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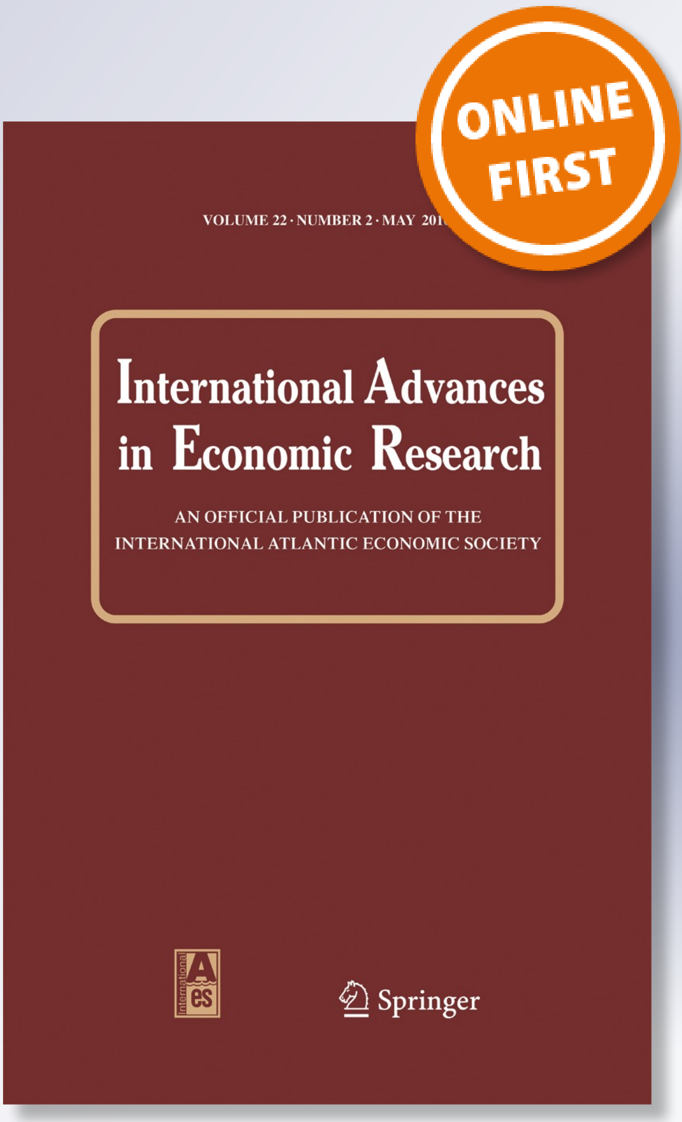

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Ambient Air Pollution in China: Predicting a Turning Point

Anna Shostya[1]

Abstract One of the most debatable questions among developmental economists and sinologists today is the question that deals with the time it would take China to reduce its current ambient air pollution levels to the levels acceptable by the World Health Organization. Some studies suggest that an increase in the standard of living would improve the environmental situation, a phenomenon that is termed the environmental Kuznets curve (EKC). The objective of this study is to estimate the EKC and identify major factors leading to ambient air pollution in China during 2004–2013. We use time-series panel data in 27 provinces to estimate the variability in the levels of ambient air pollution as measured by particulate matter, sulfur dioxide and nitrogen dioxide. Some policy implications are drawn.

Keywords Ambient air pollution · Environmental degradation · Environmental Kuznets curve · China's economic growth and development · Environmental clean-up

JEL Classification O10 · O50

Introduction

The speed of growth in China, particularly over the past 20 years, is staggering. Averaging about 10 % of the annual rate of growth during the last two decades, China's gross domestic product (GDP) surpassed that of Japan in 2012, and in 2014 the International Monetary Fund (IMF) announced that China's economy became the largest one in the world, in purchasing power parity dollars (IMF World Economic Outlook 2014). In only 30 years, urbanization has increased from 20 % to 52 %, lifting more than 500 million people above the poverty line (The Economist 2014b). China's economic rise, however, has come at

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the expense of its environment and public health. Rapid urbanization and industrialization have caused a series of environmental problems including arable land loss, urban congestion, flooding, health hazards due to toxic materials, water and air pollution, biodiversity loss, and the emission of carbon dioxide (CO_2) in the atmosphere, a major contributor to global warming. China is now emitting almost twice as much CO_2 as the United States, has become the second biggest polluter in the world, and has the most polluted cities whose levels often reach 40 times the level declared safe by the World Health Organization (WHO) (The Economist 2014a). As a result, China has one of the worst air pollution problems in the world and thus places its residents at significant health risks.

There are many factors that contribute to the sluggishness of the cleaning up attempts in China. Studies cite the Chinese government's explicit and implicit preference for economic growth (Zhao and Zhang 1999), China's dependence on cheap coal (Chow 2015), and the mismatch between the incentives for local governments to clean up and the laws that are passed by the central government (Man 2013). Others suggest that China's environmental situation is similar to those in developed countries on the eve of their development (Kahn 2013) and is an inevitable by-product of the fast economic growth resulting from high investment rates and cost-saving mass production that relies on cheap energy. Investment consistently has accounted for more than 40 % of China's annual economic growth during the last decade. In fact, "no significant economy has ever witnessed anything like this investment level outside of a wartime period" (Clifford 2015, p. 29).

One of the major issues associated with this phenomenon is over-capacity and wastefulness, driven by over-investment on the one hand, and underpriced factors of production on the other hand. Steel, cement, and shipbuilding, as well as many other energy-intense industries have significant overcapacity prompted by too much capital expansion and the discretion of local officials who favor high rates of output. A "soft budget system," under which underperforming firms can deceive the government subsidies, leads to subsidizing many large unprofitable firms that may be deemed "too important to fail," providing companies with incentives to invest heavily and expand. "This failure of market discipline makes China's economic growth inherently more volatile" (Clifford 2015, p. 31). The government subsidizes production in those industries that are assumed to have a strong effect on national security: telecommunications, utilities, and petroleum.

The proposal that the environmental problems are not stand-alone issues, but rather a natural result of fast economic growth, a relatively low standard of living, and high population density in urban manufacturing centers suggests that China could possibly grow its way out of environmental problems. The environmental Kuznets curve (EKC), in fact, reflects the idea that an increase in standard of living would necessarily improve the environmental situation. Some studies support this hypothesis stating that all that is necessary for environmental improvement is an increase in per capita income, so the turning point will "appear" once a country reaches a certain threshold of per capita income (Ankarhem 2005). Zheng et al. (2010) used data for 30 large Chinese cities to estimate the "turning point." They found that for the particulate matter (PM) up to 10 μm in size (PM_{10}), the turning point is roughly $2500 and it is slightly higher for sulfur dioxide (SO_2).

In the light of these various factors that can affect air quality, our empirical methodology analyzes the data at the regional level. The objective of this study is to estimate the

EKC using regional data in China during 2004–2013 and identify major factors leading to the increase in air pollution. Using time-series panel data on 27 provinces, we investigate the role of economic forces (the role of urban population pressures, manufacturing growth, technological advance, and rise in consumption) in increasing the levels of ambient air pollution as measured by PM, SO2 and nitrogen dioxide (NO2).

Theoretical Framework

It is widely accepted that environmental quality is a normal good. That is, as people's income increases, they demand more clean air. But there is still a debate about whether or not environmental quality is a luxury good, that is, spending on it increases disproportionally as income increases (Yandle et al. 2004). Theory suggests that the link between environmental quality and GDP per capita is similar to that between income inequality and GDP per capita. Environmental economists adopted this inverted U-shaped relationship originally introduced by Simon Kuznets to explain a similar pattern between economic development and environmental quality: economic development first damages the environment but after a turning point higher economic development leads to a better environmental quality (Grossman and Krueger 1996; Harbaugh et al. 2002). Some cross-national studies indicate that the turning point, while different for different pollutants, on average is about U.S. $8000 in 1990s dollars (Grossman and Krueger 1996; Harbaugh et al. 2002; Hilton and Levinson 1998; Levinson 2002).

Literature indicates that the EKC is a result of several effects of a country's growth, mainly a result of structural changes (Panayotou 1993; Panayotou et al. 2000). First, an increase in GDP is associated with an increase in economic activity, so pollution increases, too. This is called a scale effect and it is illustrated by a positively sloped portion of the EKC. An increase in GDP at a decreasing rate will be then followed by decreased marginal pollution. In addition, modern economic growth results in a structural change, from a predominantly manufacturing economy to a service economy. Unlike the manufacturing sector, the service sector does not contribute to pollution (Cole 2000). Finally, an increase in GDP per capita makes "environmentally friendly" construction, housing, transportation, and production more affordable. Wealthier economies can afford better technology. Rising income levels therefore are associated with a decreasing income elasticity of demand for pollution-intensive products (Cole 2000). This is called an abatement effect and it is represented by a negatively sloped portion of the EKC.

Breaking the correlation between economic growth (as measured by GDP) and similar upward trend in environmental pollution is referred to as decoupling (Harris and Roach 2013). The term was defined by the Organization for Economic Cooperation and Development (OECD) to draw a distinction between "environmental bads" and "environmental goods" (Pearce 2003). Relative decoupling exists when the environmental impact growth rate is positive, but less than the GDP growth rate. Absolute decoupling exists when the level of the environmental impact is either stable or decreasing, while GDP is growing. Harris and Roach (2013) used the World Bank data to track the correlation between global CO2 emissions (standardized for comparison reasons, 1961 = 1) and real global GDP (1961 = 1). They found absolute decoupling in the UK (1970–2008). Japan introduced successful decoupling efforts under the Top Runner Program. A United Nations report found that to achieve absolute decoupling, the world needs ambitious government policies (Fischer-Kowalski and Swilling 2011).

Literature Review

The empirical literature, however, does not support the EKC hypothesis in a consistent way. Some studies indicate that the EKC applies to some pollutants (SO2, PM and NO2), but not all environmental impacts. Llorca and Meunié (2009), for example, estimated the EKC for the SO_2 emissions in a panel of 28 Chinese provinces and revealed an N-shaped EKC with a turning point of 4500 yuan. A 2003 report concluded that "there is little evidence for a common inverted U-shaped relation between urban ambient concentration of some pollutants and income though this should be tested with more rigorous time series or panel data methods" (Stern 2004, p.11). Yandle et al. (2004) suggests that the EKC hypothesis should be viewed with caution because "improvement of the environment with income growth is not automatic but depends on politics and institutions" (p. 29). The study also emphasized the role of a well-functioning market system. It is also important to note that greenhouse gas emissions are a global phenomenon and require joint efforts and cooperation. More effective environmental policy can shift the EKC down but better environmental regulations do not appear automatically with an increase in income.

He and Pan (Man 2013) used data on SO2 emissions and industrial dust in 30 cities in China during 2003–2008 to test the environmental impacts of market and power decentralization. They found that market decentralization and administrative decentralization had a large impact in the central and western regions and small and medium-sized cities. They concluded that there is a trade-off between economic growth and environmental quality in China. Their results also confirm the existence of the EKC effect in large and medium-sized cities (mainly because they can afford an environmentally-friendly technology). State-owned enterprises (SOEs) are more likely to pollute than privately-owned enterprises (He and Pan 2013). This is because they have stronger bargaining power with local governments regarding environmental regulations.

Kahn (2013) used city-level data from 30 cities during the period of 2003–2007 to estimate the relationship between city size and pollution and to track pollution over time. He found PM10 elasticity of 0.16 and SO_2 of 0.23 with respect to population. This means that an increase in population by 10 % increases ambient air pollution by approximately 2 %. They also found that holding everything else constant, cities with warmer climates have lower air-pollution levels. This is because pollution concentration in urban centers not only depends the magnitude of local emission sources, but also on the prevailing meteorological ventilation of the area, in itself a function of the atmospheric pressure, temperature, humidity levels, and the average wind speed through that atmospheric layer. In fact, this leads to a self-perpetuating cycle as heavy concentrations of air pollutants increase temperature and precipitation in and around cities.

Because urban populations usually increase and the income of urban residents generally rises, ambient urban air quality can improve only if there is a replacement of old polluting techniques with new, environmentally friendly ones. Studies show that introduction of new cleaner techniques can offset most of the pollution impact, if one controls for a city's size and composition of economic activity (Chow 2010). In the light of its environmental degradation, ever-escalating urban pressure and high economic growth, it was inevitable that China started to look for alternative energy sources, in particular, solar energy and wind power. China has recently overtaken the U.S. as the world's largest market for installed wind turbines (Global Wind Energy Council 2014). China is also building more nuclear power plants than the rest of the world (Bradsher 2009). The speed, however, at which it adapts clean energy is a political decision. China has spent about $50 billion during the last decade building the world's largest solar manufacturing industry.

Yet, some consider this effort "a mirage, built on subsidized electricity, most of it produced by coal-fired power plants and often using dirty manufacturing processes that have themselves resulted in environmental damage; financed with large amounts of inexpensive loans; and benefiting from preferential land and tax policies" (Clifford 2015, p. 33). Because of the weak intellectual property protection system resulting in a large number of copycats, the profits are very low. In addition, local favoritism and interests "often determine whose electrical solar or wind power gets dispatched, and thus who gets paid, from among myriad power producers" (Clifford 2015, p. 32). Heavily subsidized by the Chinese government (since 2007), solar energy is thus still more expensive than traditional sources and is still a very small source of the total energy output in China. It is expected to reach a total capacity in 2020 of 20,000 MW, which is only about half the output of coal-fired factories built in one year (Bradsher 2009).

This study contributes to the existing literature by offering a model that allows us to compare the effect of different sources of pollution on the levels of PM, SO2, and NO2 and estimate the number of years that it would take for China to lower its current levels of ambient air pollution to the standards set by the WHO and the Environmental Protection Agency (EPA).

Data and Empirical Model

China has 34 provincial-level administrative units: 23 provinces, four municipalities (Beijing, Tianjin, Shanghai, Chongqing), five autonomous region*s* (Guangxi, Inner Mongolia, Tibet, Ningxia, Xinjiang) and two special administrative regions (Hong Kong, Macau). Data for the 31 regions selected for this study (we excluded Hong Kong and Macau) were obtained from China Statistical Yearbooks, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014. Environmental variables statistics came from specific cities that were matched for each region (see Appendix for the complete list of the regions and cities). Due to lack of some data, Hainan, Guizhou, Tibet, and Qinghai were excluded from the regression analysis, so the final list included data on 27 regions over a 10 year period.

The model estimates changes in three indicators of ambient pollution: PM, SO2 and NO2, all measured in milligrams per cubic meter. PM is airborne particles with diameters less than or equal to 2.5 μm (PM2.5) and less than or equal to 10 μm (PM10), usually a bi-product of the power plants production, woodstoves, diesel vehicles and other mobile and stationary sources (EPA website). SO2 emissions are an outcome of some industrial processes that involve metal smelting and burning fuels that contain sulfur (mostly coal and oil). NO2 gases originate when fuel is burned at high temperatures and come mainly from motor vehicles exhaust and industrial boilers. These three pollutants were chosen because the literature has documented that exposure to these pollutants has detrimental effects on human health. PM's major effects are on the respiratory system, damage to lung tissue, cancer, and premature death (Sacks et al. 2010; Valavanidis et al. 2008; Harrison and Yin 2000). The major health concerns associated with exposure to high concentrations of SO2 include effects on breathing, respiratory illness, alterations in pulmonary defenses, and aggravation of existing cardiovascular disease. Children, the elderly, and people with asthma, cardiovascular disease or chronic lung disease (such as bronchitis or emphysema) are most susceptible (WHO 2006; Venners et al. 2003). NO2 can lower resistance to respiratory infections such as influenza. The effects of short-term exposure are still unclear, but continued or frequent exposure to concentrations that are typically much higher than those normally found in the ambient air may cause increased incidence of acute respiratory illness in children (EPA website; WHO 2006).

The basic empirical model is a reduced form of an equation that estimates the EKC and can be stated as follows:

$$\text{lnAmbient Pollutantjt} = \alpha + \beta\text{lnDIpcjt} + y\text{lnXjt} + c\text{TimeTrendjt} + \text{ujt},$$

where *DIpcjt* is urban disposable income per capita (measured in national currency, RMB) and *Xjt* is a set of control variables that include number of vehicles (*VEH*), industrial electricity output (*ELECT*) and population density (*POPden*). The industrial electricity output variable was only used in the equation estimating the variations in PM. This is because studies show that the electric power industry accounts for the higher emissions of PM among all industries in China (Yi et al. 2006). Numerous studies link deteriorating air quality, and especially an increase in NO2 emissions, in China's urban centers to a rapid increase in vehicle ownership (Wang and Hao 2012; Yang et al. 2011; Du et al. 2012). Studies also cite population density as one of the main sources of ambient air pollution (Schoolman and Ma 2012; Kahn 2010). The main variable of interest is *DIpc*, a way of estimating the EKC (Chen 2010; Zhang et al. 2010; Schoolman and Ma 2012). A negative coefficient on this variable would indicate an abatement effect, a positive coefficient would indicate a scale effect. Because we only use data for 10 years, it is difficult to capture the entire structural change effect, thus we do not use a *DI* squared or cubed, the variables that are usually included in the EKC estimations. Another main variable of interest is *TimeTrend*. Researchers often use the time trend variable to account for changes over time that are not picked by other variables (Kahn 2013). Since we are estimating an equation for time-series panel data, including years as a variable in the equation will allow us to estimate the effect of policy changes and the use of environmentally-friendly technologies that have taken over in the last 10 years. Finally, *ujt* is an error term.

All specifications are estimated for fixed effects because it is difficult to compare the regions with such high dispersion in parameters. In fact, the estimated models indicated a very high coefficient for intraclass indicating that about 90 % of the variation is due to differences between the regions. We then tested the model for validity, using the Hausman test. Testing whether the unique errors are correlated with the regressors, the test evaluates the null hypothesis that the preferred model is random effects (Greene 2003). We rejected the null hypothesis (the errors are not correlated) because probability > Chi2 is less than 0.05, so we used a fixed effects model.

Empirical Results

Table 1 presents summary statistics for 31 regions. The results indicate a large disparity between the values across all the variables. The highest per capita disposable income was in Shanghai in 2013 (43,851.36RMB) and the lowest was in Ningxia in 2004 (7217.87RMB). In fact, Shanghai and Beijing regions registered the highest average disposable income per capita among all regions during the 2004–2013 period (28,723.94RMB and 26,548.61RMB, respectively). The highest concentration of PM was recorded in Shanxi in 2004 (0.175 mg/cu.m). The highest levels of SO2 and NO2 were recorded in Fujian in 2005 (0.016 mg/cu.m) and Hainan in 2009 (0.073 mg/cu.m) respectively.

Table 2 presents coefficient estimates and standard errors (in parentheses) of the effect of per capita disposable income, vehicles possession, population density, and electricity production on various pollutants. The results indicate that an increase in disposable income per capita has a negative effect (albeit not statistically significant) on PM supporting the argument documented in the literature that China has passed the turning point on the Kuznets curve. An increase in the disposable income per capita has a negative effect on changes in SO2 and NO2, suggesting that the turning point has not been reached yet for these pollutants. Changes in the disposable income per capita have the largest impact on local SO2 concentrations. The SO2 elasticity with respect to *DIpc* is 1.73, suggesting that a 10 % increase in the disposable income leads to a 17 % increase in SO2 concentration (statistically significant at 1 % confidence level). This is consistent with other studies that found a large positive and statistically significant effect of income on ambient air pollutants in selected provinces (Schoolman and Ma 2012).

Table 1 Summary statistics

	Mean	Standard Deviation	Minimum	Maximum
PM, mg/cu.m	0.098	0.026	0.033	0.175
SO2, mg/cu.m	0.046	0.021	0.003	0.016
NO2, mg/cu.m	0.041	0.013	0.012	0.073
Urban DI per capita, RMB	16,245.78	6887.672	7217.87	43,851.36
Total vehicles, 10,000 units	213.067	209.218	7.07	1199.71
Industrial electricity output, 100 mil kwh	1202.061	901.86	11.65	4289.41
Urban population density, 1000 inhabitants/km sq.	2482.622	1386.035	186	6307.4

Data Source: China Statistical Yearbooks, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014

Table 2 Regression Results

	lnPM	lnSO2	lnNO2
ln*DIpc*	−0.145	1.731	0.066
	(0.86)	(4.15)***	(0.24)
ln*VEH*	0.211	0.097	0.316
	(2.57)**	(0.54)	(2.63)***
ln*POPden*	0.018	0.022	0.014
	(1.29)	(0.67)	(0.64)
ln*ELECT*	0.101		
	(1.95)*		
Time trend	−0.026	−0.119	−0.026
	(2.65)***	(5.03)***	(1.67)*
_cons	50.203	229.144	50.013
	(2.67)***	(5.01)***	(1.65)*
R^2	0.45	0.35	0.04
N	270	270	270

Data Source: China Statistical Yearbooks, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

PM elasticity with respect to vehicles possession is 0.21, which indicates that a 10 % increase in the number of vehicles in the region would make local air-pollution levels 2 % worse. The coefficient is significant at a 5 % level of confidence. The results indicate that a 10 % increase in the vehicles in the region would increase local NO2 concentration by 3.2 %. The effect on SO2 is much smaller (about 1 %), but it is not statistically significant. This is consistent with other studies. Wang and Hao (2012), for example, found that during 2000–2010 vehicle population increased 300 % while NO2 increased 200 %. A study in Beijing found that about 30 % of total NOx emissions comes from vehicle sources (Wu et al. 2010).

The PM elasticity with respect to electricity production is 0.101, suggesting that a 10 % increase in the local electricity production would increase PM concentration by 1 %. It is interesting to note that although population density has expected positive coefficients in all specifications, their magnitudes are rather small and not statistically significant. This is somewhat different from other studies that found population density to be one of the factors leading to the air quality deterioration (Schoolman and Ma 2012). This implies that the population density per se is not a determining factor of the local air-pollution levels but perhaps is a source of urban human activities that can be linked to the air pollution directly.

The time trend reveals much better news about SO2 than about the other two pollutants. While PM and NO2 concentration are declining by about 3 % per year, SO2 concentrations are declining by almost 12 % a year. These estimates are statistically significant in all specifications. The time trend variable picks up whatever is not picked up by other explanatory variables, and in this case it possibly reflects the changes in government policies and enforcement, as well as the changes in the Chinese public's attitudes toward air pollution. These results are somewhat different from those of Kahn's (2013), who used city-level data from 2003 to 2007 for 35 major cities. He found that PM was declining by 5.9 % per year during that period, while SO2 was declining by 3.2 % per year. His estimates, however, were not statistically significant.

Conclusions, Limitations, and Policy Implications

This study uses China's regional data on 27 provinces during 2004–2013 to identify major factors leading to the increase in air pollution. We investigated the role of economic forces (urban population pressures, disposable income per capita, electricity production, and rise in vehicle ownership) in contributing to the increase in the levels of ambient air pollution as measured by PM, SO2 and NO2. The results of our study indicate that the disposable income per capita has different effects on different pollutants. The negative effect it has on PM implies that China has already reached the turning point on the EKC that represents a relationship between PM and disposable income per capita. However, an increase in the disposable income per capita tends to still increase SO2 and NO2, which possibly indicates that China has not reached yet the turning points for these pollutants.

However, the results are statistically significant in the estimations of the changes in SO2 level only. It is possible that the model suffers from some endogeneity problems. When panel data are analyzed, the ordinary least squares (OLS) technique often results in biased estimators because some unobservable individual-specific terms may be correlated with explanatory variables. The ownership of vehicles, for example, is not only highly correlated with the disposable per capita income, but, in fact, might be dependent on it. The production of electricity is also highly correlated with the disposable income and might be an outcome of higher demand as the purchasing power in the regions is increasing. Getting more detailed data on specific sources of pollution that may not directly affect the disposable income may solve the problem of endogeneity.

Our results also indicate that an increase in electricity production leads to a higher PM in the air, but the latter has been decreasing with each year by 3 %. The reason why the improvement in the ambient air quality is so sluggish is because of the local governments' inability and resistance to cooperate with the central government and their subsequent failure to meet national environmental goals (Zhang 2013). Shutting down highly-polluting factories would lead to a job-loss and lower output. This would result in lower tax revenues for local government officials and smaller personal gains for them. Since 2007, the central government has been trying to de-emphasize economic growth and GDP and provide incentives for local officials to meet environmental goals. For example, meeting environmental quality targets has been now included in promotion standards. Since 2004, the central government has been releasing a blacklist of the 10 most polluted cities in China. The central government has also recognized the need to give incentives to close down outdated production capacity. In November 2007 it transferred two billion yuan to provincial governments. Although this is a miniscule amount, compared with the total transfer amount that is needed, this is perceived as good news as it signifies the central government's recognition of such environmental policy (Zhang 2013).

Another important factor in the improvement in the environmental situation in China is Chinese citizens' willingness and ability to afford better environmental quality. Chinese are often too reliant on the government to take care of the outstanding issues and thus an environment movement, the backbone of the air clean-up in the United States, is virtually nonexistent. Even though the number of environmental units has increased, they are mostly non-confrontational and passive. The solution to the clean air in China seems to be manifested via a simple supply and demand model. The local governments should be provided with incentives to reinforce the laws introduced by the central government, especially the ones related to vehicular emission standards and the use of green technology by factories. This one would increase the supply (perfectly inelastic) of clean air in China, At the same time, wealthier people who can "afford" more clean air (assuming it is a normal good) should be more active in stating their demands. That would result in a well-defined inverted U-shape of the EKC. It is also possible that the shape of the EKC is different in different regions, thus estimating the EKC for individual regions might be insightful. Another potentially valuable extension is to group the regions according to their dimensions (gross regional product or per capita income) and estimate the EKC for each group separately. This could provide important information to policy makers. Further research is also necessary to include more years in the sample, which would estimate better the shape of the EKC.

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Appendix

Coding of Chinese cities and regions

Code	Region	Cities
1	Beijing	Beijing
2	Tianjin	Tianjin
3	Hebei	Shijiazhuang
4	Shanxi	Taiyuan
5	Inner Mongolia	Hohhot
6	Liaoning	Shenyang
7	Jilin	Changchun
8	Heilongjiang	Harbin
9	Shanghai	Shanghai
10	Jiangsu	Nanjing
11	Zhejiang	Hangzhou
12	Anhui	Hefei
13	Fujian	Fuzhou
14	Jiangxi	Nanchang
15	Shandong	Jinan
16	Henan	Zhengzhou
17	Hubei	Wuhan

18	Hunan	Changsha
19	Guangdong	Guangzhou
20	Guangxi	Nanning
21	Hainan*	Haiko
22	Chongqing	Chongqing
23	Sichuan	Chengdu
24	Guizhou*	Guiyang
25	Yunnan	Kunming
26	Tibet*	Lhasa
27	Shaanxi	Xi'an
28	Gansu	Lanzhou
29	Qinghai*	Xining
30	Ningxia	Yinchuan
31	Xinjiang	Urumqi

*The regions excluded from the regression analysis due to lack of data

References

Ankarhem, M. (2005). A dual assessment of the environmental Kuznets curve: The case of Sweden. Umeå: Umeå University, no. 660, 24. Retrieved on September 13th, 2015, from http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A143725&dswid=5212.

Bradsher, K. (2009). China outpaces US in cleaner coal-fired plants. *The New York Times*, 11.

Chen, C. (2010). Spatial inequality in municipal solid waste disposal across regions in developing countries. *International journal of Environmental Science and Technology, 7*(3), 447–456.

China Statistical Yearbook. (2005). National Bureau of statistics of China. China statistical yearbook. Retrieved from: http://www.stats.gov.cn/tjsj/ndsj/2005/indexeh.htm.

China Statistical Yearbook. (2006). National Bureau of statistics of China. *China Statistical Yearbook*. Retrieved on from: http://www.stats.gov.cn/tjsj/ndsj/2007/indexeh.htm.

China Statistical Yearbook. (2007). National Bureau of statistics of China. *China Statistical Yearbook*. Retrieved on from: http://www.stats.gov.cn/tjsj/ndsj/2007/indexeh.htm.

China Statistical Yearbook. (2008). National Bureau of statistics of China. *China Statistical Yearbook*. Retrieved from: http://www.stats.gov.cn/tjsj/ndsj/2008/indexeh.htm.

China Statistical Yearbook. (2009). National Bureau of statistics of China. *China Statistical Yearbook*. Retrieved from: http://www.stats.gov.cn/tjsj/ndsj/2009/indexeh.htm.

China Statistical Yearbook. (2010). National Bureau of statistics of China. *China Statistical Yearbook*. Retrieved from: http://www.stats.gov.cn/tjsj/ndsj/2010/indexeh.htm.

China Statistical Yearbook. (2011). National Bureau of statistics of China. *China Statistical Yearbook*. Retrieved from: http://www.stats.gov.cn/tjsj/ndsj/2011/indexeh.htm.

China Statistical Yearbook. (2012). National Bureau of statistics of China. *China Statistical Yearbook*. Retrieved from: http://www.stats.gov.cn/tjsj/ndsj/2012/indexeh.htm.

China Statistical Yearbook. (2013). National Bureau of statistics of China. *China Statistical Yearbook*. Retrieved from: http://www.stats.gov.cn/tjsj/ndsj/2013/indexeh.htm.

China Statistical Yearbook. (2014). National Bureau of statistics of China. *China Statistical Yearbook*. Retrieved from: http://www.stats.gov.cn/tjsj/ndsj/2014/indexeh.htm.

Chow, G. C. (2010). *China's environmental policy: a critical survey*. Center for Economic Policy Studies: Princeton University.

Chow, G. C. (2015). *China's economic transformation*. Chichester: John Wiley and Sons.

Clifford, M. L. (2015). *The Greening of Asia: The Business Case for Solving Asia's Environmental Emergency*. New York: Columbia University Press.

Cole, M. A. (2000). Air pollution and 'dirty industries': how and why does the composition of manufacturing output change with economic development? *Environmental and Resource Economics, 17*(1), 102–123.

Du, X., Wu, Y., Fu, L., Wang, S., Zhang, S., & Hao, J. (2012). Intake fraction of PM 2.5 and NO X from vehicle emissions in Beijing based on personal exposure data. *Atmospheric Environment, 57*, 233–243.

Fischer-Kowalski, M., and Swilling, M. (2011). *Decoupling: natural resource use and environmental impacts from economic growth*. United Nations Environment Programme. Retrieved on September 13, 2015, from http://www.unep.org/resourcepanel/decoupling/files/pdf/Decoupling_Report_English.pdf.

Global World Energy Council (2014). *Global Wind Report Annual Market Update 2014*. (n.d.). Retrieved on September 13, 2015, from http://www.gwec.net/wp-content/uploads/2015/03/GWEC_Global_Wind_2014_Report_LR.pdf.

Greene, W. H. (2003). *Econometric analysis*. Upper Saddle River: Pearson Education.

Grossman, G. M., & Krueger, A. B. (1996). The inverted-U: what does it mean? *Environment and Development Economics, 1*(01), 119–122.

Harbaugh, W. T., Levinson, A., & Wilson, D. M. (2002). Reexamining the empirical evidence for an environmental Kuznets curve. *Review of Economics and Statistics, 84*(3), 541–551.

Harris, J. M., and Roach, B. (2013). *Environmental and natural resource economics: A contemporary approach*. ME Sharpe.

Harrison, R. M., & Yin, J. (2000). Particulate matter in the atmosphere: which particle properties are important for its effects on health? *Science of the Total Environment, 249*(1), 85–101.

He, C., & Pan, F. (2013). Decentralization and the environment: industrial air pollution in Chinese cities. In J. Y. Man (Ed.), *China's environmental policy and urban development* (pp. 41–58). Cambridge: Lincoln Institute of Land Policy.

Hilton, F. H., & Levinson, A. (1998). Factoring the environmental Kuznets curve: evidence from automotive lead emissions. *Journal of Environmental Economics and Management, 35*(2), 126–141.

IMF World Economic Outlook (WEO), October 2014: Legacies, Clouds, Uncertainties – Table of Contents. (n.d.). Retrieved September 13, 2015.

Kahn, M. E. (2010). New evidence on trends in the cost of urban agglomeration. In *Agglomeration economics* (pp. 339–354). Chicago: University of Chicago Press.

Kahn, M. E. (2013). The greenness of China's cities: air pollution and household greenhouse gas emissions. In J. Y. Man (Ed.), *China's environmental policy and urban development* (pp. 95–105). Cambridge: Lincoln Institute of Land Policy.

Levinson, A. (2002). *The ups and downs of the environmental Kuznets curve. Recent Advances in Environmental Economics* (pp. 119–139). Cheltenham: Edward Elgar.

Llorca, M., & Meunié, A. (2009). SO2 emissions and the environmental Kuznets curve: the case of Chinese provinces. *Journal of Chinese Economic and Business Studies, 7*(1), 1–16.

Man, J. Y. (Ed.) (2013). *China's environmental policy and urban development*. Cambridge: Lincoln Institute of Land Policy.

Panayotou, T. (1993). *Empirical tests and policy analysis of environmental degradation at different stages of economic development (No. 292778)*. Geneva: International Labour Organization.

Panayotou, T., Peterson, A., & Sachs, J. D. (2000). *Is the environmental Kuznets curve driven by structural change? What extended time series may imply for developing countries*. Cambridge: CAER II Discussion Paper No. 80.

Pearce, D. W. (2003). Conceptual framework for analyzing the distributive impacts of environmental policies. In *Prepared for the OECD Environment Directorate Workshop on the Distribution of Benefits and Costs of Environmental Policies*, Paris.

Sacks, J. D., Stanek, L. W., Luben, T. J., Johns, D. O., Buckley, B. J., Brown, J. S., et al. (2010). Particulate matter-induced health effects: who is susceptible? *Environmental Health Perspectives, 119*(4), 446–454.

Schoolman, E. D., & Ma, C. (2012). Migration, class and environmental inequality: exposure to pollution in China's Jiangsu Province. *Ecological Economics, 75*, 140–151.

Stern, D. I. (2004). The rise and fall of the environmental Kuznets curve. *World Development, 32*(8), 1419–1439.

The Economist (2014a). China's Environment: A Small Breath of Fresh Air. February 8th.

The Economist (2014b). China: Building the Dream. April 19th. EPA website. Environmental Protection Agency. Retrieved on September 14th, 2015. http://www.epa.gov/airtrends/aqtrnd95/no2.html.

Valavanidis, A., Fiotakis, K., & Vlachogianni, T. (2008). Airborne particulate matter and human health: toxicological assessment and importance of size and composition of particles for oxidative damage and carcinogenic mechanisms. *Journal of Environmental Science and Health, Part C, 26*(4), 339–362.

Venners, S. A., Wang, B., Xu, Z., Schlatter, Y., Wang, L., & Xu, X. (2003). Particulate matter, sulfur dioxide, and daily mortality in Chongqing, China. *Environmental Health Perspectives, 111*(4), 562.

Wang, S., & Hao, J. (2012). Air quality management in China: issues, challenges, and options. *Journal of Environmental Sciences, 24*(1), 2–13.

World Health Organization (WHO). Regional Office for Europe, and World Health Organization (2006). *Air quality guidelines: global update 2005: particulate matter, ozone, nitrogen dioxide, and sulfur dioxide*. Geneva: World Health Organization.

Wu, Y., Wang, R., Zhou, Y., Lin, B., Fu, L., He, K., et al. (2010). On-road vehicle emission control in Beijing: past, present, and future. *Environmental Science and Technology, 45*(1), 147–153.

Yandle, B., Bhattarai, M., & Vijayaraghavan, M. (2004). Environmental Kuznets curves: a review of findings, methods, and policy implications. *Research study, 2*, 1–16.

Yang, F., Tan, J., Zhao, Q., Du, Z., He, K., Ma, Y., et al. (2011). Characteristics of PM 2.5 speciation in representative megacities and across China. *Atmospheric Chemistry and Physics, 11*(11), 5207–5219.

Yi, H., Guo, X., Hao, J., Duan, L., & Li, X. (2006). Characteristics of inhalable particulate matter concentration and size distribution from power plants in China. *Journal of the Air and Waste Management Association, 56*(9), 1243–1251.

Zhang, Z. X. (2013). Government Decentralization, Energy Saving, and Environmental Protection. In Y. Man J. (Ed.), *China's environmental policy and urban development*. Cambridge: Lincoln Institute of Land Policy.

Zhang, D., Aunan, K., Seip, H. M., Larssen, S., Liu, J., & Zhang, D. (2010). The assessment of health damage caused by air pollution and its implication for policy making in Taiuan, Shanxi, China. *Energy Policy, 38*(1), 491–502.

Zhao, X. B., & Zhang, L. (1999). Decentralization reforms and regionalism in China: a review. *International Regional Science Review, 22*(3), 251–281.

Zheng, S., Kahn, M. E., & Liu, H. (2010). Towards a system of open cities in China: home prices, FDI flows and air quality in 35 major cities. *Regional Science and Urban Economics, 40*(1), 1–10.