, k is the ridge parameter, and $\hat{\beta}(k)$ is more stable than OLS.

The property of the ridge regression estimation: Using MSE to represent the mean square error (MSE) of estimated vector, there is $k > 0$, makes

$$MSE(\hat{\beta}(k)) < MSE(\hat{\beta}) \quad (8)$$

Namely,

$$\sum_{j=1}^p E(\hat{\beta}_j(k) - \beta_j)^2 < \sum_{j=1}^p D(\hat{\beta}_j) \quad (9)$$

When the ridge parameter k changes within the range $(0, \infty)$, $\hat{\beta}_j(k)$ is the function of k . Draw the function $\hat{\beta}_j(k)$ on the plane coordinate system, so the curve is called the ridge trace. In the empirical analysis, k value is between 0 to 1 and the step length for 0.01, 0.05 or 0.1 in the ridge regression method. According to the shape change of the ridge trace curve, determine appropriate value of

k , and select the independent variables, in order to determine the model equation. This not only can avoid multicollinearity effect and improve the model's accuracy and explanation, but also can be used to understand the role of each variables and the relationship between the independent variables.

This paper uses SPSS18.0 ridge regression analysis. Draw the ridge trace of the regression coefficients to get **Figure 1**.

Figure 1 reflects the K value and β . The X-axis represents the K value, and Y-axis represents the β value of the corresponding variables. In **Figure 1**, the model began to stabilize from $K = 0.6$, function to estimate the regression coefficient has slowly evolved into parallel to the X axis. In accordance with the general principles of choose k value in the ridge trace method, we take $k = 0.6$. When $k = 0.6$, the ridge regression analysis results are shown in **Tables 2-4**.

In **Table 2**, $R^2 \approx 0.9625$, indicates that the regression equation can reduce 96.3% variance fluctuation of the dependent variable $\ln I$. The fitting effect of model is better.

The results of variance analysis are presented in **Table 3**. This table contains the significance of residual sum of squares (SS), mean square (MS), F value and Sig F . From $F = 84.388$ and $p = 0.000$, it can be known that the model is statistically significant, and the model overall fitting is well.

Table 4 outputs the ridge regression results of $K = 0.6$. It covers unstandar-

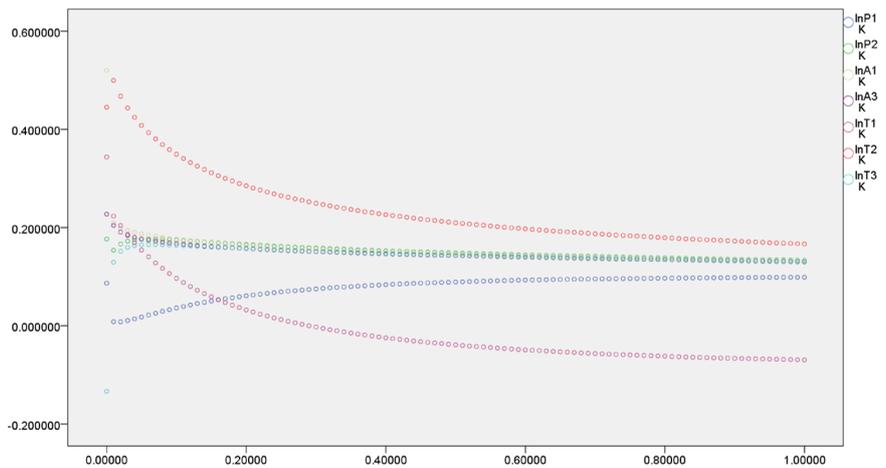


Figure 1. Ridge Trace.

Table 2. Ridge Regression Results with $k = 0.6$.

Multiple R	R Square	Adjusted R Square	SE
0.981083	0.962523	0.951118	0.121832

Table 3. Anova Table.

	df	SS	MS	F value	Sig F
Regress	7.0000	8.7680	1.2530	84.3881	0.0000
Residual	23.0000	0.3410	0.0150		

Table 4. $k = 0.6$ Variables in the Equation

	B	SE(B)	Beta	B/SE(B)	sig
lnP1	0.66603	0.08826	0.09296	7.54580	0.00000
lnP2	0.28357	0.01701	0.14459	16.67300	0.00000
lnA1	0.10075	0.00461	0.14316	21.87350	0.00000
lnA3	0.04043	0.00177	0.13978	22.82961	0.00000
lnT1	-0.08803	0.02831	-0.04898	-3.10888	0.00494
lnT2	0.20259	0.01449	0.19737	13.98171	0.00000
lnT3	0.13668	0.00638	0.14054	21.43743	0.00000
Constant	-0.59067	1.00871	0.00000	-0.58557	0.56387

dized regression coefficients, standardized regression coefficients and the estimation error of standardized regression coefficient B . In **Table 4**, the significant value of $\ln P_1$, $\ln P_2$, $\ln A_1$, $\ln A_3$, $\ln T_1$, $\ln T_2$ and $\ln T_3$ are all less than 0.05, indicating that these variables have a significant influence on $\ln I$. In addition, by following the principle of selecting variables in ridge regression, $\ln A_2$ is eliminated from the model because of its non-significant effect to $\ln I$.

From the result of the regression that $R^2 = 0.9625234$, it indicates that there is a significant linear relationship between the dependent variables and the independent variable. The explanatory power is strong, and the model is in a good fitting. Combined with the result of **Table 3**, $F = 84.3881$ and $\text{Sig } F = 0.000$, the regression equation passes the test with the significant level of 1%. This paper can conclude the expression of STIRPAT:

$$\ln I = 0.6660 \ln P_1 + 0.2836 \ln P_2 + 0.1008 \ln A_1 + 0.0404 \ln A_3 - 0.0880 \ln T_1 + 0.2026 \ln T_2 + 0.1367 \ln T_3 - 0.5907 \quad (10)$$

4.2. The Empirical Result Analysis

1) The population which is an important index of demographic factors, and has a great impact on CO_2 emissions. Its elastic coefficient is 0.666, so we can say that the increase in population is of a significant driving force for CO_2 emissions. Although China implemented one-child policy from 1983, the population still increased from 1.05851 billion in 1985 to 1.37462 billion in 2015, China still has the greatest population in the world. Remain other factors unchanged, demand for resources, energy products and services will increase with larger population, this will inevitably lead a higher CO_2 emissions.

2) The rate of urbanization has a great influence on the increase of CO_2 emissions, and the elastic coefficient is 0.2836. The increasing rate of urbanization is firstly reflected in the expansion of urban area. It adds the urban transportation distance and energy consumption. Secondly, the housing area of urban residents will increase, and the number of urban heating system and cooling system also will increase, so energy consumption will increase. Moreover, the construction of urban infrastructure facilities will increase, such as urban housing and recrea-

tional facilities buildings. It will cost a lot of building materials, so these factors will directly increase CO₂ emissions. In addition, with the improvement of urbanization rate, we are not allowed to ignore the indirect effects of the CO₂ emissions, for example, the expansion of urbanization process makes the vegetation coverage area reduced.

3) The energy consumption structure is an index of technical level, among which consumption of coal and oil has significant positive driving force to the CO₂ emissions. Its elastic coefficient is 0.2026 and 0.1367 respectively. Nowadays, in China's energy consumption structure, coal still has an overwhelming proportion. Within the research range of this paper, China's coal consumption ratio remains around 70%, even if the proportion has a downward trend in recent years. But by 2015, the national coal consumption proportion is still about 64%. China's consumption proportion of coal is much higher compared to the European Union and the United States. According to statistics, coal combustion creates 1.6 times and 1.2 times the amount of CO₂ than gas and oil, so, such energy consumption structure will inevitably lead CO₂ emissions come from the combustion of coal.

4) As indicators of economy, real GDP per capita and private car ownership have significant influence on China's CO₂ emissions, and the elastic coefficient is 0.1008 and 0.0404 respectively. With the continuous development of China's economy, the per capita real GDP growth and the improvement of residents' consumption will cause significant impact on CO₂ emissions. Data shows that China's private car ownership has a rapid growth from 284,900 in 1985 to 140,991,000 in 2015, nearly 500 times. Private cars, directly or indirectly cause the increase of CO₂ emissions, which embodied in the process of its production, sales, and put into use. So, we advocate low carbon travel, and help reduce CO₂ emissions.

5) From the fitting results of the regression, the elastic coefficient of China's energy intensity (T_1) on CO₂ emissions is less than zero in 1985-2015, and it does not make sense obviously, and remains to be further analysis. The elastic coefficient is -0.088. When the elastic coefficient of energy intensity is negative, it is called the "rebound effect", which associated with China's current economy and technology development stage. 1985-2015, China's real GDP per capita grew 12.1 times, CO₂ emission grew 5.06 times, and the intensity of energy was reduced by 64.29% only. It can be explained by economic expansion. The economic expansion will lead to a large energy consumption, weaken or even offset the CO₂ emission reduction which contributed by the increase in energy utilization efficiency, the decrease of the energy intensity and other technical progress factor. Along with the advancement of the economic transformation, the increase of the labor force quality, the industry upgrade, development of city and countryside integration and the increase of the proportion of modern services, we have reason to believe that energy intensity's falling has positive effects on reducing CO₂ emissions.

6) The regression result shows that the industrial structure of secondary in-

dustry is not significant, and it has no obvious influence on CO₂ emissions. From the perspective of the existing researches, there are many scholars also concludes that the adjustment of industrial structure has limited effect on CO₂ emissions. This may be related with the stage of economic development. China is still in the middle stage of industrialization, and has not yet entered the mature period. So, the change of industrial structure has little effect on the reduction of CO₂ emissions.

5. Conclusions and Policy Recommendations

The ridge regression result of STIRPAT model shows that it can reduce CO₂ emissions by controlling population growth, improving the level and quality of urbanization and adjusting economic structure and energy consumption structure. Therefore, this article's suggestions about CO₂ emission reduction can be put forward as listed.

From the perspective of population, considering the complex demographic problems such as an ageing population, if we continue to implement the strict control of population, it will no longer be conducive to China's social and economic development. So, we can improve the population quality and people's consumption concept to reduce CO₂ emission, such as raising people's awareness of environmental protection, advocating the garbage classification, encouraging the old stuff recycling and so on. In addition, we can also advocate low carbon life and promote afforestation.

From the perspective of town development, urbanization is the inevitable path in developing economy in China. However, its own development law is inconsistent with the environment. In order to protect the environment and reduce CO₂ emissions but hinder the development of urbanization, is clearly not appropriate. And the government should not value the level of urbanization rate as the only sign of the national modernization level. It should fully consider the environmental carrying capacity, take the urbanization road of green, new and low carbon, improve the rate of urbanization but guarantee the level of urbanization, so it can achieve the low-carbon development of the urbanization.

From the perspective of the economy, it is necessary to strictly implement the requirements of sustainable development, realize the economic growth in both quantity and quality, continue to realize the transformation of the economy efficiently, transform the mode of economic growth and promote industrial upgrading, improve the efficiency of energy utilization, and form the effective supervision and management system, look for the new economic growth point, strongly support the creative industries and high-tech industries, to reverse the bias of only emphasizing the economic growth in the past and realize the sustainable development of national economy.

From the perspective of energy consumption structure, it is necessary to develop renewable energy and new energy actively, optimize the existing single energy consumption structure, increase the research and utilization on clean energy such as hydropower, wind energy, nuclear energy and solar energy,

gradually increase the consumption proportion of renewable energy and low carbon energy, reduce the proportion of coal and oil in the primary energy consumption structure, reduce CO₂ emissions effectively and increase funding for energy research & development and investment in innovation of science and technology. Using technology to improve the efficiency of energy consumption is another big effective way to change the energy structure, for example, strengthen the technological innovation of existing energy, research on clean coal technology and energy saving technology and retrofit combustion device to guide the independent energy technology innovation, so that the combustion of fossil fuels is more efficient, clean and low carbon. It can reduce CO₂ from the source, encourage the promotion of new energy vehicles, and also can introduce foreign advanced energy technology to realize innovative development of China.

While expanding the STIRPAT model, this paper mainly analyzes the population size, urbanization rate, real GDP per capita, industrial structure, private car ownership, energy intensity, coal consumption and oil consumption these eight indexes of driving force to the CO₂ emissions. However, because of my limited knowledge and research ability, the study does not cover such as the working-age population ratio, energy price and the influence of environmental regulation on CO₂ emissions. These aspects still need deeper research and discussion.

References

- [1] York, R., Rosa, E.A. and Dietz, T. (2003) STIRPAT, IPAT and Impact: Analytic Tools for Unpacking the Driving Forces of Environmental Impacts. *Ecological Economics*, **46**, 351-365. [https://doi.org/10.1016/S0921-8009\(03\)00188-5](https://doi.org/10.1016/S0921-8009(03)00188-5)
- [2] Long, A.H., Xu, Z.M., Wang, X.H. and Shang, H.Y. (2006) Impacts of Population, Affluence and Technology on Water Footprint in China. *Acta Ecologica Sinica*, **26**, 3358-3365.
- [3] Wang, L.M. and Kang-Lin, H.E. (2006) Analysis on Temporal Variation of Environmental Impact Based on STIRPAT Model—A Case Study of Energy Consumption of China. *Journal of Natural Resources*, **21**, 862-869.
- [4] Wei, T. (2011) What STIRPAT Tells About Effects of Population and Affluence on The Environment? *Ecological Economics*, **72**, 70-74. <https://doi.org/10.1016/j.ecolecon.2011.10.015>
- [5] Liddle, B. (2013) Population, Affluence, and Environmental Impact across Development: Evidence from Panel Cointegration Modeling. *Environmental Modelling & Software*, **40**, 255-266. <https://doi.org/10.1016/j.envsoft.2012.10.002>
- [6] Ehrlich, P.R. and Holdren, J.P. (1971) Impact of Population Growth. *Science*, **171**, 1212-1217. <https://doi.org/10.1126/science.171.3977.1212>
- [7] Dietz, T. and Rosa, E.A. (1994) Rethinking the Environmental Impacts of Population, Affluence and Technology. *Human Ecology Review*, **1**, 277-300.
- [8] Chen, S. (2009) Energy Consumption, CO₂ Emission and Sustainable Development in Chinese Industry. *Economic Research Journal*, **4**, 41-55.
- [9] Hoerl, A.E. (1962) Application of Ridge Analysis to Regression Problems. *Chemical Engineering Progress*, **58**, 54-59.

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