IOP Conf. Series: Earth and Environmental Science **170** (2018) 032044 doi:10.1088/1755-1315/170/3/032044

The driving force of carbon emissions in china: 1995-2015 hierarchically provincial evidence

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Abstract. This paper computes the provincial carbon emissions, use a “region-province-time” three-dimensional panel data set from 1995 to 2015, and conduct an empirical study to explore the driving force of carbon emissions in China. A hierarchically spatial autoregressive error (HSEAR) model is established, which takes into account the hierarchical structure and spatial error effect. The empirical results suggest the carbon emission and per capita GDP forming an “N” shape Environment Kuznets Curve (EKC). Meanwhile, by the growth of coal population, consumption proportion and the number of private cars will significantly increase the carbon emissions. The significantly positive spatial correlation of the error terms implies that the error impact of carbon emissions in the area has a significant positive spatial correlation with the adjacent area, which corrects the error of the general spatial error model to the socio-economic reality.

1. Introduction

There is a lot of evidence in the statistical data and literature that carbon dioxide (CO2)-based greenhouse gas emissions are the main cause of global warming. With the rapid economic development in China, the amount of carbon emissions becomes a serious Chinese issue. It is important to explore the factors which drive the carbon emissions. The existing research on the driving forces of carbon emissions in China including the environmental Kuznets curve (EKC model) and environmental impact factor decomposition method. In the empirical research literature of EKC model, Du et al. (2007), Song et al. (2007), Ago et al. (2009) mainly used time series data set to study the relationships between economy and carbon emissions; Zoo (2007), Ma (2013), Du (2010; 2012), Sun (2014), Cu (2014) and Ran (2014) used the common two dimensional panel data set to investigate the factors of carbon emission from different perspectives. In the literature, the spatial econometric model is rarely used. Chen and Long (2011a; 2011b), Han et al. (2015), Zhao et al. (2018) introduced the spatial panel data model to amend the influencing factors of China's regional carbon emissions and their impact. However, the spatial panel data does not take into account the nested or hierarchical structure of data, such as different provinces belong to different regions, regions may have different characteristics due to different government policies, economic conditions, and geographical location. This study will consider the nested relationship between different levels of research objects and hierarchical spatial data, spatial data econometric models, and introduce the EKC analysis framework of the factors affecting carbon emissions, consider the hierarchical effects of regional carbon emissions.

2. Data description and provincial carbon emission estimates in China

Organizing the environmental and economic data from 1995-2015 across 30 provinces and municipalities in China (according to the China Statistical Yearbook and China Energy Statistical Yearbook 1996-2016). We divide the Chinese provinces and municipalities into 4 regions by the unbalanced development of economy, including Eastern China (Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan), Central China (Shanxi, Anhui, Jiangxi, Henan, Hubei and Hunan), Western China (Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang) and Northeast China (Liaoning, Jilin and Heilongjiang).The annual data are arranged by provinces or municipalities nested within regions.

Provincial carbon emissions from 1995 to 2015 are needed to be estimated by using the method from Du et al. (2010; 2012):

$$\left(CO_2\right)_{jt} = \sum_{k}^{8} Cons_{jt,k}\delta_k$$

where $\left(CO_2\right)_{jt}$ represents the carbon dioxide emissions of province j in year t, $Cons_{jt,k}$ represents the consumption of carbon emission source k within province j in year t, δ_k represents the coefficient of carbon emission source k (i.e. δ (coal, coke, gasoline, kerosene, diesel, fuel oil, natural gas, cement)={ 1.647, 2.848, 3.045, 3.174, 3.150, 3.064, 21.670, 0.527}).

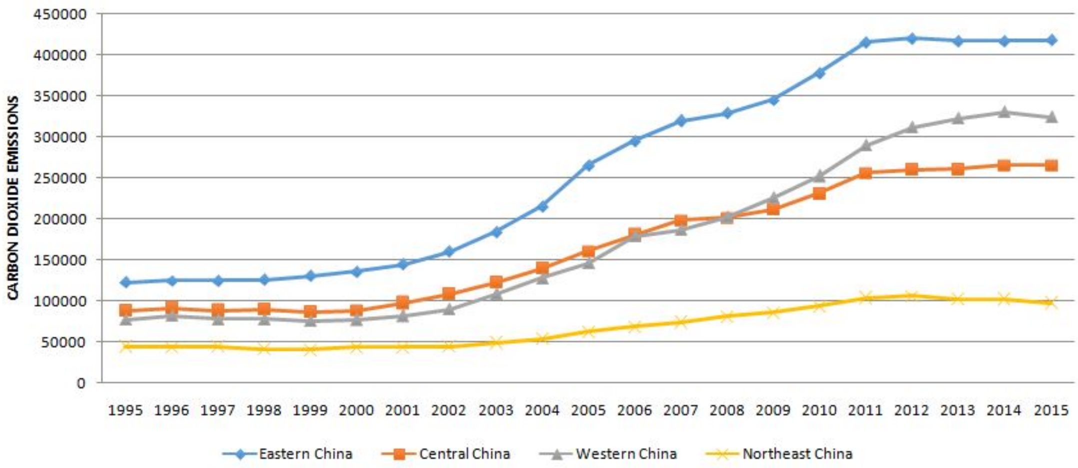

Figure 1. Trend graph of Regional Carbon Dioxide Emissions 1995-2015

As is shown in Figure 1, the four curves show the fluctuation of regional carbon dioxide emissions, the increase of CO_2 emissions is fabulous in amount. From 1995 to 2015, the carbon dioxide emissions in the four regions of China showed a year-on-year growth. Since 2002, the growth rate of carbon emissions has been accelerating and it has only slowed down until 2007. However, after 2009, China's carbon emissions have accelerated again, then carbon emissions have entered a flat stage in 2011. By the end of 2012, the total emissions of above-mentioned 4 regions reached more than 10 billion tons, which is about 3 times as 1995. With the rapid development of Eastern China, the number of carbon dioxide emissions sharply went up to 417.99 thousand tons in 2015 grew by 7% every year compared with 122.61 thousand tons in 1995. The growth rate of CO_2 emissions in Central China and Western China was about 6% and 8%, which had the similar tendency of growth from 1995 to 2012. Northeast China, by contrast, kept a steady growth rate in carbon emissions.

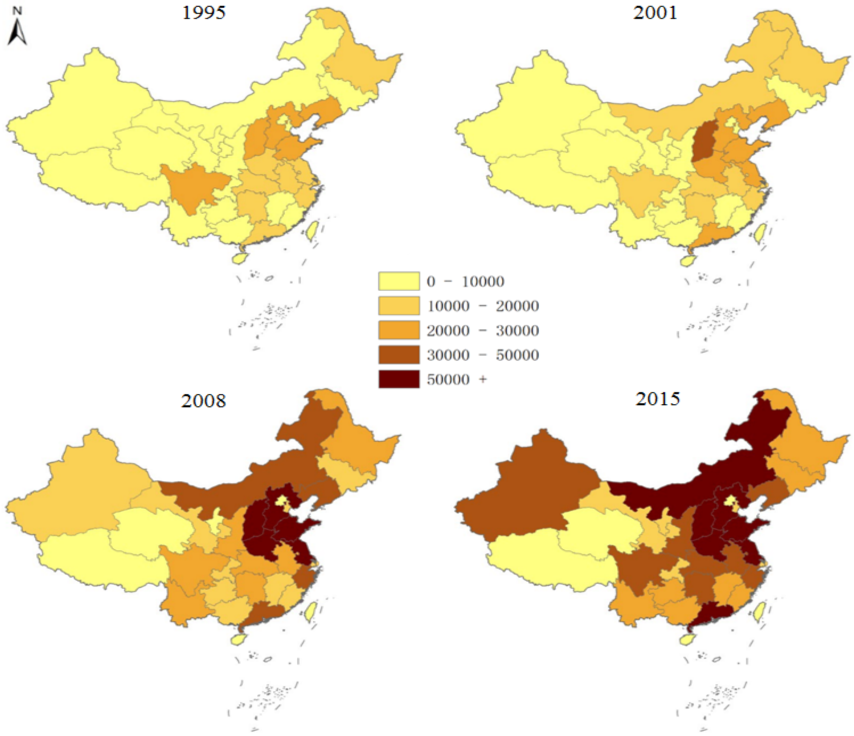

Figure 2. Carbon Dioxide Emissions (Ton) in Chinese Provinces and Municipalities 1995, 2001, 2008 and 2015

Figure 2 maps the data for four snapshots of the year 1995, 2001, 2008 and 2015 which clearly described the heterogeneous and spatially correlated carbon emissions distribution across provinces and municipalities. It is not difficult to find that the neighboring provinces with similar carbon emissions show the regional agglomeration trends. Dramatically changes over the period from 1995 to 2015, there were 22 (of 30) provinces and municipalities, which had a lower emission volume, produced emissions under 200 million tons in 1995. By 2001, Hebei, Jiangsu, Shandong, Guangdong, Shanxi, Henan, and Liaoning emitted over 200 million tons. In 2008, there were 16 provinces emitted exceeding 200 million tons. As of 2015, the carbon emissions increased to 22 provinces emitting over 200 million tons, among which the carbon emissions of Hebei, Jiangsu, Shandong, Guangdong, Shanxi, Henan, and Inner Mongolia even exceeded 500 million tons. The areas with carbon emissions from high to low are located in the eastern region, followed by the northeast and central region, and the lowest is the western region.

3. The theoretical model of the Driving Force of Chinese Carbon Emissions

Ye and Long (2016) suggested the GMM-FGLS estimate for a hierarchically spatial error autoregressive (HSEAR) model, which consider the hierarchical structure of the data and spatial effects simultaneously. Based on the above data description, the carbon emissions' hierarchically spatial error autoregressive (HSEAR) model established as follows:

$$CDE_{ijt} = \beta_1 PGDP_{ijt} + \beta_2 PGDP_{ijt}^2 + \beta_3 PGDP_{ijt}^3 + \beta_4 PP_{ijt} + \beta_5 COAL_{ijt} + \beta_6 CARP_{ijt} + u_{ijt}$$

$$u_{ijt} = \rho \sum_{g=1}^{N} \sum_{h=1}^{m_g} \omega_{ij,gh} u_{ght} + \varepsilon_{ijt}$$

$$\varepsilon_{ijt} = \alpha_i + \mu_{ij} + v_{ijt}$$

where CDE_{ijt} represents the total carbon dioxide emissions of province j nested in region i in year t, the explanatory variables vector including the per capita GDP, its quadratic form, and its cubic form, provincial population, the ratio of coal consumption and the number of private cars. β Represents the vector of parameters to be estimated. u_{ijt} Denotes the disturbance term of the j province nested in the region i in year t time period. The nested random effects are introduced via the disturbance of u_{ijt} which follows an error component structure. ρ Denotes the scalar spatial autoregressive coefficient to be estimated. α_i Denotes the itch unobservable region-specific effect which is assumed to be i.e. $\left(0,\sigma_{\alpha}^{2}\right)$. μ_{ij} Denotes the nested effect of the jet province within the itch region which is assumed to be i.e. $\left(0,\sigma_{\mu}^{2}\right)$. v_{ijt} Denotes the remainder disturbance which is also assumed to be i.e. $\left(0,\sigma_{v}^{2}\right)$.The spatial matrix $\left(\omega_{ij,gh}\right)$ is constructed by the Latitude and longitude distance between capital cities.

4. Estimation results of the HSEAR model

After estimated by using the suggested approach of GMM-FGLS via GAUSS 15.0, the results of HSEAR model and general spatial autoregressive error model (SEAR) as comparison are reported in Table 1.

Table 1. Estimation results of the HSEAR model for CO_2 emissions

Variable	SEAR Model	Standard Error	t Value	HSEAR Model	Standard Error	t Value
stdPGDP	0.2428***	0.0250	9.7195	0.2601***	0.0277	9.3828
stdPGDP2	-0.4126***	0.0539	-7.6608	-0.4479***	0.0587	-7.6325
stdPGDP3	0.2056***	0.0337	6.1014	0.2243***	0.0364	6.1539
step	0.0569***	0.0150	3.8015	0.0485***	0.0156	3.0971
stdCOAL	0.8371***	0.0091	92.0010	0.8277***	0.0094	87.7220
scarp	0.1518***	0.0078	19.5230	0.1598***	0.0082	19.5210
ωu	-0.1118	0.0986	-1.1340	0.1398***	0.0690	2.0275
stigmata	-	-	-	0.0014	-	-
sigma	0.0805	-	-	0.0833	-	-
sigma	0.0879	-	-	0.0880	-	-
Adj.R2	0.9855	-	-	0.9948	-	-
AIC	-4.2253	-	-	-5.2269	-	-
BIC	-4.1829	-	-	-5.1845	-	-

Note: *** indicates significant at 1% confidence level, ** indicates significant at 5% confidence level, * indicates significant at 10% confidence level.

It can be seen from the Table 1 that all coefficients of HSEAR and SEAR are significant at the 1% level, implying that the estimators are theoretically acceptable. The adjusted R2 of model HSEAR is higher than model SEAR, AIC and BIC of model HSEAR is lower than model SEAR, revealing that the model HSEAR has better performance than SEAR. Under the circumstance of dividing China into 4 regions by HSEAR model, the PGDP, its quadratic form, and its cubic form are 0.2601, -0.4479 and 0.2243, respectively. This suggests that after carbon emission growth enters the inflection point, carbon emissions gradually become smooth. With the rapid development of economy, the carbon emissions enter the rising stage once again, forming the environment's Kuznets "N" shape EKC curve, which became a national symbol that the quick advancement of China's industrialization and urbanization.

The carbon emissions elasticity on population and Civil Car Parc are 0.0485 and 0.1598, which point out that more carbon dioxide will be emitted with the number of population and private cars increase. Furthermore, on average, a 1% proportion of coal consumption in total energy consumption increase will lead a 0.8277% increase in the carbon dioxide emissions, enlightening that it is the main reason of the carbon emission. This suggests that we can reduce carbon dioxide emissions by reducing the proportion of total coal consumption in total energy consumption, adopt energy conservation and emission reduction measures, and population control. For various provinces in the same region of China, there is a relatively small regional difference $\sigma_\alpha = 0.0014$ by HSEAR model, and compared with the previous inter-provincial effect 0.0805 by SEAR model, it is significantly lowered; the standard deviation of effect $\sigma_\mu = 0.0833$ that the province is nested in regions represents the group difference between provinces among provinces and regions. Compared with various provinces in the same region, various provinces of different regions in China have a greater difference, which highlights the feature that "there is a larger difference between groups and a small difference within groups".

An interesting finding of the estimates of spatial autoregressive error correlation is that compared with the non-significant $\hat{\rho}_{SEAR} = -0.1118$ by SEAR model, HSEAR model is significantly positive, $\hat{\rho}_{HSEAR} = 0.1398$. We infer that this reason is due to the sensitivity of regional grouping. It is further demonstrated that we use HSEAR model can identify the positive spatial correlation of the error terms in the model. It shows that the error impact of carbon emissions in the area has a significant positive spatial correlation with the adjacent area, which corrects the error of the general spatial error model to the socio-economic reality.

5. Conclusion

In this paper, we consider a "region-province-time" three-dimensional panel data set for 30 provinces from 1995 to 2015. Firstly, we calculate the carbon emission for every province and group them as four regions (the Eastern, Central, Western, and Northeast China) by the unbalanced development of economy and analyze the distribution of interprovincial carbon emission. By introducing the hierarchical structure and spatial autoregressive error term into the error term, we construct an HSEAR model to investigate the impact factors of carbon emissions. The empirical results imply that the carbon emission and PGDP performing an "N" shape EKC Curve. It is important for China to reduce the proportion of total coal consumption in total energy consumption, restrict the issuance of new car license, and control the population growth rate. The standard deviations of the hierarchical effects feature that "there is a larger difference between groups and a small difference within groups". HSEAR model can identify the positive spatial correlation of the error terms in the model. In other words, the status of carbon emissions in China is unbalanced and regional agglomerate. Therefore, China has the challenge to adjust the energy composition, develop clean energy, and create an energy sustainable development system.

Acknowledgements

The authors acknowledge the Natural Science Foundation of Guangdong Province, China (Grant No.2015A030313216) and the Special and Innovative Project of Guangdong Education Bureau, China (Grant No.2014WTSCX001) and China Scholarship Council.

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IOP Conf. Series: Earth and Environmental Science **170** (2018) 032044 doi:10.1088/1755-1315/170/3/032044

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