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Wei Zheng
School of Economics and Development, Wuhan University, China
School of Politics and International Relations, University College Dublin, Dublin, Ireland

Patrick Paul Walsh
School of Politics and International Relations, University College Dublin, Dublin, Ireland

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Urbanization, trade openness, and air pollution: a provincial level analysis of China

Wei Zheng[1] **Patrick Paul Walsh**[2]

Abstract

As the largest developing country in the world, with fast-paced urbanization development, China has achieved rapid economic growth since the "Reform and opening-up" policy implemented in 1978. This growth, however, has resulted in persistent and severe environmental problems. This paper evaluates urbanization, trade openness, energy consumption and PM2.5 in the Chinese economy using Fixed effect (FE), fixed effect instrumental (FE-IV), and system generalized method of moments (GMM-sys) estimation methods from 29 provinces over the period 2001–2012. Results demonstrated that PM2.5 is a continuous process that the previous period has positive effect on the current level of PM2.5; Environmental Kuznets Curve (EKC) hypothesis was not supported by analyzing the relationship between economic growth and PM2.5 in China; temperature is not a crucial influencing factor in affecting the amount of PM2.5; urbanization is beneficial to the decrease of PM2.5. PM2.5 from neighboring regions is an important factor increasing the local PM2.5, and the influencing factors of international trade, heavy industry and private cars are contributors to PM2.5 level as well.

Key words: PM2.5, Energy consumption, Urbanization, Average temperature level

[1] Corresponding author. E-mail address: 6182zw@163.com, wei.zheng@ucdconnect.ie. School of Economics and Development, Wuhan University, China. School of Politics and International Relations, University College Dublin, Dublin, Ireland

[2] E-mail address: ppwalsh@ucd.ie. School of Politics and International Relations, University College Dublin, Dublin, Ireland

1 Introduction

Since initiating "Reform and Opening-up policy" in the late 1970s, China has become one of the fastest growing economies in the world, which has seen it move from a centrally planned to a market-based economy. Over the past decades, China's GDP growth has averaged nearly 10 percent a year. The rapid economic growth, the rapid process of urbanization, industrialization, large scale of energy consumption has resulted in an environmental crisis. The United Nations projected that by 2050 about 64% of the developing world and 86% of the developed world will be urbanized. China's urban population has surpassed 50% in 2011, which was the first time in the country's history that the urban population exceeded that of rural areas. The fast development of cities has brought many changes in the environment. One of the concerns is urban heat island when industrial and urban areas produce and retain heat. Other impacts also include reducing soil moisture and a reduction in reabsorption of carbon dioxide emissions. Nonetheless, Stewart (2009) argued that the emigration from rural areas reduces destructive subsistence farming techniques, such as improperly implemented slash and burn agriculture that is primarily positive for the environment.

Industrialization is another hallmark of economic growth. Usually the process of industrialization means the evolution of the industries from light industries, heavy industries and chemical industries, to high-degree processed and technology-intensive industries. The economic growth and industrialization in China do show this trend in last 20 years. China has progressively entered the stage of rapid development of heavy and chemical industries since 2000; the growth rate of these industries, such as energy, petrochemical, metallurgy, construction materials, were high and increased the proportion of secondary industry in the economy. In 2008, the proportion of heavy and chemical industry among industrial value added jumped to as high as 71.3%. With economic growth, the consumption of energy, especially the fossil energy, is also increasing rapidly. China's economic development has encountered two kinds of restrictions: energy shortages and environmental degradation. The data from China's yearbooks (2000–2013) showed that the total primary energy consumption reached 4.02 billion tons of coal equivalent (tce) and accounted for approximately 20% of global energy consumption in 2012. The energy consumption increased by 203.9% from 1985 to 2008. China has become one of the largest energy consumers in the world, and the demand for energy sources has continued to rise over the last decades.

Therefore, economy, energy and environment form a complicated interdependent system. Understanding the relationship between energy consumption and air pollution is very significant for regulating energy and environmental policies in China.

Based on the literature review, the main contributions of this paper can be summarized in three points:

First, numerous studies on PM2.5 are based on natural science perspective. Very few studies on the subject have been conducted with econometric models. This paper uses the STIRPAT model and adopts provincial panel data from 2001 to 2012 to examine the key driving forces of PM2.5 emissions in China;

Second, static and dynamic panel models are applied to the panel data set to analyze the relationship between PM2.5 and the influencing factors. PM2.5 is a persistent process, so the previous level of PM2.5 has a large impact on the current level. Using dynamic models can capture this effect.

Third, for the first time, the effects of air pollution in neighboring areas on local level of PM2.5 is discussed, which provides a precise result to examine the key driving forces of PM2.5 emissions in China. The neighboring effect and temperature level factors are taken into consideration when initiating policies to reduce PM2.5 in China.

2 Literature review

The four most dangerous pollutants that are emitted in the economic growth are sulfur dioxide (SO2), nitrogen dioxide (NO2), carbon monoxide (CO), and particulate matter (e.g. PM2.5). Particulate matter (including soot) is emitted during the combustion of solid and liquid fuels, such as power generation, domestic heating and in vehicle engines. Particulate matter varies in size (i.e. the diameter or width of the particle). PM2.5 refers to the mass per cubic meter of air of particles with a size (diameter) generally less than 2.5 micrometers (μm). PM2.5 poses greatest health risks that can penetrate human lung and blood tissue and can increase the age-specific mortality risk, particularly from cardiovascular causes. Children, the elderly and those with predisposed respiratory and cardiovascular disease are known to be more susceptible to the health impacts from air pollution (WHO, 2016). Numerous studies have confirmed that PM2.5 is the main form of air pollutants (Wang *et al*., 2015a) and has caused serious air deterioration in most metropolitan areas around the world, which can be worsened by inefficient energy consumption practices, the rapid increase of private motor vehicles and traffic congestion.

Exploring the effect of driving forces on PM2.5 emission from the economic and social point of view has been the subject of intense research over the past few decades (Mallia *et al*., 2015; Mardones and Sanhueza, 2015; Meng *et al*., 2015 ; Zhang and Cao, 2015). Kirchstetter *et al*. (1999) estimated the effect of PM2.5 from light and heavy-duty vehicles on the air pollution problems and this study found that heavy-duty diesel vehicles in California were responsible for nearly half of oxides of nitrogen emissions and greater than three-quarters of exhaust fine particle emissions from on-road motor vehicles. Xu *et al*. (2015) found the driving forces of urbanization, economic growth, private cars and coal consumption on PM2.5 pollutant in China using nonparametric additive regression models. Meng *et al*. (2015) examined a supply-chain approach to more effectively mitigate primary PM2.5 pollutant in China from the perspectives of production, consumption and their linkages using structural path analysis.

Guan *et al*. (2014) applied structural decomposition analysis to analyze the magnitudes of economic growth, capital formation and exports in driving primary PM2.5 emission level changes in China during the period 1997–2010. Their results showed that China's significant efficiency gains fully offset emissions growth triggered by economic growth. Jiao *et al*. (2014) revealed that local provincial economic growth and pollutant emission exhibited an inverse-N-shaped relationship; pollutant emission had a negative effect on economic structure and economic growth in China, which can reduce the positive contribution of economic structure to economic growth by performing the multivariate regression model. Lin *et al*. (2014) analyzed the effect of multiple topographical and socioeconomic factors on PM2.5 using the topographical weighted regression (GWR) model in China for the years 2001–2010. Huo *et al*. (2014) analyzed the emissions and GDP performance of 36 production sectors. Their results showed that the equipment, machinery and devices manufacturing, and construction sectors contributed more than 50% of air pollutant emissions in China.

Shen *et al*. (2014) examined the effects of different means of transport on $PM_{2.5}$ emissions and found that the extensive use of motor vehicles has become one of the main sources of PM2.5 emissions. However, these literatures studied the driving forces of air pollution mainly from social and economic perspectives, and few of the studies control for the effect of temperature and neighboring on PM2.5 pollutants. Wind, temperature, precipitation and other weather conditions influence the dilution and scouring of the air pollution. For instance, compared with a plain, basin topography is not conducive to the spread of air pollution as it is surrounded by mountains. Sica and Susnik (2014) who tested whether the Environmental Kuznets Curve is influenced by the geographical dimension in Italy found that the geographical dimension significantly influences the relationship between income and pollutant emissions. However, in their paper, the researchers simply divided Italy into four regions according to the characteristics of the Italian productive system. Khan *et al*. (2015) investigated distribution and sources of 16 polycyclic aromatic hydrocarbons bound to PM2.5 during different seasons and observed strong seasonal dependency of the total PAHs in their study. The total pollution in any area forms from the combination of local and upwind sources. Air transport refers to pollution from upwind emission sources that impact air quality in a given location downwind.

The remaining sections of the paper are organized as follows. Section 3 explores China's energy consumption structure from two perspectives: types of energy consumption and energy consumption by sectors. In the next Section 4 we discuss the methodology and model specification. Section 5 provides the empirical results and analysis. The final section is the conclusion and policy suggestion of the paper.

3 China's energy structure

3.1 Five main types of energy consumption

In China, the primary energy consumption mainly includes five types: coal, oil, gas, nuclear and renewables (Bilgen, 2014). Coal, as the dominant fuel type, is overwhelmingly abundant and more widely distributed and plays a strategic role in China's economic growth (Li and Leung, 2012). The share of coal consumption in the total energy consumption has been accounted for approximately 70% over the last decades. Compared with the abundance of coal, the reserve of oil of China only accounts for 2% of the world oil reserves. To sustain the economic growth, about 61% of oil consumption was imported in 2015 (NBS, 2015). In comparison to oil reserves, China is rich in natural gas reserves. The authorities have estimated that the ultimately recoverable resources (URR) and technically recoverable resource (TRR) of natural gas are 6.1 trillion cubic meters tcm and 37 tcm, respectively (Hou *et al*., 2015; Zhou *et al*., 2015). The slow development of gas industry during China's industrial period has greatly limited the gas consumption that just accounted for 4.5% of total energy consumption in 2012. Facing the energy shortages and environmental deterioration situation, natural gas as a kind of clean energy resource to replace coal will increase due to continued policy backing from the central government. Meanwhile, besides natural gas, nuclear power has been regarded as another alternative to coal (Zhou and Zhang, 2010). By the end of 2017, China has 38 nuclear reactors operating with a capacity of 34.5 GW and 18 under construction with a capacity of 21 GW. The nuclear energy consumption soared from 4.0Mtoe in 2001 to 48.6 Mtoe in 2015, with an annual growth rate of 17.6%. China's National Development and Reform Commission has indicated the intention to raise the percentage of China's electricity produced by nuclear power from the current 2% to 6%

by 2020 (compared to 20% in the United States and 74% in France). In terms of renewable energy resources, China is a leading country in producing electricity by renewable energy that mainly includes hydroelectric, wind, bioenergy, geothermal, solar and other renewables. However, the renewable energy just provided 24% of its electricity generation, with most of the remainder provided by coal power plants. Nevertheless, the renewable electricity consumption increased rapidly with an annual growth rate of 10% over the last decades.

3.2 Energy consumption by sectors

China's energy consumption can be commonly divided into three energy-consuming end use sectors: building sector, transport sector, industry sector. In the building sector, the energy consumption gradually increased from 314 Mtoe in 1990 to 506 Mtoe in 2013, which was used for equipment, providing heating, lighting, cooling and other household needs (Zhang *et al*. 2015). However, the share of energy consumption by building sector has decreased from 35.7% in 1990 to 16.7% in 2013.

The transport sector accounted for about 8.2% of the total energy consumption in 2013, among which the large share was attributed to private cars. With the increase of income, individuals are more capable of affording motor vehicles. According to data from the Statistic Bureau of China, the number of private car increased from 7.71 million in 2001 to 88.29 million in 2012. The increase of private cars has pushed up the energy consumption, which contributed to nearly 70% of the cities' air pollution.

The industry sector has increased rapidly over the past two decades, rising from 245 Mtoe in 1990 to 881 Mtoe in 2013, and the share in China total energy consumed rose from 27.9% in 1990 to 29.0% in 2013.

4 Methodology and model specification

4.1 Model specification

The IPAT identity is a widely recognized framework for analyzing the impact of human activities on environmental change (Stern *et al*., 1992; Harrison and Pearce, 2000), which was developed in the early 1970s. However, the IPAT model has its limitation in that it assumes the elasticity of environment change with respect to population (P), affluence (A), and technology (T) is only one respectively, which has been criticized by many researchers (Dietz and Rosa, 1994; Tursun *et al*., 2015). Furthermore, it does not permit hypothesis testing since the known values of some terms determine the value of the missing term (York *et al*., 2003a). Based on IPAT model, Dietz and Rosa (1997) generated a new model known as Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) as follows:

$$I = aP_t^{a_1}A_t^{a_2}T_t^{a_3}e_t \tag{1}$$

Equation (1) preserves the multiplicative logic of the original model of I=PAT. Here I refers to the environmental impact; P denotes population size; A is a country's affluence and T is the level of environmentally damaging technology; t is time series; e is the error term; a is the constant term, b, c and d are the elasticities of environmental change with respect to P, A and T respectively. STRIPAT has been successfully utilized to analyze the effects of driving forces on a variety of environmental impacts (Dietz and Rosa, 1997; DeHart and Soule´, 2004; Shi, 2003; York *et al*., 2003a). After taking the natural logs forms the following Model (2):

$$LI_{it} = La + \alpha_1(LP_{it}) + \alpha_2(LA_{it}) + \alpha_3(LT_{it}) + e_{it} \tag{2}$$

Where the subscript i denotes the observational units; t—the year; α_1, α_2, and α_3 are respectively the coefficients of P, A, and T; e is the error term, and a is the constant.

As York *et al*. (2003b) indicated that the other driving forces of environmental change can be added into the Equation (2) as long as these influencing factors are consistent with the three main factors: population size (P), affluence (A) and technology (T), we add urbanization level (urban), heavy industry (heavy) rate, international trade ($traderatio$, $tradeGDP_{t-1}$and $tradepop$), $temperature$ and $coal$ into the models. Meanwhile, considering the nonlinear relationship between urbanization, economic growth, energy consumption, and PM2.5, the quadratic terms of GDP per capita is added to the models. Finally, Equation (2) can be rewritten as follows (3) and (4):

$$LPM_{it} = La + \alpha_1(Lgdp_{it}) + \alpha_2\left(Lgdp_{it}^2\right) + \alpha_3(urban_{it}) + \alpha_4(temp_{it}) + \alpha_5 Lcoal_{it} + \alpha_6 Lneighbour + X_{2it}^{'}\beta + \delta_t + \eta_i + e_{it} \quad (3)$$

$$LPM_{it} = La + \alpha_0 LPM_{it-1} + \alpha_1(Lgdp_{it}) + \alpha_2\left(Lgdp_{it}^2\right) + \alpha_3(urban_{it}) + \alpha_4(temp_{it}) + \alpha_5 Lcoal + \alpha_6 Lneighbour + X_{2it}^{'}\beta + \delta_t + \eta_i + e_{it} \quad (4)$$

Model (3) is a static model using FE and FE-IV to estimate the impact of driving forces on PM2.5. Model (4) is a dynamic model by applying the GMM-sys estimation method.

Where $coal$ represents energy consumption structure. PM is PM2.5 emission intensity ($ug\ per\ cubic\ M$). GDP denotes economic development level measured by real GDP per capita (yuan, based on 2000s). $temp_{it}$ refers to annual average temperature level of province i in time t.

$urban_{it}$ is the urbanization level measured by urban population to total population of province i in time t. $X_{1it}^{'}$ are the other control variables which include heavy industry rate, $traderatio$, $tradeGDP_{t-1}$ and $tradepop$. $X_{2it}^{'}$ includes heavy industry rate, $traderatio$, $tradeGDP_{t-1}$and $tradepop$, *private car inventory* and the *neighboring factor*. The subscript i refers to province and t is time year; δ_t is the variable that is used to capture the other factors that are changed over time, such as the environmental regulation, price of energy, the progress of technology. η_i is to measure the differences among provinces. e_{it} is the error term.

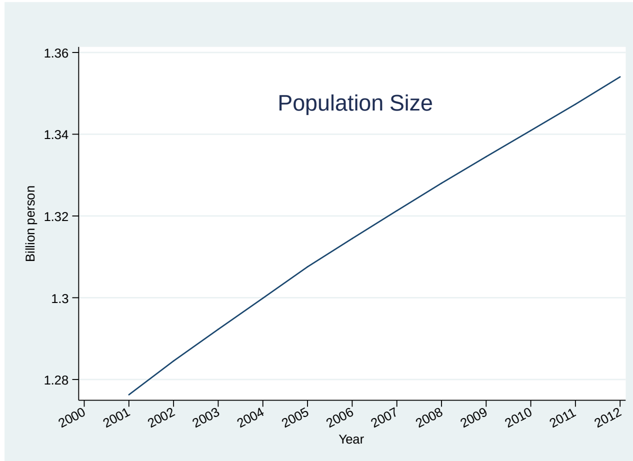

Figure 1 China's population size from 2000-2012

Here the study does not put the population size (P) into the equations as the population size of China showed stable growth from 2001 to 2012. As shown in Figure 2.1, the total population size reaches 1.354 billion in 2012 from 1.276 billion in 2001 at an average annual growth rate of 0.54%, which will not change the estimation results if added.

4.2 Data source and description

4.2.1 Data source

The data used in this paper were obtained from each year's China Statistical Yearbooks (2002–2013), China Energy Statistical Yearbooks (2002–2013), China Industrial Yearbooks (2002–2013), provincial statistical yearbooks (2002–2013) and the meteorological administration of each province. The PM2.5 data (2001–2012) were obtained from Battelle Memorial Institute and Center for International Earth Science Information Network at Columbia University.[3] The dataset is a balanced panel that consists of observations for 29 provinces[4] covering the period 2001–2012. The 29 provinces are shown in Table 1. The

[3] The PM2.5 data was collected by a team of researchers from Battelle Memorial Institute, Columbia University, and Yale University who used satellite readings to produce data on fine particulate concentrations for all of China over the last decade. These satellite measurements provide the first estimates of ground-level annual average concentrations of the pollutant PM 2.5.

[4] Taiwan, Hongkong, Macau and Tibet autonomous regions are not included due to lack of available data. The information about Sichuan and

definition of the variables is shown in Table 2, and the statistical description of the variables is shown in Table 3.

Table 1 Distribution of the 29 administrative regions

Area	Administrative regions
Northeastern	Heilongjiang, Jilin, Liaoning
Northern	Neimenggu, Beijing, Tianjin, Hebei, Shandong, Henan, Shanxi, Shannxi
Southern	Jiangsu, Zhejiang, Fujian, Guangdong, Hubei, Hunan, Hainan, Shanghai, Anhui, Jiangxi
Western	Qinghai, Xinjiang, Ningxia, Gansu
Southwestern	Yuannan, Guizhou, Guangxi, Sichuan

Table 2 Definition of all the variables

Variable	Definition	Units of measurement
PM2.5	PM2.5 emissions intensity	ug per m3
GDP	GDP per capita	Yuan
Coal	The share of coal consumption in total energy consumption	%
Tradeshare	The total volume of export and import to GDP	%
Tradepop	The total volume of export and import to total population	Yuan/person
Trade share /GDP_{t-1}	The total trade volume as a share of the lagged values of GDP	%
Urbanization	The urban population to the total population	%
PC	Private cars inventory	10^4 units
Heavy industry	The total value of heavy industry to the industry value	%
Temperature	Annual average temperature level	℃
Neighboring effect	$\frac{1}{\sqrt{(D_{i1,t})}} * 100 * PM_{1t} + \frac{1}{\sqrt{(D_{i2,t})}} * 100 * PM_{2t} + \cdots + \frac{1}{\sqrt{(D_{ij,t})}} * 100 * PM_{jt}$ （$i \neq j, j = 1,2,3, \dots .28$）	ug per m3

Chongqing provinces is merged together.

Table 3 The statistical description of the data in the model

Variable	Obs	Mean	Std. Dev.	Min	Max
PM2.5	348	27.09	11.60	2.17	51.94
GDP	348	10357.39	7152.80	1751.95	40820.1
Coal	348	85.329	393.544	10.9	7397
Trade share	348	0.341	0.422	0.036	1.721
Tradepop	348	0.998	1.826	0.015	10.693
$Trade/GDP_{t-1}$	348	0.403	0.496	0.039	2.034
Urban rate	348	.474	0.149	0.204	0.893
Private car	348	135.085	155.471	3.16	864.3
Heavy industry	348	0.734	0.111	0.398	0.954
Temperature	348	14.09	5.324	2.9	25.4
Neighboring	348	6.089	3.101	0.731	13.047

4.2.2 Data description

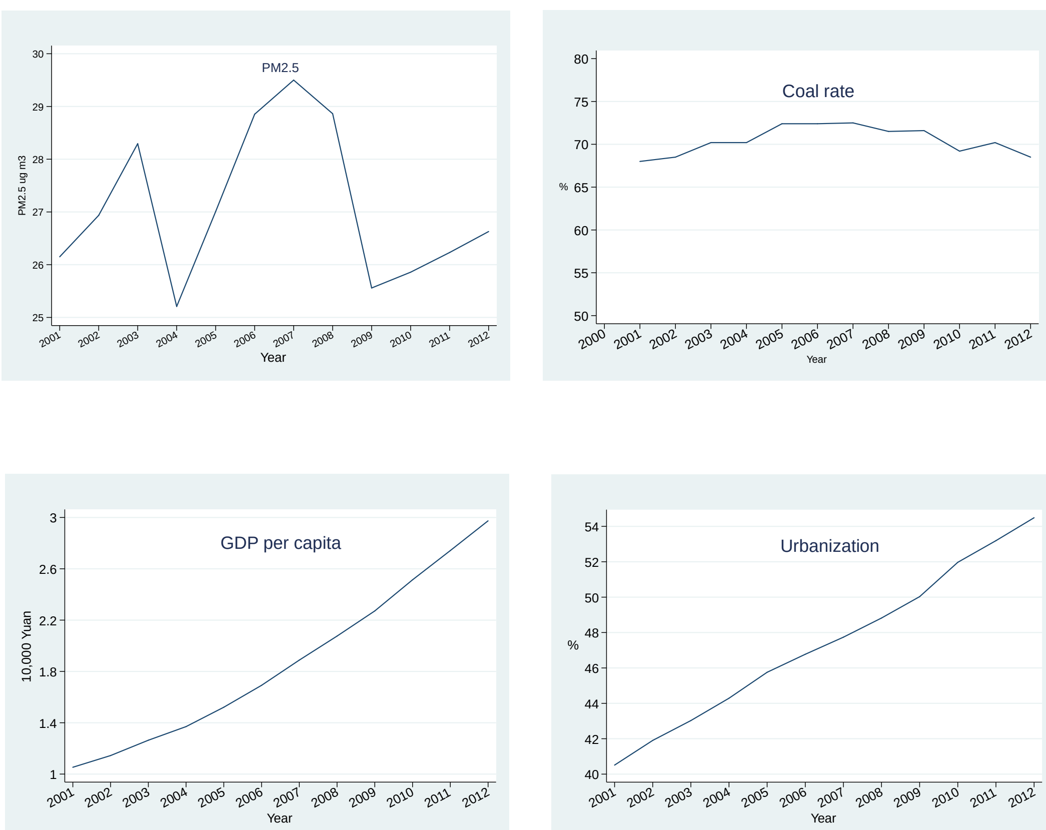

Figure 2 The trends of urbanization level, energy consumption by capita, total energy consumption, trade ratio, heavy industry and private car inventory

Figs 2 plots the evolution paths of PM2.5 level, economic growth, urbanization, energy consumption (coal rate) and trade volume and population size from 2001 to 2012.

As seen in Figure 2, the level of PM2.5 shows an irregular change from 2001 to 2012; the average annual GDP growth rate was about 10% during the past few decades, which was called a "growth miracle". Per capita GDP increased from 8690 yuan (Chinese currency) in 2001 to almost 40,000 yuan in 2012, with an annual growth rate of approximately 14.9%. The rapid economic growth has been accompanied by an expansion of the urban area population. The urban population reached 52% in 2012 (Fig.2), which was the first time in China's history that the urban population surpassed that of rural areas. The urbanization trend is likely to continue in the future (Liu and Diamond, 2005). Heavy industry accounts for over 70% of the total industry value added in China from 2001-2012 (Fig.2). The heavy industry is mainly fueled by coal, which is regarded as the major source of air pollution. The trade ratio represents the share of total exports and imports to GDP. China's trade ratio was 38.5% in 2001; however, it soared to 65% in 2006 and then decreased to 47% in 2012 after the economic crisis, with an average increase of 1.84% (Fig. 2). The quick pace of economic growth, rapid urbanization and rising trade ratio have been achieved by huge energy consumption. Energy consumption increased at an average annual growth rate of 7.9% over the past 10 years. China's total energy consumption increased from 15.55 million tons of standard coal equivalent (tce) in 2001 to 40.21 million tce in 2012, with the result that China is now one of the largest energy consumption countries and the amount of energy consumption is expected to surpass United States by 68% in 2035. Meanwhile, energy consumption per capita rose from 1.22 tce in 2001 to 2.97 tce in 2012, representing a more than 2.4-fold increase (Fig.2).

In China, coal as the principal energy source plays a strategic role in the economic growth (Li and Leung, 2012). In comparison with oil, natural gas and others, coal is overwhelmingly abundant and more widely distributed in China. As the dominant fuel type, the share of coal consumption has accounted for roughly 70% of the total energy consumption over the last decades from 2001-2012 (Fig. 2). In China, the transport sector accounts for about 8.0% of the total energy consumption in 2012. The number of private cars in China shows rapid growth, with an average annual growth rate of 24.8% from 2001 to 2012 (Fig. 2). Although private car ownership level was only 98 vehicles/1000 people in 2012, much lower than the global average level, especially compared with the developed countries (OICA,2015). The energy demand of China's transport sector increased gradually from 34 Mtoe in 1990 to 240 Mtoe in 2012, with its share in the total energy consumed rising from 4.0% in 1990 to 8.0% in 2012. With the rapid growth in the private car demand, energy consumption is expected to increase in the coming decades.

In this study, using the provincial panel data set covering the 29 provinces over the period 2001–2012, we explore the linkage between the driving factors and PM2.5 in China.

4.2.2 Endogeneity and instrumental variables

The paper tries to estimate trade's impact on economic growth, while this relationship may not reflect an effect of trade on economic growth (Frankel and Romer, 1999). As Helpman (1988), Bradford and Chakwin (1993), Rodrik (1995a), and many others observed, trade share may be endogenous: the high-income countries or the rapid economies may trade more. The previous studies (Linneman, 1966, Frankel *et al*., 1995, and Frankel, 1997, Redding and Venables, 2004) have observed that geography is a powerful determinant of bilateral trade using gravity model of trade. The distance of a region to the international ports provides considerable information about the amount that it trades. For example, the fact that Qinghai, one of western provinces of China is far from most of the ports of China reduces its trade; the fact that Shanghai, one of the biggest ports of China, is close to many of the world's most populous countries increases its trade. The better this market access is, the higher a country's level of income. The region's geographical disadvantages are often viewed as an important deterrent to its economic development. More generally, the effects of a region's geographic characteristics on its economic growth is mainly through its impact on trade.

Thus, countries' geographic characteristics can be used to obtain instrumental variables estimates of trade's impact on economic growth.

In this paper, we construct the foreign market access (FMA) as the instrument for international trade.

Taking into account the geographical features of inland and coastal provinces of China, we use the transport distance instead of Euclidean distance to measure a region's openness. The relevant data was obtained from Google Maps. Simply knowing how far a region is from the main coastal ports provides considerable information about the amount that it trades: coastal provinces have more trade than central and western provinces. Since this is a permanent advantage, it implies a longer history of international interaction, a more developed commercial and communications infrastructure and a greater familiarity with world markets.

We measured the transport distance of coastal provinces by D_{ii}.D_{ii} is calculated by the $\frac{2}{3}\sqrt{S_i}$, S_i refers to the area of the province i (Redding and Venables, 2004).The transport distance of the inland provinces was measured by the shortest distance $minD_{ij} + D_{ii}$ from the capital cities to the ten main ports of China (Appendix 2). We then take the inverse distance times 100 to avoid any zero values as the foreign market access. Assume C is the set of the coastal provinces, so the FMA can be specified as follows:

$$FMA = \begin{cases} 100D_{ii}^{-1}, & i \in C; \\ 100(minD_{ij} + D_{ij})^{-1}, & i \notin C, j \in C \end{cases} \tag{1.3}$$

As the FMA is time-invariant, following Acemoglu *et al*. (2005), using the FMA by the time dummies, we construct FMA*D2002, FMA*D2003…FMA*D2012 as the external instruments of trade openness ratio.

Meanwhile, we also use the one period lagged variable of trade openness as the instruments that is commonly used in the empirical studies. However, this is only an effective estimation strategy if the lagged values do not themselves belong in the respective estimating equation and if they are sufficiently correlated with the simultaneously determined explanatory variable.

4.2.3 Main explanatory variables specification

Neighboring effect

The neighboring factor can also be called a “spillover effect”, whereby air quality of one province is affected by its neighboring regions as the pollutants are transported by wind or precipitation from one region to another. For example, Beijing is the China’s political and cultural center and has very few heavy industries or the other high pollution industries. However, the city’s air pollution is very serious. If we look at Beijing on the Chinese map (Appendix 1), Beijing is surrounded by the heavy industry province Hebei. The report (2015) from Ministry of Environmental Protection pointed out that eight out of ten of the most polluted cities are in Hebei Province in China. So, one possible reason to explain Beijing's severe air quality is the pollutants mainly from its neighbor Hebei Province.

To capture the other influencing factors (e.g. geographical factors) on PM2.5. The factor is constructed as below:

$$neighbour_{it} = D_{I1,t}^{\emptyset} * 100 * PM_{1t} + D_{I1,t}^{\emptyset} * 100 * PM_{2t} + \cdots + D_{I1,t}^{\emptyset} * 100 * PM_{jt} \quad (i \neq j, j = 1,2,3, \ldots .28) \quad \emptyset \in (0,1) \qquad (5)$$

Taking $\emptyset = -0.5$, the above equation can be written as below:

$$neighbour_{it} = \frac{1}{\sqrt{(D_{i1,t})}} * 100 * PM_{1t} + \frac{1}{\sqrt{(D_{i2,t})}} * 100 * PM_{2t} + \cdots + \frac{1}{\sqrt{(D_{ij,t})}} * 100 * PM_{jt} \quad (i \neq j, j = 1,2,3, \ldots .28) \quad (6)$$

Here $\sqrt{D_{ij}}$ is used to describe the nonlinear effect and capture the other influencing factors such as wind, rainfall etc.; D_{ij} is the line distance between province i and province j which has same boarder. Using the inverse $\sqrt{D_{ij*}} * 100$ to capture the decay effect: the effect decreases with the increase of the distance between the boarder provinces. PM_{jt} is the amount of PM2.5 of province j in time t.

In China's Statistics Yearbooks, due to lack of available wind and rainfall data at the provincial level, we have no better ways to estimate the effect of these factors on PM2.5.

Annual average temperature level

China has a great diversity of climates because of tremendous differences in latitude, and altitude. The northeast experiences hot and dry summers and bitterly cold harsh winters, with temperatures known to reach as low as $-20^{\circ}c$. The north and central region has almost continual rainfall, temperature in summers reaching $26^{\circ}c$ and cool winters when temperatures reach $0^{\circ}c$. The southeast region has substantial rainfall, and can be humid, with semi-tropical summer. Temperature has been known to reach over $40^{\circ}c$, although this is highly unusual, but during summer temperature over $30^{\circ}c$ is normal. Winters are mild, with lows of around $10^{\circ}c$ in January and February. He *et al*. (2001) found the seasonal variation of PM2.5 concentration was remarkable, with the highest in winter and the lowest in summer by collected PM2.5 concentration data from July 1997 to September 2000 in the city center and urban area in Beijing.

Here $temperature_{it}$ refers to the average annual temperature level of province i in time t. The temperature can affect mortality rate by two ways. Firstly, the low temperature can cause the physical discomfort, especially to the old people; secondly, the low temperature can lead to the increase of the energy consumption and then cause the pollution emission increase then affect the mortality. The level of PM2.5 usually rises during the winter when demand for heating soars and coal-fired power plants are used more intensively.

Heavy industry rate

China's industrial structure is dominated by heavy industry, which accounts for over 70% of the total industry (Lin and Liu, 2016). High energy consumption is a typical characteristic of heavy industry (Lin and Li, 2014) that mainly includes the metallurgy, machinery, energy, chemical, building material industry, etc. Since 2009, heavy industry has become the largest energy consumer that accounts for over 60% of the national total electricity and nearly 65% of the national total energy consumption, and because of the unreasonable industrial structure that locate in the inner city intersect with the commercial and living areas, the energy consumption may surge in the future. Therefore, this study prefers to use heavy industry rate instead of industrialization as an indicator to measure the change of industrial structure and to analyze its effect on air pollution.

Human capital

This paper takes the average years of education as the instrument for GDP per capita to denote the state of human capital. (Li and Qi, 2011; Peng, 2005). Human capital is the fundamental source of economic growth. It is a source of both increased productivity and technological advance. We used the laborer's average educational level as human capital, which can be classified into four categories according to China's education system: primary, secondary, high and college and above education. The primary education is 6 years; secondary education is 9 years; high education is 12 years and college and above is 16 years. The function can be written as follows in Equation (7):

$$Human = \ emploment\ share\ of\ primary * 6 + secondary * 9 + high * 12 + college\ and\ above * 16 \quad (7)$$

Energy consumption structure

Here we use the share of coal consumption to the total energy consumption represents the energy consumption structure of China. In 2012, China's total primary energy consumption reached 4.02 billion tons of coal equivalent (tce) and accounted for 20% around of global energy consumption. In China, coal as the dominant fuel type is overwhelmingly abundant and more widely distributed that plays a strategic role in economic growth (Li and Leung, 2012). The share of coal consumption has accounted for approximately 70% of the total energy consumption over the last decades. Therefore, taking the share of coal consumption in the total energy consumption can fully reflect the change of energy consumption structure.

5 Empirical results and analysis

5.1 Unit root test and co-integration test

To investigate the possibility of panel cointegration, LLC, ADF-fisher and IPS tests are used to determine the existence of the unit roots in the data series. The results demonstrate that the minority of the variables are non-stationary (Table 4), but their first difference series are stationary (Table 5). The next step is to test for the existence of a long-run cointegration among PM2.5 and the independent variables using panel cointegration tests suggested by Kao (1999). As the results (Table 2.6) suggest, there exist long-run cointegration between the dependent and independent variables.

Table 4 Results of panel unit root tests for level

Variable	Intercept			Intercept and trend		
	LLC	ADF-fisher	IPS	LLC	ADF-fisher	IPS
PM2.5	-7.861***	119.677***	-5.063***	-8.204***	83.135***	-2.580***
GDP	-3.270***	88.515***	4.476	-2.945***	44.955	2.347
Coal	-17.742***	77.685***	-2.938***	-2.988***	43.576	1.958
Private car	-4.974***	57.486	3.864	-11.917***	80.219**	-1.965**
Urbanization	-4.640***	50.452	3.994	-5.514***	73.367*	-0.795
Heavy Industry	-16.382***	157.611***	-7.491***	-4.603***	38.698	1.880
Temperature	-7.573***	105.236***	-4.421***	-10.572***	94.574***	-3.495***
Tradeshare	-5.444***	-72.507*	-1.361*	-6.787***	50.942	0.045
Tradepop	-7.290***	75.725*	1.385*	-6.430***	53.009	-0.049
Trade/GDP t-1	-6.302***	82.792**	-2.411**	-7.944***	53.986	-0.324

Note: Lags are all automatically selected by SIC standard. *, ** and *** indicates rejection of the null hypothesis of no unit root at 10%, 5% and 1% levels of significance.

Table 5 Results of panel unit root tests for first difference

Variable	Intercept			Intercept and trend		
	LLC	ADF-fisher	IPS	LLC	ADF-fisher	IPS
PM2.5	-19.105***	240.888***	-12.361***	-17.525***	163.310***	-6.310***
GDP	-5.545***	79.289***	-2.173**	-7.548***	97.480***	-2.102**
Coal	-12.825***	182.171***	-8.590***	-17.465***	175.102***	-8.188***
Private car	-14.453***	198.378***	-9.954***	-18.482***	165.548**	-6.110***
Urbanization	-11.736***	158.169***	-7.783***	-13.230***	129.436***	-4.659***
Heavy industry	-9.028***	145.614***	-6.562***	-20.409***	218.300***	-12.244***
Temperature	-22.308***	284.011***	-15.009***	-20.171***	202.255***	-7.879***
Neighbouring	-16.965***	208.537***	-10.520***	-15.634***	134.678***	-4.968***
Tradeshare	-13.193***	154.720***	-7.470***	-13.324***	115.336***	-3.740***
Tradepop	-13.563***	162.838***	-7.975***	-14.192***	125.588***	-4.289***
Trade/GDP t-1	-15.322***	173.382***	-8.629***	-15.269***	137.370***	-4.708***

Note: Lags are all automatically selected by SIC standard. *, ** and *** indicates rejection of the null hypothesis of no unit root at 10%, 5% and 1% levels of significance.

Table 6 Kao residual cointegration test

	t-Statistic	Prob.
ADF	-2.607285	0.0046
Residual variance	586302.1	
HAC variance	1104086.	

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(RESID)
Included observations: 261 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
RESID(-1)	-0.202693	0.039577	-5.121515	0.0000
D(RESID(-1))	0.279008	0.057883	4.820217	0.0000

R-squared	0.127965	Mean dependent var	95.96167
Adjusted R-squared	0.124599	S.D. dependent var	965.4092
S.E. of regression	903.2647	Akaike info criterion	16.45754
Sum squared resid	2.11E+08	Schwarz criterion	16.48486
Log likelihood	-2145.709	Hannan-Quinn criter.	16.46852
Durbin-Watson stat	2.120416		

Note: Automatic lag length selection based on SIC with a max lag of 2; Newey-West automatic bandwidth selection and Bartlett kernel.

5.2 Results and analysis

Table 7 Results of static model

Variables	(1) FE	(2) FE	(3) FE	(4) FE-IV	(5) FE-IV
GDP	0.0610	0.162	-0.0271	0.176	0.0305
	(0.297)	(0.384)	(0.291)	(0.269)	(0.361)
GDP^2	0.00688	-0.000468	0.00859	-0.00102	0.0123
	(0.015)	(0.018)	(0.015)	(0.014)	(0.025)
Urbanization	-0.186*	-0.335	-0.186*	-0.364***	-0.0154
	(0.099)	(0.202)	(0.099)	(0.130)	(0.165)
Tradeshare	0.0548*			0.0847***	-0.140
	(0.030)			(0.028)	(0.173)
Tradepop		0.0592			
		(0.036)			
$Trade/GDP_{t-1}$			0.0570*		
			(0.031)		
Coal	0.033***	0.033***	0.033***	0.034**	0.021
	(0.008)	(0.008)	(0.008)	(0.013)	(0.021)
Heavy industry	0.0798	0.192*	0.0789	0.200**	0.0300
	(0.085)	(0.112)	(0.084)	(0.082)	(0.090)
Private car	0.0263	0.0492**	0.0266	0.0552***	-0.0143
	(0.023)	(0.019)	(0.023)	(0.020)	(0.052)
Temperature	0.0273	0.0297	0.0258	0.0153	0.154
	(0.048)	(0.055)	(0.048)	(0.077)	(0.158)
Neighboring	0.857***	0.904***	0.857***	0.901***	0.876***
	(0.108)	(0.099)	(0.108)	(0.069)	(0.081)
Constant	0.447	-0.143	1.120	-0.176	-0.0939
	(1.493)	(2.098)	(1.450)	(1.439)	(2.751)
Observations	348	319	348	319	348
R-squared	0.579	0.609	0.580		
Number of id	29	29	29	29	29

Notes: Estimation is from a balanced panel of 29 provinces covering the period 2001-2012. The superscripts ***, ** and * denote significance at the 1%, 5% and 10% levels respectively. Year dummies are included in each specification; standard errors in parentheses.
Source: China Statistical Yearbooks (2002-2013), China Industry Economy Yearbooks (2002-2013), Energy Yearbooks (2002-2013) and Provincial Yearbooks (2002-2013).

Table 8 Results of dynamic model

Variables	(6) sys-GMM	(7) sys-GMM	(8) sys-GMM
L.PM2.5	0.328***	0.419***	0.322***
	(0.116)	(0.137)	(0.116)
GDP	0.0192	-0.0739	-0.276
	(0.560)	(0.670)	(0.685)
GDP^2	-0.00690	-0.00124	-0.00275
	(0.027)	(0.032)	(0.031)
Urbanization	-0.542***	-0.414***	-0.555***
	(0.157)	(0.141)	(0.170)
Tradeshare	0.215***		
	(0.057)		
Tradepop		0.167***	
		(0.061)	
$Trade/GDP_{t-1}$			0.218***
			(0.061)
Coal	0.130***	0.113**	0.128***
	(0.043)	(0.045)	(0.043)
Heavy industry	0.617***	0.467**	0.639***
	(0.181)	(0.192)	(0.186)
Private car	0.166**	0.141*	0.171**
	(0.070)	(0.075)	(0.070)
Temperature	-0.0496	-0.0228	-0.0494
	(0.099)	(0.104)	(0.102)
Neighboring	0.381***	0.327***	0.383***
	(0.083)	(0.104)	(0.083)
Constant	0	1.099	0
	(0.000)	(3.336)	(0.000)
AR (1)	0.001	0.001	0.001
AR (2)	0.789	0.912	0.810
Hansen	0.792	0.381	0.762
Observations	319	319	319
Number of id	29	29	29

Notes: Estimation is from a balanced panel of 29 provinces covering the period 2001-2012. The superscripts ***, ** and * denote significance at the 1%, 5% and 10% levels respectively. Year dummies are included in each specification; standard errors in parentheses. AR and Hansen tests are the value of prob> z. In the GMM estimation, the predetermined variable is L.lpm, the instrumental variable is GDP and $traderatio$;To L. lnpm, using the lagged one as the instruments; to GDP and trade ratio, using the lagged one and two as the instruments.
Source: China Statistical Yearbooks (2002-2013), China Industry Economy Yearbooks (2002-2013), Energy Yearbooks (2002-2013) and Provincial Yearbooks (2002-2013).

Following the model specification and the introduction of the variables, Tables 7 and 8 report a series of empirical results demonstrating the effect of driving forces on PM2.5 using FE, FE-IV and sys-GMM estimation methods respectively.

According to the estimated results, economic growth has no significant effect on PM2.5 that neither supports the existence of Environmental Kuznets Curve hypothesis (EKC). There is no guarantee that economic growth improves the air quality. There are many other factors that may affect the PM2.5 emission, such as the effectiveness of government regulation, population levels and people’s awareness of environmental protection etc. Urbanization and

PM2.5 show a negative relationship in most of the specifications, which proves urbanization is one of the main contributors to the decrease of PM2.5 from 2001 to 2012. With the rapid growth of urbanization, the implementation of new technology, the scientific and reasonable urban planning, the popularity of electric and hybrid-energy cars, even the increasing of people's environmental protection awareness and the strict environmental protection laws implemented by government can mean that the PM2.5 is gradually decreased, and air quality will improve. The elasticity of urbanization ranges between 0.192 and 0.589.

Concerning effects of trade on PM2.5 are negative. On the negative point, the well-known "race to the bottom" hypothesis is supported by the results. The hypothesis of "race to the bottom" refers to countries trying to compete with other countries and adopting less stringent environmental regulations and cutting tax rates due to the fear of adverse effects on their international competitiveness (Frankel, 2009). Further, the comparative advantage and industries division also contribute to this trend. Many developed economies have seen a reduction in industry and growth in service sector, but they are still importing goods from developing countries. In that sense, they are exporting environmental degradation. Pollution may reduce in the UK and the US, but countries who export to these countries are seeing higher levels of environmental degradation. Higher income countries tend to stop the process of deforestation, but, at the same time, they still import meat and furniture from countries who are creating farmland out of forests.

Temperature as an influencing factor has no significant effect on PM2.5, which demonstrate that temperature as a kind of environmental influencing factor is not a main consideration in curbing air pollution.

The factors of heavy industry and private car inventory also exert positive impacts on PM2.5, though are not significant in some of the specifications. From 2001 to 2012, the share of heavy industry had been accounted for around 70% and the number of private car increased from 2,500 thousand in 1995 to 88,386 thousand in 2012, with an average annual growth rate of about 23.33%. The positive sign of heavy industry indicates that the higher rate of heavy industry is inclined to increase PM2.5. It is well known that coal accounts for 95% of China's fossil fuels endowments. It determines that the heavy industry is coal fuel powered, which is a main source of air pollution emissions. The elasticity of heavy industrial share on PM2.5 ranges from 0.192 to 0.637; To private car inventory, the elasticity covers a range between 0.049 and 0.171. Likewise, the share of coal in the energy consumption exerts significant positive impact on PM2.5 that elasticity covers a range between 0.033 to 0.130.

The neighboring factor plays a significant positive role in increasing PM2.5 level. The elasticity ranges from 0.327 to 0.904. That means that a region's PM level that is correlated with its neighbors might be caused by wind, rainfall or the other influencing factors. Air pollution has no boarder, but that requires that environmental control must be a comprehensive system project. The central government needs to make a blue map that allows the locals work together to manage the environmental crisis.

The estimated coefficients on the lagged one period of PM2.5 variable show a positive and statistically significant in all the specifications estimated by sys- GMM technique. The ranges of these estimators are 0.328, 0.419 and 0.322, which implies that air pollution is a continuous process and has a long-term effect on air quality.

5.3 Collinearity diagnostics

In this section, VIF test is used to check the multicollinearity between the variable. As a rule of thumb, a variable whose VIF values are greater than 10 may merit further investigation. Tolerance, defined as 1/VIF, is used by many researchers to check on the degree of collinearity. A tolerance value lower than 0.1 is comparable to a VIF of 10. It means that the variable could be considered as a linear combination of other independent variables.

By applying the VIF test, the results (Table 9) show that the values of VIF are all less than 10 and the values of Tolerance are more than 0.1, which means that multicollinearity is not a problem.

Table 9 Results of collinearity diagnostics

Variable	VIF	SQRT	Tolerance.	R^2
GDP	6.78	2.60	0.1475	0.8525
Heavy Industry	1.85	1.36	0.5401	0.4599
Tradeshare	4.57	2.14	0.2188	0.7812
Urbanization	5.59	2.36	0.1788	0.8212
coal rate	1.01	1.01	0.9864	0.0136
private car	1.91	1.38	0.5234	0.4766
neighboring	1.27	1.13	0.7870	0.2130
temperature	2.11	1.45	0.4744	0.5256
Mean VIF	3.14			

6 Conclusion and policy implications

Between 2001 and 2012, China's economy experienced high-speed growth, with an average annual growth rate of 10%. This rapid economic growth was achieved by huge energy consumption (Zhao and Wang, 2015). At present, rapid energy consumption, increase of private cars, and expansion of international trade have led to environmental deterioration. In light of the severe environmental pollution and the higher growth rate of energy consumption, the government policy makers should pay more attention to the linkage among urbanization, energy consumption and air pollution. Although there has been extensive literature exploring the linkage between urbanization, energy and air pollution in the case of China, the most significant impact channel is not clear and very little is known about whether temperature or the neighboring factor exert significant impacts on air pollution. Based on the above empirical results under static (FE and FE-IV) and dynamic (GMM-sys) estimation methods, it is found that neighboring factor plays an important role in air pollution. Environmental management is a systematic comprehensive project that needs the government co-ordinate all the regional activities of the nation.

The difficulty facing the government is how to realize the sustainable growth and curb energy consumption and pollution while promoting urbanization. Fossil fuels (coal) as the main energy consumption in China's economic growth, the direct strategy of curbing fossil fuels consumption might cause many social problems, such as unemployment and bankruptcy of the firms (Zhao and Wang, 2015). So, the feasible ways can be summarized as below:

Firstly, develop clean coal technology and improve energy efficiency. As is known, China is rich in coal, which accounts for 95% of the country's fossil fuels endowments. According to the Chinese Ministry of Land and Resources, China's proven coal reserves of 170 Mt correspond to 19% of the global total, ranking second in the world after the United States (Tu and Sabine, 2012). The lack of natural gas and the other clean energies mean that coal will be the dominant fuel in next few decades in China. Therefore, developing clean coal technology and improving energy efficiency becomes very urgent and necessary.

Secondly, upgrade and adjust the industrial structure. The main problem is the distortion of the three industrial sectors (Agriculture, Industrial and Tertiary) of China. The main direction of adjusting industrial structure is to reduce the proportion of the heavy industry and promote the development of tertiary industry. Between 2001 and 2015, the tertiary industry as a proportion of GDP increased from 41.2% to 50.2%, with an average annual growth rate of 1.42%. The proportion of tertiary industry is lower by 10–20% point than that of the developed countries' level. The internal structural of industry also needs to be adjusted. The heavy industry accounts for 70% in the past ten years of China's economic development, which led to the surge of energy consumption and environmental degradation, and resulted in a relative surplus of industrial goods, hence industrial capacity is under-utilized (Guo, 2001).

Thirdly, conduct scientific city planning based on the principle of sustainable development; carry out urban construction rationally; strengthen city planning administration and environmental protection. China's urbanization has achieved a notable achievement since 1978 the reform and opening-up policy. Since 2012, more than half of the population has lived in urban areas, which has led to energy scarcity and environmental degradation. At the same time, the government should improve the infrastructure of the big cities, promote the development of small and medium-sized cities, emphasize the quality of urbanization and take a path of energy-conserving and environment-friendly urbanization.

Fourthly, reasonable control over the number of private car power by the traditional energy resources, and develop hybrid, electric cars.

Finally, strengthen exchange and cooperation among the regions to decrease the air pollution. The estimation results show that air pollution is not just a local problem. A region's air quality is also affected by its neighboring regions. So, curbing the air pollution emission requires an overall planning and design. Th central and provincial level governments should work together to solve it.

References

Acemoglu, D.; Johnson, S.; Robinson, J., 2005, The rise of Europe: Atlantic trade, institutional change and economic growth, American Economic Review 95 (3),546-579.

Bilgen, S, 2014, Structure and environmental impact of global energy consumption, Renewable and Sustainable Energy Reviews 38, 890–902.

Bradford, C. Jr.; Chakwin, N., 1993, Alternative Explanations of the Trade-Output Correlation in East Asian Economies, OECD Development Centre Technical Paper No. 87.

DeHart, J. L.; Soule, P. T., 2004, Does I = PAT work in local places? The Professional Geographer 52 (1), 1-10.

Dietz, T.; Rosa, E.A., 1997., Effects of population and affluence on CO2 emissions, Ecology 94, 175–179.

Dietz, T.; Rosa, E.A.,1994, Rethinking the Environmental Impacts of Population, Affluence and Technology, Human Ecology Review1, 277-300.

Frankel, J. A., 1997, Regional trading blocs in the world trading system. Washington, DC: Institute of International Economics.

Frankel, J. A.; Stein, E.; Wei, S. J., 1995, Trading Blocs and the Americas: the natural, the unnatural, and the supernatural, Journal of Development Economics 47(1), 61–95.

Frankel, J.,2009, Environmental Effects of International Trade, HKS Faculty Research Working Paper Series RWP09-006, John F. Kennedy School of Government, Harvard University.

Frankel, J.; Romer, D., 1999, Does trade cause growth? The American Economic Review 89(3), 379-399.

Guan, D. B.; Su, X.; Zhang, Q.; Glen, P. P.; Liu, Z.; Yu, Lei.; He, K.B., 2014, The socioeconomic drivers of China's primary PM2.5 emissions, Environmental Research Letters 9 (2), 1-9.

Guo, K.S., 2001, The strategic adjustment of China's industry structure in the next five years, China and World Economy 2.

Harrison, P.;Pearce, F., 2000, AAAS Atlas of Population and Environment, Berkeley, University of California Press/American Association for the Advancement of Science.

Helpman, E.,1988, Growth, technological progress, and trade, NBER working paper series No. 2592.

Hou, Z.M.; Xie, H.P.; Zhou, H.W.; Were, P.; Kolditz, O., 2015, Unconventional gas resources in China, Environmental Earth Science 73(10), 5785–5789.

Huo, H.; Zhang, Q.; Guan, D.B.; Su, X.; Zhao, H.Y.;He, K.B., 2014, Examining air pollution in China using production and consumption-based emissions accounting approaches, Environmental Science Technology 48 (24), 14139–14147.

Jiao, R.J.; Zhang, P.D.; Zhu, S.; Li, H.; Niu, H.P., 2014, Identification and implications of relationships among pollutant emission, economic structure and economic growth in China through multivariate analysis, Environmental Science and Management 17 (1), 1-11.

Kao, C.,1999, Spurious Regression and Residual-Based Tests for Cointegration in Panel Data, Econometrics 90 (1), 1-44.

Khan, M. F.; Latif,M.T.; Lim, C. H.; Amil, N.; Jaafar, S. A. D.; Doreena, N. M. S. M.; Sahani, M.;Tahir, N.M., 2015, Seasonal effect and source apportionment of polycyclic aromatic hydrocarbons in PM2.5, Atmospheric Environment 106, 178–190.

Kirchstetter, T. W.; Harley, R. A.; Kreisberg, N.M.; Stolzenburg, M.R.; Hering, S.V., 1999, On-road measurement of fine particle and nitrogen oxide emissions from light- and heavy-duty motor vehicles, Atmospheric Environment 33(18), 2955–2968.

Li, K.; Qi, S.Z., 2011, Trade Openness, Economic Growth and Carbon Dioxide Emission in China (*translation*), Economic study 11,60-102.

Li, R.; Leung, G. C. K., 2012, Coal consumption and economic growth in China, Energy Policy 40, 438–43.

Li, R.; Leung, G. C. K., 2012, Coal consumption and economic growth in China, Energy Policy 40, 438–43.

Lin, B.Q.; Li, J.L., 2014, The rebound effect for heavy industry: Empirical evidence from China, Energy Policy 74, 589–599.

Linneman, H., 1966, An econometric study of international trade flows. Amsterdam: NorthHolland.

Mallia D.V.; Lin J.C.; S. Ehleringer, U. J.; Nehrkorn, T., 2015, Impacts of upwind wildfire emissions on CO, CO2, and PM2.5 concentrations in Salt Lake City, Utah, Journal of Geophysical Research: Atmospheres 120 (1), 147–166.

Mardones, C.; Sanhueza, L., 2015, Tradable permit system for PM2.5 emissions from residential and industrial sources, Environment Management 157 (1), 326–331.

Meng, J.; Liu, J.F.; Xu, Y.; Tao, S., 2015, Tracing primary PM2.5 emissions via Chinese supply chains, Environmental Research Letter 10 (5),1-12.

Meng, J.; Liu, J.F.; Xu, Y.; Tao, S., 2015, Tracing primary PM2.5 emissions via Chinese supply chains, Environmental Research Letter 10 (5),1-12.

NBS,2015, China statistical yearbook, http://www.stats.gov.cn/tjsj/ndsj/2015/indexeh.htm.

OICA, 2015, World motor vehicle sales, Organisation Internationale des Constructeurs d'Automobiles.

Peng, G.H., 2005, The Disparity of Income, TFP and the Convergence Hypothesis in Chinese Provinces (*translation*), Economics 9, 19–29.

Redding, S.; Venables, A. J.,2004, Economic Geography and International Inequality, Journal of International Economics 62 (1), 53 —82.

Rodrik, D., 1995a, Getting Interventions Right: How South Korea and Taiwan Grew Rich, Economic Policy 20, 53–97.

Shen, X.B.; Yao, A.L.; Huo, H.; Zhang, K.B.; Zhang, Y.Z.; Liu. H.; Yu, Y., 2014, PM2.5 emissions from light-duty gasoline vehicles in Beijing, China Science of Total Environment 487, 521–527.

Shi, A.Q., 2003, The impact of population pressure on global carbon dioxide emissions, 1975–1996: evidence from pooled cross-country data, Ecological Economics 44(1), 29–42.

Sica, E.; Susnik, S., 2014, Geographical dimension and environmental Kuznets curve: the case of some less investigated air pollutants, Applied Economics Letters 21(14), 1010–1016.

Stern, P. C.; Young, O. R.; Druckman, D., 1992, Global Environmental Change: Understanding the Human Dimensions, National Academy Press, Washington, D.C.

Stewart, B., 2009, Whole Earth Discipline: An Ecopragmatist Manifesto, Viking Penguin Group, New York, USA.

Tu, K. J.J.; Sabine, J.R., 2012, Understanding China's Rising Coal Imports, Carnegie policy outlook.

Tursun, H.; Li,Z.Y.; Liu, R.; Li, Y.; Wang, X.H., 2015, Contribution weight of engineering technology on pollutant emission reduction based on IPAT and LMDI methods, Clean Technologies Environment Policy 17(1), 225–235.

Wang, L.L.; Liu, Z.R.; Sun, Y.; Ji, D.S.; Wang, Y.S., 2015a, Long-range transport and regional sources of PM2.5 in Beijing based on long-term observations from 2005 to 2010, Atmospheric Research 157, 37–48.

WHO Regional office for Europe, 2003, Health aspect of air pollution with particulate matter, ozone and nitrogen dioxide, Report on a WHO working group, Bonn, Germany.

WHO, 2016, Ambient air pollution: A global assessment of exposure and burden of disease.

Xu, B.; Luo, L.Q.; Lin, B.Q., 2015, A dynamic analysis of air pollution emissions in China: Evidence from nonparametric additive regression models, Ecological Indicators 63 (1), 346-358.

York, R.; Rosa, E. A.; Dietz, T., 2003a, Footprints on the Earth: the environmental consequences of modernity, American Sociological Review 68(2), 279–300.

York, R.; Rosa, E.A.; Dietz, T., 2003b. STIRPAT, IPAT and ImPACT: analytic tools for unpacking the driving forces of environmental impacts, Ecological Economics 46(3), 351–365.

Zhang, Y.L.; Cao, F., 2015, Is it time to tackle PM2.5 air pollutions in China from biomass-burning emissions? Environmental Pollution 202, 217–219.

Zhang, Y.L.; Cao, F., 2015, Is it time to tackle PM2.5 air pollutions in China from biomass-burning emissions? Environmental Pollution 202, 217–219.

Zhao, Y.B.; Wang, S.J., 2015, The relationship between urbanization, economic growth and energy consumption in China: an econometric perspective analysis, Sustainability 7 (5), 5609-5627.

Zhou, S.;Zhang, X.L., 2010, Nuclear energy development in China: a study of opportunities and challenges, Energy 35 (11), 4282–4288.

Zhou, X.D.; Sha, J.H.; Zhong, S., 2015, Measuring the impacts of urbanization on energy consumption and economic growth in China: A computable general equilibrium analysis, International Conference on Advances in Energy and Environmental Science (ICAEES 2015).

Appendix 1-Map of China

Appendix 2 -The ten largest ports in China