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An Estimation of the Environmental Kuznets Curve

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Abstract

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Using provincial carbon dioxide emissions data, commercial coal consumption data and regional gross product data for 31 provinces in China from 1996 to 2015, I adopt a panel approach with fixed effect to examine the relationship between CO_2 emissions and economic development. This paper tests the Environmental Kuznets Curve (EKC) hypothesis, which suggests that the relationship between carbon emissions and economic development should be inverted U-shaped. My results suggest that this relationship does hold. Moreover, by using the first-order condition, I calculate the turning point and find that Beijing and Tianjin have crossed the inflection point and entered the later stage where the carbon emissions decrease with economic development. However, the majority of provinces are still in the early stage of development. Thus, it is crucial for the government to promote the usage of renewable energy and to facilitate environmental protection.

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I. Introduction

Would economic development hinder the well-being of our environment? Or, rather, would it actually raise concerns over living standards and health-related issues, thereby enforcing the protection of the environment and improving ecological conditions? In this paper, I seek to address this problem in the setting of China, one of the fastest-growing developing economies and the largest CO_2 emitters in the world. With the dramatic development in the manufacturing industry and technology, China has experienced a rapid economic growth since the 1970s. As of 2016, China has an annual economic growth rate of 6.7% and an average of above 9% (FRED). Nevertheless, such development does not come without a cost. Environmental issues in China including air pollution, water contamination and loss of vegetation have raised growing concerns. As one of the largest greenhouse gas emitters and a fast-growing emerging country, China is facing tradeoffs between economic growth and environmental preservation. One of the biggest challenges encountered by China right now is the high level of CO_2 emissions. According to International Energy Agency, as of 2015, China emits 9040.74 Mt of CO_2, which accounts for 28% of the world's total CO_2 emissions, surpassing the United States and becoming the world's largest emitter.

The importance of studying carbon dioxide emissions is twofold; firstly, although the use of fossil fuels seems inevitable in the process of modern civilization, the dramatically increasing level of greenhouse gas emission has raised concern of scientists as well as the public, since such trend could potentially push the Earth past its threshold and into a new stage of climate. Second, due to human's excessive exploitation of the non-renewable energy, energy shortage could also become a serious problem. Despite the need of developing the economy, reducing poverty and raising the living standard, this problem still needs to be emphasized and demonstrated because of two main reasons; first, CO_2 has a long lifespan and it takes a long time for the natural process, such as fertilization or dissolution, to remove it. Moreover, CO_2 is responsible for many positive climate feedbacks. Higher concentration of CO_2 could lead to environmental hazards such as loss of ice, sea level rise, and ocean acidification, which could trigger more serious issues such as global warming, human health-related problems and loss of biodiversity. As Yan and Yang (2010) point out, CO_2 is responsible for 72% of global warming effects. Second, since the main anthropogenic source of CO_2 is the burning of fossil fuels, CO_2 also plays a crucial role in indicating economic activities. Therefore, studying the relationship between CO_2 and economic growth could be in the interest of policymakers, economists, environmentalists, as well as anyone who could be affected by the changing climate.

There have been some improvements in the way the Chinese government handles such issue. Started in the early 2000s, the Chinese government began emphasizing the importance of pollution reduction and raised the idea of "Green Growth", attempting to shift towards a more sustainable way of development. More specifically, in 2016, Chinese government stated in the 13th Five-Year Plan, which is a series of economic and social development goals set by the Chinese government on a five-year time frame, that China will aim to reduce its CO_2 intensity by 18% and energy intensity by 15% over the next five years. In 2016, China ratified the Paris Climate Accord and pledged to reduce its CO_2 emissions per unit of GDP by 60% compared to the 2005 level. To achieve this goal, it is important for the Chinese government to consider the relationship between CO_2 and economic growth, to explore alternative paths of economic development and to attain a higher efficiency of energy use.

In this study, I use China's provincial CO_2 emissions data to conduct an empirical panel data analysis using the model presented by Apergis and Payne (2009). This paper aims to add more insights into the existing research and explore the relationship between environmental pollution and economic development, thereby providing political implications regarding more efficient energy use and the importance of sustainable development. The remaining sections of the paper are structured as follows: Section 2 summarizes some of the past literatures in the related fields and introduces some of their limitations. Section 3 described the datasets and methods I employ in this study. Section 4 provides the results I obtain from my analysis. Finally, political implications, limitations of the study, and conclusions are presented in Section 5.

II. Literature Review

The relationship between environmental indicators and economic growth has been studied by many scholars. In the 1950s, Kuznets (1995) advanced the hypothesis that as the economy develops, market forces first enlarge and then reduce the economic inequality. As Kuznets demonstrated, when an economy is at its early stage of development, new investment opportunities would favor those with more capital to invest, which further increases their wealth, whereas people with fewer capital would become poorer because they don't have as much access to investment. However, as the economy matures, social welfare and democratization takes place and eventually reduces the inequality. As early as 1991, Grossman and Krueger (1991) tested the hypothesis of Environmental Kuznets Curve (EKC), which is an inverted U-shaped relationship between environmental pollution and macroeconomic index. They further argued that CO_2 emissions and economic growth are positively related when the income is low, but as income rises, the relationship shifts from positive to a turning point, and then to negative, implying that as the economy develops to a certain level, an increase in economic growth would actually improve the environmental condition (Grossman and Krueger 1995). After this study, researchers implemented a considerable amount of empirical and theoretical studies, testing the validity of the EKC, in which they reached mixed conclusions. For example, Stern (1998), Maddison (2006) and Bartz and Kelly (2008) pointed out that the inverted U-shaped curve is only applicable to some specific environmental indicators. Holtz-Eakin and Selden (1995) discovered that the relationship is only negative until the GDP reaches a very high level, while Agras and Chapman (1999) and Richmond and Kaufman (2006) concluded that there is no statistically significant relationship between CO_2 emissions and economic development. Later, by using panel data from 98 countries, Wang (2012) pointed out that, on the contrary to the EKC hypothesis, there exists a nonlinear relationship between the two variables. Such conflicting findings are primarily because of the time frame and geological region that's being considered, as well as the different model employed by scholars.

There are several shortcomings, as mentioned above, in many existing studies on related subjects. First, some studies used cross-sectional methods and compared different locations within a certain time frame. One problem associated with this method is that different countries or locations may have different modes of development, that is, some countries might be dependent on manufacturing industry, while others rely more heavily on services. Such discrepancies may make it challenging to compare the CO_2 level associated with each economy, since the CO_2 emissions level between secondary and tertiary economies would likely differ. Moreover, since many researchers adopted a linear regression model, the result is sensitive to the underlying assumptions of the model. Therefore, if the data does not, in fact, satisfy the assumptions, the estimations could be biased, and the results could potentially be misleading.

Problems regarding CO_2 emissions and economic development in China have also raised many economists and environmental scientists' attention, prompting them to conduct a considerable amount of studies targeted specifically at regions in China.

For example, Wang, et al. (2011) deployed panel methods and analyzed the causal relationship between CO_2, energy consumption, and GDP, and found a long-run co-integrated relationship between the three variables, as well as an inverted U-shaped curve just as the EKC suggested. Li, et al. (2011) adopted a similar method and attained similar results, suggesting that there is a positive long-run co-integrated relationship between real GDP and energy consumption. Halkos and Tzeremes (2011) also indicated the existence of the inverted U-shaped EKC between China's CO_2 emissions and GDP per capita, and that trade plays a crucial role in such a relationship.

Although studies exploring the relationship between CO_2 emissions and GDP in China are not unprecedented, there are several dimensions that are commonly neglected. First, few studies emphasized the different paths of development undertaken by different provinces. For example, provinces in northern China such as Shanxi may rely excessively on energy exploitation or heavy industry, while southern China has a more diverse industrial structure. Therefore, I decide to explore more about individual provinces and their main modes of development and analyze how different economic paths could affect the relationship between pollution and economic development. Second, observing the fact that most existing studies used the data provided by official data institutions in China such as the China Statistical Yearbook, I compare the data released by China and those by some main international research agencies and find that there is a considerable amount of discrepancy between them. As Zhu (2014) concluded after comparing China's CO_2 emissions data officially released by China and data from other sources, there is a significant difference between the two. Guan, et al (2012) also demonstrated that, as of 2010, CO_2 emissions calculated based on the two publicly available official energy data sets differ by 1.4 gigatonnes. To address this problem, Shan, et al (2016) recalculated Chinese provincial CO_2 emissions data using the Apparent Energy Consumption Approach, through which they estimated fossil fuel-related CO_2 emissions by energy types according to the mass balance of carbon. (More information on the specific approach can be found in the paper presented by Shan, et al (2016).) Therefore, in this study, I utilize the experimental data obtained by Shan, et al (2016) to conduct panel regression, and compare the result with those studies using the data officially released by the China National Bureau of Statistics. Moreover, since energy consumption links closely to the extensive burning of fossil fuels and plays a major role in the emission of CO_2, it could potentially provide information regarding the relationship between CO_2 emissions and economic growth. Thus, I also include data on energy consumption in this research.

III. Data and Methods

To elucidate my research question, I use three main datasets in this study. The first one is the provincial CO_2 emission inventories in China from 1996 to 2015 calculated using the Apparent Energy Consumption Approach, the second one is the per capita commercial energy consumption collected by China Energy Group, and the last one is the real gross region product collected from the National Bureau of

Statistics of China. The sample of provinces are Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangdong, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang. Due to the relatively limited time series data for my sample, I analyze my data using a panel approach with fixed effects, as suggested by Apergis and Payne (2009). Such approach takes individual heterogeneity into account and allows me to control for factors that change over time for each province. To be more specific, fixed effects study the effect of carbon dioxide emissions within each province and omit the time-invariant characteristics.

As mentioned in the previous section, since CO_2 is a crucial indicator for energy consumption, and there exists a nonlinear relationship between CO_2 emissions and output according to the Environmental Kuznets Curve hypothesis, I adopted the same approach deployed by Ang (2007). As Ang suggested, the long-run relationship between CO_2, energy consumption and GDP per capita can be described by:

$$C_{it} = \beta_0 + \beta_1 E_{it} + \beta_2 G_{it} + \beta_3 G_{it}^2 + \alpha_i + \varepsilon_{ii},$$

where C_t is the CO_2 emissions (measured in metric tons per capita) in year t, E_t being the commercial energy use (measured in kilogram of coal equivalent per capita); G_t being the per capita real GRP (measured in thousand CNY) and G_t^2 being the square of per capita real GRP. The parameters β_1, β_2, and β_3 estimate the elasticity of CO_2 emissions as energy consumption, per capita real GRP and the square of per capita real GRP changes, respectively. β_1 is expected to have a positive sign since an increase in coal consumption would increase the emission of CO_2. Meanwhile, if the EKC hypothesis holds, β_2 is expected to be positive, while β_3 would have a negative sign in front. This model is employed to test the long-run relationship between CO_2 emissions and per capita real GRP in China.

Table 1. Summary statistics of total CO_2 emissions (total), per capita GRP (GRP3), and consumption of energy (conscoal).

Variable	Obs	Mean	Std. Dev.	Min	Max
total	570	224.6319	210.0205	.8	1553.8
GRP3	620	23.01488	20.81779	2.048	107.96
conscoal	382	876.035	499.5756	-1423.178	3486.552

Table 1 shows the descriptive statistics for the three variables, per capita carbon dioxide emissions (denoted total), per capita gross regional product (denoted GRP3), and per capita commercial energy use (denoted conscoal), that are used in this analysis.

IV. Empirical Results and Analysis

By looking at the CO_2 emissions, gross regional product and consumption of coal from 1996 to 2015, I employ a fixed-effect model, since the parameter—carbon emissions—is non-random. Moreover, by dividing the country data into provincial data, I model each group as fixed effect since each province has its own province-specific fixed mean. This approach helps me to control for the unobserved heterogeneity which is constant over time because it removes this heterogeneity through differencing. The panel regression with fixed effects returned the following result:

$$C_{it} = -23.5834 + 0.0989E_t + 9.3682G_t - 0.0557G_t^2,$$

Table 2. Empirical results with regular standard error.

total	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
conscoal	.0989367	.0200419	4.94	0.000	.0595185	.1383549
GRP3	9.368204	.9259284	10.12	0.000	7.547103	11.18931
GRPsquare	-.0557281	.009737	-5.72	0.000	-.0748787	-.0365775
_cons	-23.5843	15.84798	-1.49	0.138	-54.75386	7.585253
sigma_u	169.64157					
sigma_e	88.024211					
rho	.78787301	(fraction of variance due to u_i)				

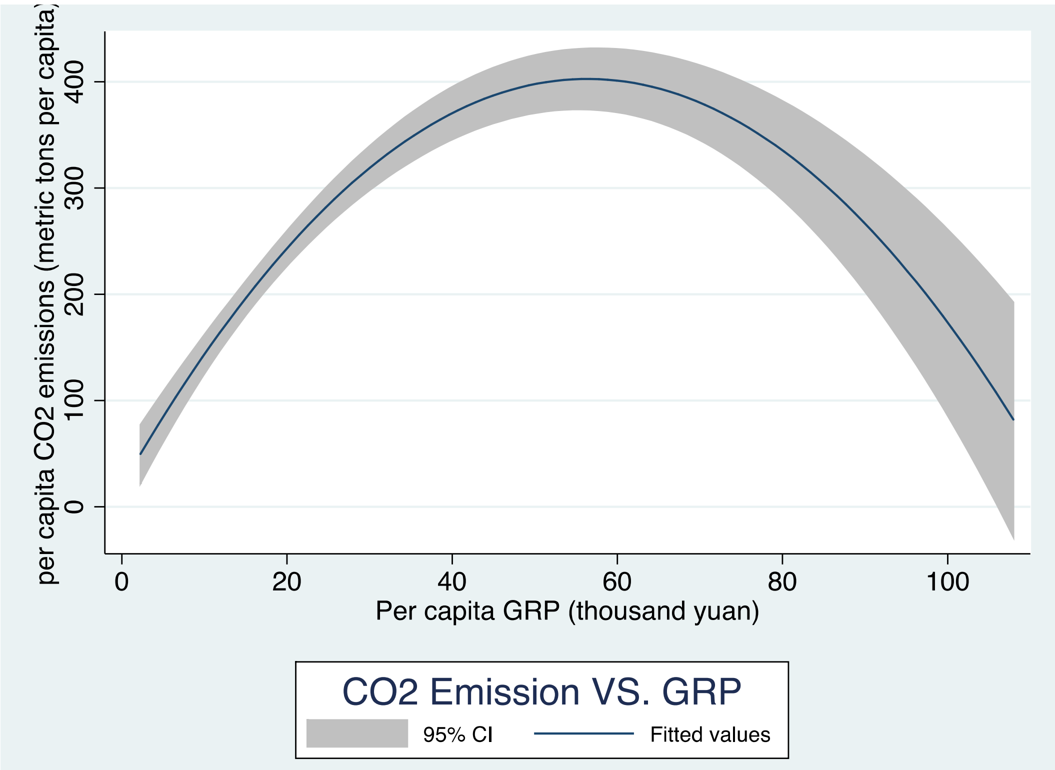
F test that all u_i=0: F(29, 349) = 42.87 Prob > F = 0.0000

Table 3. Empirical results with robust standard error.

total	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
conscoal	.0989367	.0537628	1.84	0.076	-.0110206	.208894
GRP3	9.368204	1.638779	5.72	0.000	6.016524	12.71988
GRPsquare	-.0557281	.0151194	-3.69	0.001	-.0866507	-.0248054
_cons	-23.5843	51.7844	-0.46	0.652	-129.4953	82.32669
sigma_u	169.64157					
sigma_e	88.024211					
rho	.78787301	(fraction of variance due to u_i)				

In alignment with the prediction stated in the previous section, *β1* and *β2* indeed have positive signs, and *β3* has a negative sign. At the 99% confidence level, I reject the null hypothesis and conclude that there is a strong relationship between the per capita gross regional product, energy consumption and total CO_2 emissions. Table 2 and Table 3 present the empirical results using regular standard error and robust standard error, respectively. The carbon dioxide emissions are positively related to gross regional product and negatively related to the square of gross regional product. This result is consistent with the EKC hypothesis, and the long-run elasticity of carbon dioxide emissions with respect to the per capita GRP is $9.3682 - 0.1114G_t$. This conclusion seems to be consistent with China's carbon emissions and development stage. The turning point calculated using the first-order condition is 84095.15 (CNY). As the data suggests, CO_2 emissions in a few highly developed areas such as Beijing and Tianjin, which has a per capita GRP of 106497 CNY and 107960 CNY, respectively, are indeed leveling down after a long period of increase. Potential reasons behind this "turning point" include the advancement of more effective and environmental-friendly technologies, as well as better waste-managing systems and increasing awareness for environmental protection. The data aligns with the EKC hypothesis that the CO_2 emission level starts to drop after the region's economic development passes the turning point. However, for the coal-dependent provinces such as Inner Mongolia, it may still take a considerable amount of time for the emissions to start reducing with economic development.

Figure 1. The long-run relationship between CO_2 emissions and GDP.



As Fig. 2 illustrates, the analysis does generate an inverted U-shaped curve between per capita CO_2 emissions and economic growth, which supports the trend predicted by the Environmental Kuznets Curve.

The relationship between CO_2 emissions and per capita gross regional product by province are summarized in Fig. 2. It can be observed that Inner Mongolia, Shandong and Shanxi have a relatively steep line of total emissions. Hebei, Henan, Shannxi and Jiangsu also experienced a relatively high level of increase in their total emissions. Interestingly, Inner Mongolia, Hebei and Shanxi are all located in the North part of China, which is consistent with my hypothesis that provinces that depend more heavily on heavy industries are likely to have a larger increase in their CO_2 emissions.

More generally, Fig. 2 demonstrates the fact that carbon dioxide emissions have been increasing throughout the years with the rising GRP. More importantly, the growth rate of emission seems to be increasing at a faster rate than that of the GRP.

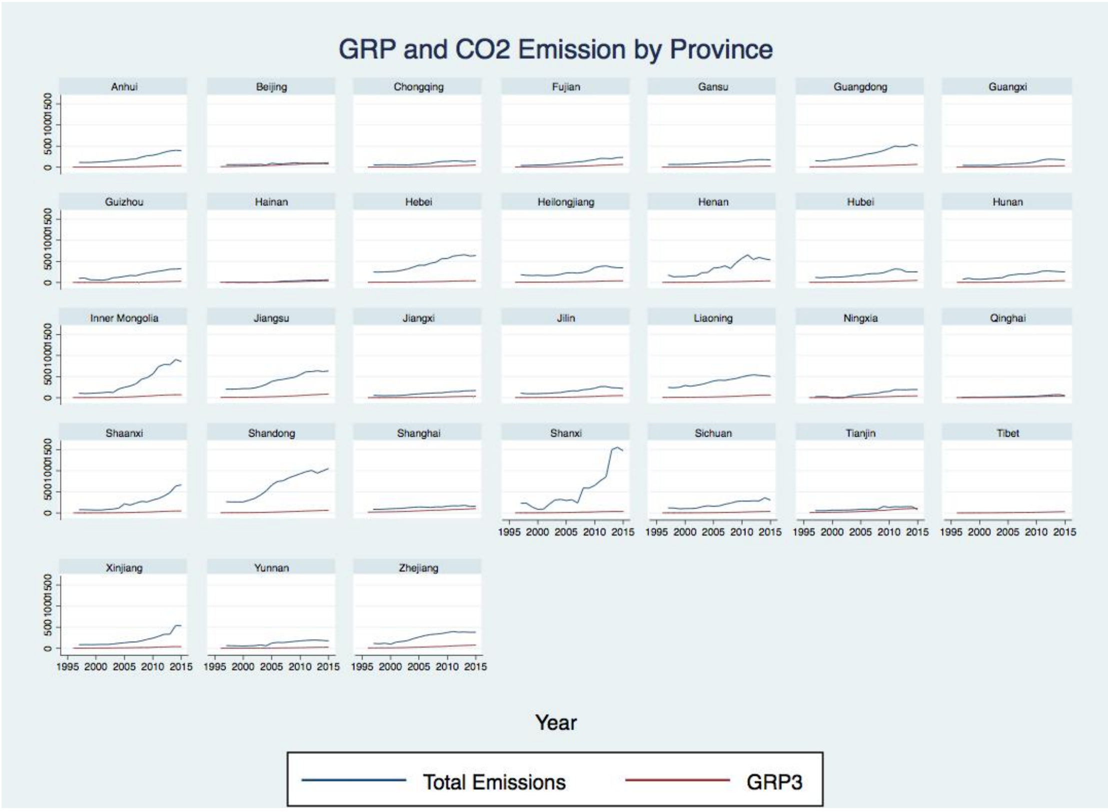


Figure 2. Per capita GRP and CO_2 emissions for 31 provinces from 1997 to 2015.

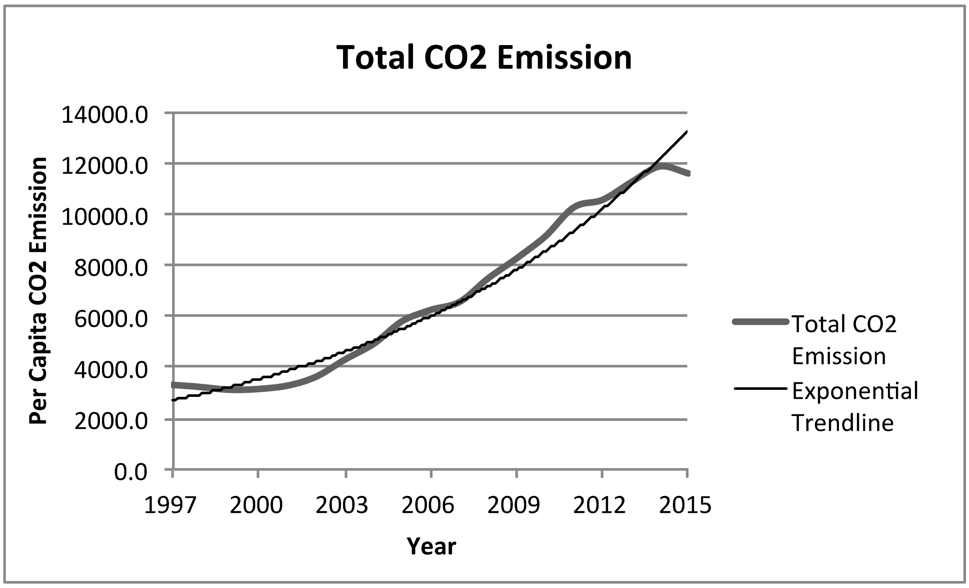


Figure 3. Total per capita CO_2 emissions in China, from 1997 to 2015.

From 1997 to 2015, the total national carbon dioxide emissions increase by 251%, from 3115 million tons to 11603 million tons. Such trend is summarized and shown in Fig. 3. Among the 30 sample provinces, Hainan experienced the largest increase in emissions, about 20.77%. Nevertheless, such high level of increase is preliminarily due to the underdevelopment of Hainan in the 1990s. Thus, despite its large value in terms of percent increase, its total emissions level actually remained very low throughout this period. In addition, Shannxi, Inner Mongolia, Ningxia, Xinjiang, and Shanxi also have a relatively high level of increase in their carbon emissions. As of 2015, the top three provinces with the highest emissions are Shanxi, Shandong, and Inner Mongolia, which is not a surprising finding since these three provinces are primary coal producers. It can be seen from Fig. 4, Fig 5, and Fig 6 that these three provinces have all experienced an increasing trend in their carbon emissions. Depending heavily on the coal-mining industry, these three provinces have relatively high levels of per capita coal usage, and therefore higher levels of emissions than the national average.

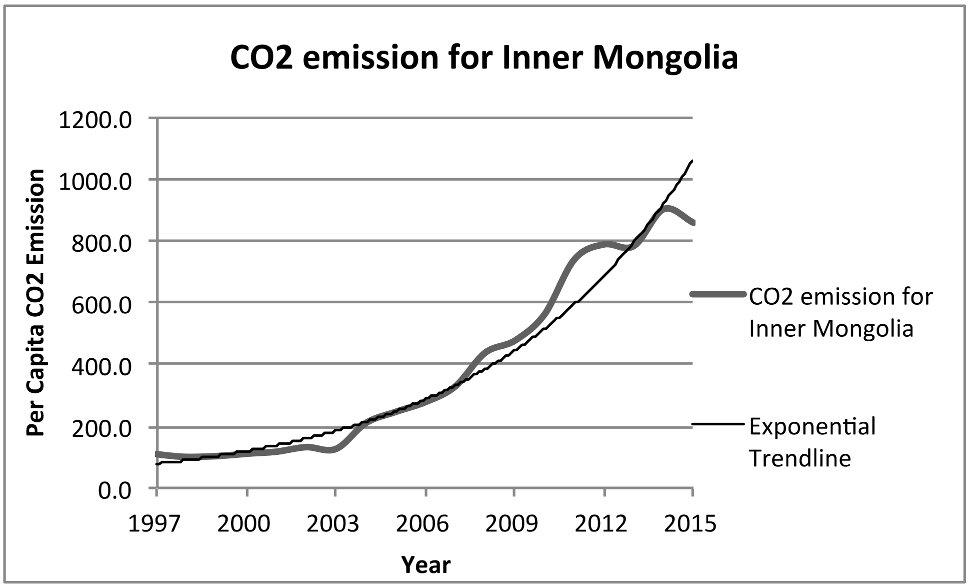


Figure 4. Per capita CO_2 emissions in Inner Mongolia, from 1997 to 2015.

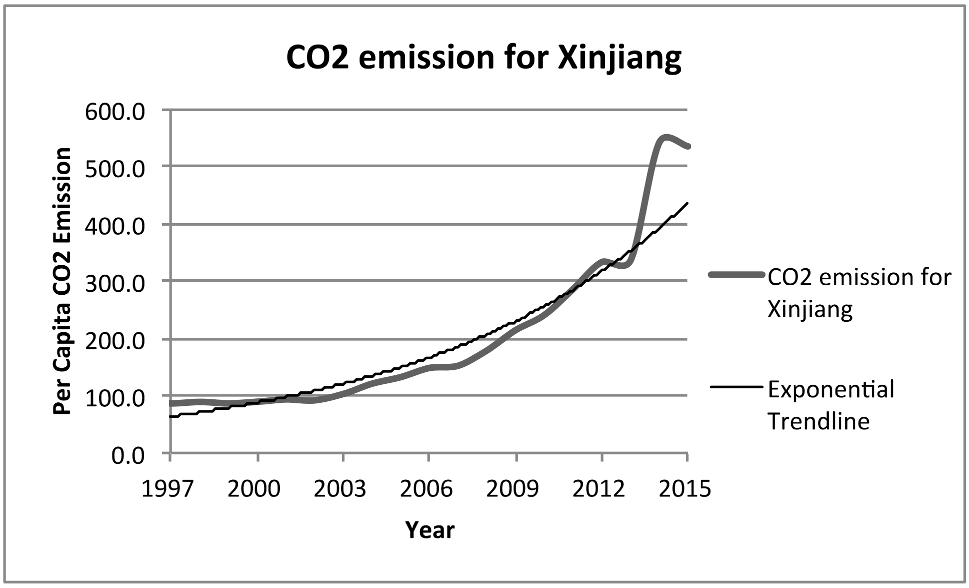


Figure 5. Per capita CO_2 emissions in Xinjiang, from 1997 to 2015.

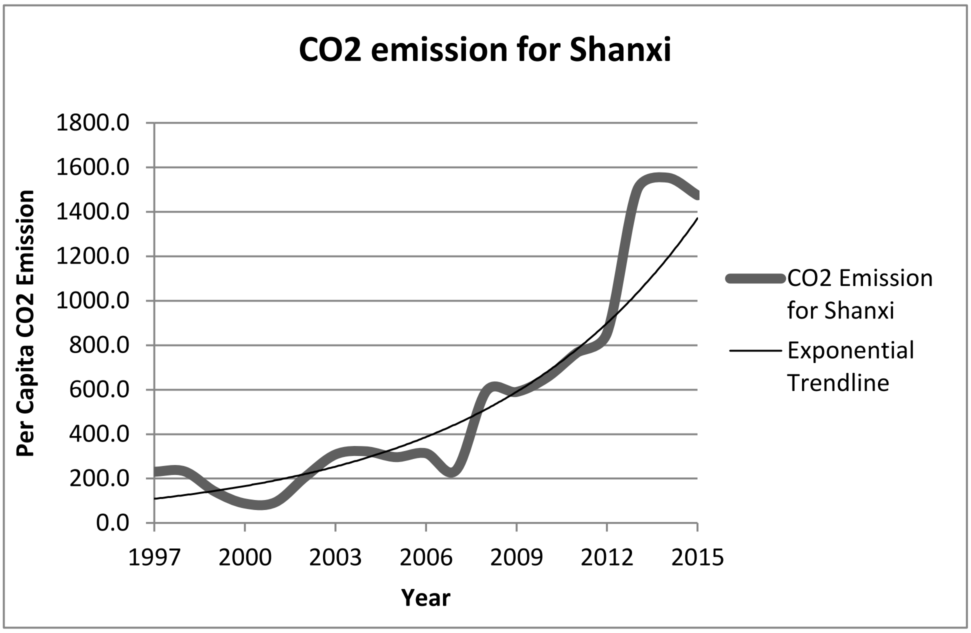


Figure 6. Per capita CO_2 emissions in Shanxi, from 1997 to 2015.

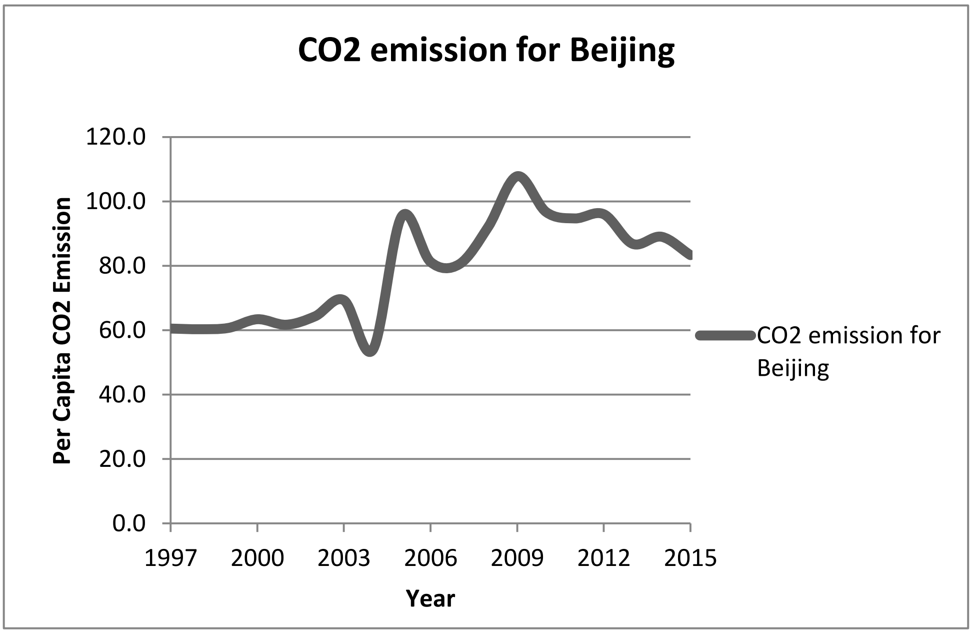


Figure 7. Per capita CO_2 emissions in Beijing, from 1997 to 2015.

As Fig. 7 illustrates, Beijing has relatively more fluctuations in its carbon emissions and does show a decreasing trend in emissions since 2009, which demonstrate the conclusions drawn by the EKC hypothesis that CO_2 emissions would eventually drop with the development of the economy.

The second highest-emission provinces include Hebei, Liaoning, Jiangsu, Shannxi, Xinjiang, which are mostly energy producers or depend largely on heavy industries. These regions as well as other less coal-dependent provinces, if in agreement with the EKC hypothesis, would still be in the earlier stages of environmental pollution, which means that their economic development would come at the cost of the environment.

V. Conclusions and Implications

By using the carbon dioxide emissions data calculated using the apparent energy approach, I conduct panel analysis for 31 provinces in China with respect to the carbon dioxide emissions, energy use, and gross regional product, and explore the relationship between CO_2 and economic growth. The result confirms the importance of changing the energy consumption structure. Moreover, the bidirectional causality between energy consumption and economic growth implies that more energy is needed to attain faster economic growth, and that promoting economic growth would inevitably raise energy consumption. Not only does this relationship suggest the possible negative effect of reducing energy consumption on economic growth, it also highlights the significance of improving the efficiency of energy use and of developing green energy. The main conclusions are summarized as follows.

First, unlike many previous studies which utilized emissions data released by the National Bureau of Statistics of China (NBS), this study focuses on the emissions data calculated using the energy consumption information. The purpose of using this alternative dataset is to shed light on the potential inaccuracies in the data reported by the NBS. I find that using the same datasets other that the CO_2 emissions data, I end up obtaining drastically different results compared to the previous research which adopted the officially released dataset. As a result, I conclude that there is a considerable amount of discrepancies between the data officially released by the China National Bureau of Statistic calculated by researchers and those calculated by researchers. Thus, CO_2 emissions data of China should be cited carefully after close comparison. Moreover, the official data source of China could inspect and update the press released data more frequently in order to prevent severe deviations and delays in research and policy-analysis due to inaccurate data. Such data-monitoring and updating could not only provide a better estimation for researchers, they also play a crucial role in the analysis and execution of policies. Additional data sources such as a detailed breakdown of emissions and air pollution indices such as PM 2.5 should also be included in order for researcher to derive more insightful results.

Moreover, by using a panel approach with fixed effect to conduct regression analysis, I find that there is indeed an inverted U-shaped relationship between commercial carbon dioxide emissions and economic development on the provincial level, which is in alignment with the Environmental Kuznets Curve hypothesis. In addition, I also find that Beijing and Tianjin have already entered the stage where economic development is accompanied with a decreasing level of environmental pollution, whereas other provinces are still in the earlier stage of the EKC curve and still trading off between economic growth and carbon emissions.

The result obtained in the study is in contrary to those concluded by Wang, et al (2011), which adopted similar panel methods but yielded a U-shaped curve between CO_2 emissions and GDP. The main difference lies in the data, since this study utilized the emissions data calculated by Shan, et al (2016) using the Apparent Energy Consumption Approach, while Wang, et al (2011) used the emissions data officially released by the China National Bureau of Statistics. The result in this study is, on the other hand, consistent with the results obtained by Zhang and Cheng (2009) and Chen and Chen (2015), and provides support in terms of the carbon emission trend in China. Provinces other than Beijing and Tianjin are still in the earlier stage of EKC, and areas that combust the largest amount of raw coal generally emit the greatest amount of CO_2. Thus, policies should focus more on the encouragement and subsidy of the development of renewable and clean energy such as thermoelectricity or hydroelectric power. Not only could such policies reduce the combustion of coal and pave the road for future economic development, they also provide a more harmonious and balanced environment for the residents, thereby guaranteeing a higher living standard and better living condition.

This study does have some limitations. To start with, the time frame of the dataset I use is fairly limited, which means that the results may not be as significant as if I employed a larger dataset with more observations. Therefore, future studies could test the result of this study by using the Apparent Energy Consumption Approach to calculate CO_2 emissions data for years before 1996, including gross regional product data, as well as commercial coal consumption data for a longer time period, and conduct analysis to draw more convincing conclusions. Besides, due to the limited access to the CO_2 emissions data officially released by the Chinese official data source, this study does not include a comparison between the results obtained by using the officially released data and the calculated CO_2 emissions data. Although I conclude that discrepancies exist between the two datasets by comparing my results with that of the other scholars who adopted the official data, such comparison could be made in a more concrete and careful way. Thus, future analysis could be conducted by comparing the empirical conclusions drawn by using the two different data source and evaluating the implication of the potential similarities or disparities of the results.

By emphasizing the different economic development paths undertaken by different geological regions of China, this paper examines the characteristics that could influence the efficiency and sustainability of energy use. Since China is seeking alternative paths of development, this paper provides insights to policymakers on how dependence of different industry could aid or hinder the idea of "Green Growth". Moreover, through comparing different datasets, this paper enables me to test the accuracy and completeness of the data officially released by China. The results offer informed assessment on the official statistics and potential areas in which Chinese Statistics Bureau could improve, and could be in the interest of scholars who plan to use the official data for research. Linking economic growth to the environmental changes Chinese residents experienced over the past decade, this study also adds the insight on how rapid economic growth at the expense of the environment could influence our daily life.

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