# Economic Growth, Urbanization and Air Pollution in China: An Empirical Research Based on Panel Data

By Yue Ji

(7248677)

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Supervisor: Professor Louis Hott

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Contents

**Abstract**

This paper analyzes the relationship between economic growth, urbanization level and air pollution based on a panel dataset compromising 27 provinces and 4 municipalities in China. Fixed effect models are used with time fixed-effect dummies and individual fixed-effect dummies included in the regression models. The estimation results show that an inverted U-shaped relationship between economic growth and air pollution exists, supporting the EKC hypothesis, although the turning points vary greatly among air pollutants. However the non-linear relationship between the urbanization level and air pollution is not clearly identified according to the results. Furthermore, some other variables included as control variables in the regression models also have effects on the air pollution.

## 1. Introduction

Environmental issues in China have drawn more and more attention in recent years. Most studies show that it is the consequence of economic growth. The relationship between environmental pollution and economic growth has been widely studied by many researchers. In addition to economic development, there are also many other causes leading to the environmental degradation. As a phenomenon of social and economic improvement, urbanization exerts an inevitable effect on the environment. It aims at not only transferring the population from rural areas to urban areas but also transferring the rural labor from agriculture to industry and the service sector. Most researchers link the relationship between economic growth and environmental pollution to the Environmental Kuznets Curve (EKC) that indicates an inverted U-shaped relation. However, a minority of studies applies environmental pollution with the Environmental Kuznets Curve hypothesis (EKC) to the relationship between the urbanization level and air pollution. What I will study in this paper is to relate these two types of relationships to the EKC hypothesis, and then to investigate the relationship between economic growth, urbanization and air pollution as well as report the empirical results.

Thus, the first specific question is how economic growth affects pollution and whether the EKC hypothesis is verified. Then I will test the existence of non-linear curve in terms of the relationship between the urbanization and air pollution. Urbanization, as I mentioned above, is not only the transfer of population from rural areas to urban areas, but also the adjustment of industry structure in China. In order to test both effects on air pollution, I use the percentage of urban population to define the urbanization level, at the same time, putting the industry structure into the estimation model. Thus, the second specific question comes up with how the number of urban population affects the air pollution in China. Finally, I put the two models together to examine how the relationships change with more explanatory variables included.

Four categories of air pollutants are introduced in the empirical study, including industrial waste gas, sulfur dioxide, dust and soot. I use panel data comprising 27 provinces and 4 municipalities in China in the period of 2001 to 2012, constructing regression models to do an empirical study. All the data stems from Chinese Yearbooks and China Environment Yearbook. It is widely acknowledged that panel data can provide researchers with more information and data points, while we cannot deny that panel data is not easy to work with. In the part of estimation strategy, I introduce time dummy variables and individual dummy variables to capture the time-fixed effect and individual-fixed effect, and then some diagnose tests are used to get better regression models and estimation results.

The main two results in this paper are that the EKC hypothesis is strongly confirmed in terms of relationship between income level and air pollution in China, and that a non-linear relationship exists between the urbanization level and air pollution. In addition, some other independent variables included into the models are important factors affecting air pollution, but their effects vary by type of air pollutants.

I organize the rest of paper as followed. In Section 2, I briefly review the previous literature. Section 3 focuses on the theory used in the paper. Section 4 describes the data. After that, section 5 presents the estimation models and strategy. In section 6, the main results will be shown. In the end, section 7 refers to conclusion.

## 2. Literature review

In this literature review, I will present seven empirical papers that consider the link between economic growth, urbanization levels and air pollution in China. These seven papers fall into two categories from an empirical perspective. The first category studies the relationship between economic growth and pollution. The second category looks at the relationship between the urbanization level and environmental pollution. We begin with the first category.

### *2.1 Growth and pollution*

Dong (2010) attempts to relate GDP per capita to three kinds of pollutants in order to test the existence of the EKC curve. These three types of pollutants are waste-gas emissions, solid wastes and waste-water discharges. A thirty province panel data for the period 1985 to 2007 in China is estimated by using panel unit root test, cointegration test and DOLS model. He finds that a long-term relationship between economic growth and all three pollutants exists, taking an inverted U-shaped Environmental Kuznets Curves. However, what he emphasizes in the paper is that the turning points are not as low as those in previous studies. His estimation results show that the turning points are respectively RMB $3.4\times10^4$, $2.3\times10^4$ and $6.7\times10^4$ Yuan (US $4106, $2777 and $8091 price on 2001) for industrial waste gas, waste water and solid wastes. Therefore, only Beijing, Shanghai, Tianjin and some other high income-level places have environmental pollution emissions that decrease with economic growth in that time period.

Shaw and Pang (2010) investigate the EKC relationship between economic development and air quality in China. They analyze this kind of relationship by using a panel dataset from 1992 to 2004. Differing from previous researches, this paper adopts city-level panel data rather than province-level. In addition, they take into account the endogeneity of the income variable. Sulfur dioxide (SO2), nitrogen oxides ($NO_x$) and deposited particles (DP) emissions are used as air quality indicators, and endogenous variables include population density, the contribution of secondary industry to GDP and a policy variable. In terms of empirical methods, they estimate time-specific fixed effects and cross-regional effects by adding dummy variables to the model. The Hausman test rejects the null hypotheses of exogeneity of income and policy variables, and thus instrumental variables are applied. The estimation results show that positive and negative coefficients of GDP and its quadratic term support the EKC hypothesis for SO2, and the turning point is RMB 1.7293×$10^4$ yuan (US$ 2,014 in 2000) that is at an early stage of economic development, which contributes to the tight political policy in China. However, the EKC hypothesis is not supported for the cases of $NO_x$ and DP among 99 cities.

Jayanthakumaran and Liu (2012) use provincial-level data from 1990 to 2007 to analyze the relationship between trade, growth and pollutant emissions. Firstly, they attempt to test the EKC hypothesis on water chemical oxygen demand (COD) and sulphur dioxide (SO2) with GDP and its quadratic term in the equation, and then estimate the turning points with respect to income levels for both pollutants. In addition to a fixed effect estimation, a random effect estimation is used to capture the uncertainty. They find similar turning points as previous studies, i.e., RMB 6859 and 15138 yuan (US$828 and $1828 in 2001) for COD and SO2, respectively. Secondly, they investigate the impact of openness on economic growth to test for the pollution haven hypothesis, i.e. developed nations transfer more environmental pollution to developing countries through international trade. Further, according to the turning points, the sample is divided into two groups based on income, below and above the turning point. And it can be known from this research that the technology have a great influence on the provinces with high level of income.

Brajer and W.Mead (2011) try to combine three types of air pollutants (sulfur dioxide, nitrogen dioxide and particulate pollution) into a single index in order to examine the overall EKC in China for air pollution rather than individual pollutants. Thus, it is worthy to note how the authors collect data and measures air pollutant as a whole. The pollutants panel data comprising 139 cities in China from 1990 to 2006 are measured in terms of annual ambient concentration rather than annual emissions. Besides that, they generate a more complex index in order to capture the overall pollution level in China. In terms of the model, the pollutants or the index of pollution are regarded as dependent variables, and at the same time they take into account several control variables, including population density, north (i.e. whether the city is situated in the north or not in China,), and coast (i.e., whether or not it is a coastal city). Four types of models are estimated for each type of pollutants or pollution index accounting for the inclusion of quadratic and cubic terms for income and other control variables using a random-effect generalized least squares (GLS) estimation. Although the estimation results provide some support for the EKC hypothesis for both specific pollutants and the aggregated pollution index, the relationship differs drastically by air pollutants and the overall income-pollution relationship cannot completely reflect the real environmental issues in China. Therefore, the results suggest that, it is not beneficial for making environmental policies and addressing the environmental issues to adopt an aggregated pollution measure.

*2.2 Urbanization and pollution*

We now turn to the analysis of links between urbanization and pollution.

Du and Liu (2008) uses a 30-province panel dataset from 1998 to 2005 to examine how the urbanization level affects the environmental quality. Fixed and random effect models are selected for the estimation of each pollutant. They measure the environmental pollution through six types of pollutant emissions: industrial waste water, waste gas, soot, dust, SO2 and solid waste, and defines the urbanization level as the proportion of urban residences among the total population in China. In the first step, they regress the pollutant emissions on urbanization level and its quadratic term, using fixed and random effect models according to the results of Hausman tests. It can be concluded from the estimation results that waste water, waste gas, solid waste and SO2 follow inverted U-shaped curve with respect to the urbanization level, while soot and dust have U-shape relationships with respect to urbanization level. Secondly, a number of control variables including trade openness, industry structure, technology and the economic growth rate, are taken into consideration. After that, the urban-pollution relationships become insignificant for solid waste and SO2, and the turning points change to 40.5%, 41.9%, 42.4% and 38.1%, respectively.

Wang and Wang (2010) attempt to analyze the Environmental Kuznets Curve (EKC) on the relationship between the environmental pollution and the urbanization level using a

28-province panel database in the period from 2004 to 2008. The percentage of urban population on the total population is as an index for urbanization level. They construct the regression model with GDP per capita, its quadratic and cubic term, further exploring the time effects and individual effects on the database. In addition to the income level variables, the authors take into consideration three types of control variables: industry structure, consumption expenditure and built-up areas. Their finding is that the inverted U-shaped relationship between the urbanization and air pollution holds, and the peak of the curve is 41.3% for waste water pollution.

Since Shaw and Pang (2010), as mentioned above, use city-level panel data, it is easy to acknowledge that the variable ‘population density’ is a proxy for urban population, which is a reference to the urbanization-pollution relationship analysis. Their results indicate that for SO2, urban population has a negative effect on the emissions of pollutants, although its explanatory power is insignificant. While in terms of $NO_x$ and deposited particles, the density of population positively influences the environmental pollution, even though the effect on the pollutants emission still is insignificant.

## 3. The theory

In the early 1990s, an influential study published in the World Development Report of World Bank by Grossman and Krueger noted the possible existence of an Environmental

Kuznets Curve (EKC) (IBRD,1992). The EKC hypothesis focused on the relationship between environmental pollution and income levels per capita, assuming that in the primary stage, environmental quality inevitably degenerates with economic growth, and after a certain level of income per capita, economic development will improve the environment. The EKC theme is widely accepted by economists because it can be reasonably explained. In the early stage of economic improvement, people pay more attention to economic growth, especially in developing countries where the economy always improves at the cost of environment degradation. However, when income per person reaches a relatively high level, environment degradation will become a bigger issue since it negatively affects the economic growth of a country. Therefore, some measures will be taken to improve the environment with economic development. Consequently, the structure of the economy, the technology and policies would have a positive effect on the pollution.

Though, EKC hypothesis, originally, assumes inverted U-shaped relationship between the income level and environment pollution, in this paper, I extensively test the inverted U-shaped curve on the link between urbanization level and pollutions.

The relationship between the urbanization level and pollution is widely studied by researchers in China. Some of them believe that the quality of the environment in a city directly influences the speed and the scale of its urbanization. Others think that it is of importance to focus on the method of urbanization development, which should be consistent with nature and environmental quality. As far as I am concerned, the effect of urbanization level on pollution is non-linear. On one hand, in the primary stage, the process of urbanization directly reflects on the high population density in cities, the expansion of city size and economic scale, which attributes to more nature sources and energy used in economic activities and thus more air pollutant emissions arise. Meanwhile, population pressure in the urban areas will essentially aggravate the damage caused by environmental pollution. As a result, urbanization level is positively related to air pollution. On the other hand, after a while, when those who only focus on the speed and scale of the economy are aware of the importance of environment, promoting the high technology application become the primary thing to do in the process of urbanization. For instance, in order to reduce the air pollutant emissions, cleaner fossil fuels and energy are used, and fuels are burned more efficiently in the economic activities without limiting economic improvement. Therefore, I try to investigate the non-linear relationship between the urbanization level and air pollution. It is expected that there is an inverted U-shaped relationship between the urbanization and air pollution across China.

Besides that, population and industry structure are supposed to be influential in affecting pollution.

For a developing country, especially China, population pressure has been a big issue for several decades. Researchers increasingly agree that population size is closely linked to environmental quality, and in general, a growing number of population will lead to more economic activities, bringing about more pollutant emissions. Thus as the number of population is growing, improving economic development without destroying the environment is a huge challenge for China.

Industry structure is a significant factor for air pollution, because most of the pollutants are directly emitted by industrial activities. It is expected that the expansion of the secondary industry will pose a positive effect on air pollution in China.

The pollution heaven hypothesis assumes that for a developing country, a high level of trade openness tends to bring about more pollution. Recently, it is argued that large industrial countries prefer to set up factories abroad, because they can make use of cheap resources and labor in developing countries without destroying their own environment. In terms of industrial nations, it is beneficial to transfer dirty industries to other foreign countries for both economic and environmental reasons, while improving international trade and economic growth at the cost of environmental degradation is not a wise choice but an absolutely indispensable way to go for developing nations. As a consequence, the impact of trade openness on pollution is expected to be positive in China.

The effect of technology on the environment quality is clearly important. The higher the level of technology is, the less the air pollutants emit. Improving the technology has always been one of the best ways to make the environmental quality better for nations all over the world.

## 4. Data description

Table 1

Descriptive statistics

| Variables | Definition | Units | Mean | Std dev | Min | Max |
|---|---|---|---|---|---|---|
| Waste gas | Yearly emissions of waste gas per province | 100 million $m^3$ | 10064.4 | 8981.84 | 12 | 56324 |
| SO2 | Yearly emissions of sulfur dioxide per province | 10000 tons | 72.58 | 46.87 | 0.1 | 200.3 |
| Dust | Yearly emissions of dust per province | 10000 tons | 25.33 | 19.94 | 0.07 | 91 |
| Soot | Yearly emissions of soot per province | 10000 tons | 23.30 | 18.77 | 0.08 | 76.9 |
| GDP | Real GDP per capita | Yuan | 16939 | 14649 | 2895 | 99395 |
| Population | Total Population | Ten thousand | 4183.51 | 2665.78 | 264 | 10440.96 |
| Urbanization | Urbanization level | ％ | 45.33 | 15.76 | 19.53 | 89.30 |
| Trade openness | The share of export and import in GDP | | 0.32 | 0.40 | 0.04 | 1.76 |
| Technology | Energy consumption per unit of GDP | Ton of SCE/ $10^4$ yuan | 1.55 | 0.78 | 0.56 | 4.43 |
| Industry | Secondary industry share in GDP | | 0.46 | 0.08 | 0.20 | 0.62 |

Table 2

Correlation between dependent variables

| | SO2 | Dust | Soot | Waste Gas |
|---|---|---|---|---|
| SO2 | 1.0000 | | | |
| Dust | 0.7445 | 1.0000 | | |
| Soot | 0.6524 | 0.7978 | 1.0000 | |
| Waste Gas | 0.6918 | 0.4543 | 0.3631 | 1.0000 |

As I mentioned above, I compile panel data from 27 provinces and 4 municipalities in the period from 2001 to 2010, and hence, for each variable, I have 310 observations. The pollutant data are derived from the China Environment Yearbook over ten years， and the rest of the dataset mainly stems from China Statistical Yearbook 2001 to 2010.

It is very important and complicated to appropriately measure pollution for econometric purposes. In terms of air pollution, emissions or air ambient quality are usually used as indexes to deal with the econometric issues. In this paper, aggregated emissions are a better indicator to measure air pollution, because it is relatively easier to collect the associated data and to understand how economic growth and urbanization level affect the pollution. From table 2, high correlation between SO2, dust and soot are shown, while the correlations between waste gas, dust and soot are relatively low.

According to table 1, ten variables are included in the empirical study, respectively four dependent variables and six independent variables. The independent variables are constructed as followed.

**GDP per capita** In order to test the EKC hypothesis that analyzes the relationship between the income level per person and environmental pollution, GDP per capita and its quadratic term are included in the regression model. For the empirical analysis, one must use real GDP instead of nominal GDP. Therefore, I directly collect the nominal GDP and GDP deflator from China Statistical Yearbook over ten years, and then combine these two factors to calculate the real GDP, deflated to 2001 prices.

**Population** The effect of total population on the air pollution is expected to be positive with all the data derived from China Statistical Yearbook over a decade from 2001 to 2010.

**Urbanization level** The proportion of urban population is used as a measure of urbanization level in this paper. I include the urbanization level as well as its quadratic term to test for the non-linear relationship between the urbanization level and air pollution. The data also comes from China Statistical Yearbook from 2001 to 2010.

**Industry** The province-level panel data about the industry share is available from China Statistical Yearbook from 2001 to 2010. With the dataset of Gross regional product and secondary industry, the share of secondary industry on GRP can be calculated easily.

**Trade openness** There is no clear consensus on the measure of trade openness in the earlier studies. I use standard measure for trade in this paper to proxy the international trade for 31 provinces and municipalities in China. It is the total value of export and import as a share of nominal GDP with all the data derived from China Statistical Yearbook. And, it accounts the trade with the rest of the world only but not trade between Chinese provinces.

**Technology** Technology plays an important role in the development of economy. In this paper, energy consumption per unit of gross regional product, as a proxy for technology, is used with the data derived from China Statistical Yearbook from 2001 to 2010.

## 5. Estimation strategy

### *5.1 Estimation strategy*

Firstly, I consider the reduced-form linear regression model for panel data as followed.

$$Y_{it}=\beta Z_{it} + \mu_{it}+\varepsilon_{it}$$

Here, Y represents the air pollutants emissions for province i in year t. Z is a vector of explanatory variables, including GDP per capita, urbanization level, industry structure, population size, trade openness and technology. $\mu_{it}$ refers to unobserved individual effects, and $\varepsilon_{it}$ is error term.

Endogeneity issue should be drawn attention in this model from the perspective of econometrics and empirical research. In general, endogeneity always arises as a result of reverse causality, measurement errors and omitted variable bias. In terms of this model, it may be noticed that a loop of causality between GDP per capita and air pollution is an important factor that gives rise to endogeneity. In this case, air pollution is taken as the dependent variable since we are concerned about how income levels affect air pollution. However, we cannot deny that, at the same time, the improvement of air quality pose a crucial impact on the economic growth. As a consequence, endogeneity issue arises, weakening the explanatory power and accuracy of this model and misleading our judgment on it. Furthermore, to some extent, the other two circumstances are also potential risks leading to endogeneity in this model. Therefore, it is necessary to proceed to some tests and corrections before regress this model.

In order to appropriately obtain estimation results of this model, I begin with a Hausman test to select the optimal model for each of regression estimation. The Hausman test assumes the random effects estimators are fully efficient under the null hypothesis. The rejection of the null hypothesis suggests that the fixed-effect model is preferred by all of the models in this paper, and then I conduct an F-test to diagnose whether the individual province effects are the same for all areas under the null hypothesis. Since the results indicate that there are province-specific effects across all areas, individual fixed-effect dummy variables are introduced into the models to capture the unobserved province-specific characteristics in the data. At the same time, time fixed-effect dummies should be taken into account in order to control the time effect during the period 2001 to 2010 on the dependent variables and independent variables. It is empirically significant to take dummy variables into the equations in this regression models. 27 province and 4 municipalities in China are confronted with totally different current situations in terms of both the economy and the environment. Generally, coastal provinces have developed faster than inland provinces do during this decade from 2001 to 2010. Meanwhile, the impact of the time period on the regression model cannot be ignored. More specifically, the individuals may suffer from economic recession without any warning like in the year 2009, while good economic situation worldwide maybe drive the income improvement in China. Therefore, using dummy variables to keep individual effect the same on the provinces is very helpful and efficient in my estimation process.

In addition, we need to consider the heteroscedasticity, contemporaneous correlations across cross-sectional units and autocorrelation due to the selection of province-level panel data and the fact that the number of cross-sectional units is much larger than that of the time periods. A modified Wald test is conducted to test groupwise heteroskedasticity for cross-sectional time-series data. Breusch-Pagan test is used to diagnose contemporaneous correlations across cross-sectional units rather than heteroskedasticity. Besides that, a Wooldridge test is also applied to panel-data model in order to test the first-order autocorrelation in the regression model.

Based on the results of these diagnostic tests, in the end, I will choose an OLS and a Prais-Winsten regression with panel-corrected standard error (PCSE) estimates to regress the models in the paper.

*5.2 Regression models*

Three regression models are estimated that differ by the inclusion of different explanatory variables for each of the respective air pollutants. We consider four different air pollutants: industrial waste gas, sulfur dioxide, suspended particles (soot) and dust.

Model 1 estimates the relationship between the pollutant's emissions and the GDP per capita in order to test the EKC hypothesis. We express the following equation for model 1:

$$LnY_{it} = \alpha_1 lnG_{it} + \alpha_2 (lnG_{it})^2 + \Phi_p + \Psi_t + \varepsilon_{it}$$

Here, $Y_{it}$ refers to the pollutant's emissions of province i in year t, and $G_{it}$ represent the GDP per capita of province i in year t. All the variables take logarithmic forms. $\alpha_1$ and $\alpha_2$ are the coefficients of GDP per capita and its quadratic term. $\varepsilon_{it}$ is error term. Finally, $\Phi_p$ represents individual fixed-effect dummies and Ψt is time fixed-effect dummies.

Model 2 uses the urbanization level variable as an explanatory variable along with its quadratic term in order to extensively examine non-linear relationship between the urbanization level and pollution. We consider the regression model as followes,

$$LnY_{it} = \theta_t + \beta_1 lnU_{it} + \beta_2 (lnU_{it})^2 + \Phi_p + \Psi_t + \mu_{it}$$

Where $U_{it}$ is urbanization level for each province in the year of t. Square of $lnU_{it}$ is included as a quadratic form in this formula to test the non-linear relation between the urbanization and the pollutant emission.

In model 3, after including other variables, the econometric model becomes:

$$LnY_{it} = \theta_t + \alpha_1 lnG_{it} + \alpha_2 (lnG_{it})^2 + \beta_1 lnU_{it} + \beta_2 (lnU_{it})^2$$

$$+ \gamma_1 lnI_{it} + \gamma_2 lnP_{it} + \gamma_3 lnO_{it} + \gamma_4 lnT_{it} + \Phi_p + \Psi t + \sigma_{it}$$

Here, we combine the formula of the model 1 and that of model 2 and include some control variables into the models. Iit represents the industry structure, using the share of industry in GDP. $P_{it}$ is population size. $O_{it}$ and $T_{it}$ are trade openness and technology respectively.

# 6. Estimation results

## *6.1 Estimation results for Sulphur dioxide(SO2)*

Table 3

Estimation results for Sulphur dioxide(SO2)

| Variables | Model 1 | Model 2 | Model 3 |
|---|---|---|---|
| lnG | 3.340 | | 6.515 |
| | (6.90) *** | | (12.94) *** |
| $(\ln G)^2$ | -0.150 | | -0.292 |
| | (-10.44) *** | | (-12.14) *** |
| lnU | | 5.998 | 4.306 |
| | | (2.78) ** | (2.19) ** |
| $(\ln U)^2$ | | -0.918 | -0.767 |
| | | (-2.74) ** | (-2.55) ** |
| lnP | | | 1.991 |
| | | | (7.54) *** |
| lnI | | | 0.178 |
| | | | (2.72) *** |
| lnO | | | -0.011 |
| | | | (-0.34) |
| lnT | | | 0.408 |
| | | | (4.56) *** |
| Cons | -15.730 | -6.135 | -5.093 |
| | (-4.31) *** | (-2.00) ** | (-1.59) |
| R Square | 0.9790 | 0.9775 | 0.9964 |
| F Test | 589.51 *** | 364.27*** | 93.43*** |
| Wald test | 6515.07 *** | 8607.77*** | 3.36e+06*** |
| Modified Wald test | 1264.32 *** | 2650.49*** | 1411.71*** |
| Wooldridge test | 53.449 *** | 45.047*** | 35.535*** |
| TP for GDP | 68413 | | 69563 |
| TP for Urban | | 26.24 | 16.54 |

NOTES: *, **, *** denote significance at the 10％, 5％, and 1% level respectively. TP refers to the turning point.

Fixed-effect models with correlated panels corrected standard errors are applied to the three regression models. According to the results of model 1 in table 3, it can be concluded that the GDP per capita has a positive effect on the SO2 emissions and the square GDP per capita negatively affects the SO2 emissions, which is consistent with the EKC hypothesis. Moreover, the effects are statistically significant and the turning point is about RMB 68413 yuan (US $8262 in 2001) per capita. The value is fairly high for the 28 provinces in China, thus most areas presently lie in the early development stage where economic growth brings about more air pollutions. Only Beijing, Tianjin and Shanghai step into the second stage where environment quality improves as the economy is steadily growing.

It is clearly observed from model 2 in table 3 that the positive and negative coefficients of urbanization and the quadratic term in the second model suggest that the inverted U-shaped curve exists, and they are both significant at the 1% level. Moreover, it is interesting to note that the turning point for urbanization is only 26.24%. That is so low that most provinces exceed this threshold in China. Yunnan, Guizhou and Gansu experienced two stages with SO2 emissions increasing and than declining over the decade, and only the urbanization level in Tibet is below 26.24% over the ten years.

In model 3, once we control for urbanization and income levels simultaneously, the sign of the coefficients for GDP per capita and its quadratic term remain the same, although their values have slightly changed. As a result, the EKC hypothesis is confirmed once again. We can calculate the turning point again to examine the EKC theory and specify the relationship between economic growth and air pollution. The turning point for income level correspondingly increases to around 69563 yuan (US $8401 in 2001). That is similar to the value of that point before adding more control variables. Therefore, it may be concluded that only Beijing, Tianjin, Shanghai exceed this point during the decade from 2001 to 2010.

Further, model 3 also convinces us that there is a non-linear relationship between the urbanization level and air pollution. But, the low level of the turning point with respect to urbanization indicates that all the provinces are on the descending portion of the inverted U-shaped curve through observing the dataset used in the paper. In other words, the effect of urbanization on SO2 emissions is significantly negative for all provinces and municipalities in the time period from 2001 to 2010. Moreover, the quadratic form suggests that the pollution-reducing effect of urbanization increases as urbanization proceeds. This is probably attributed to the technology progress during the process of urbanization, or the process of modernization. In fact, recently, more attention is paid to the quality of economic growth rather than the speed or quantity of production in China.

It is clearly observed from the table that the population size and industry structure positively influence SO2 emissions as expected. The negative coefficient of trade openness seems to support the pollution heaven hypothesis across China, whereas the fact that the coefficient of this variable loses its significance provides us an uncertain conclusion about trade openness and SO2 emissions.

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### *6.2 Estimation results for waste gas*

Table 4

Estimation results for waste gas

| Variables | Model 1 | Model 2 | Model 3 |
|---|---|---|---|
| lnG | 3.930 | | 3.840 |
| | (6.58) *** | | (4.72) ** |
| $(lnG)^2$ | -0.157 | | -0.198 |
| | (-5.68) *** | | (-5,10) *** |
| lnU | | -10.614 | -14.089 |
| | | (-7.96) *** | (-8.91) *** |
| $(lnU)^2$ | | 1.727 | 2.130 |
| | | (8.95) *** | (9.41) *** |
| lnP | | | 0.201 |
| | | | (0.46) |
| lnI | | | 0.024 |
| | | | (0.32) |
| lnO | | | -1.76 |
| | | | (-4.29) *** |
| lnT | | | -0.008 |
| | | | (-0.08) |
| Cons | -15.808 | 21.140 | 8.661 |
| | (-4.48) *** | (9.37) *** | (1.15) |
| R Square | 0.9823 | 0.9834 | 0.9990 |
| F Test | 568.30 *** | 340.32*** | 87.75*** |
| Wald test | 15525.97*** | 11002.29*** | 601727.47*** |
| Modified Wald test | 6413.45*** | 9593.19*** | 4554.19*** |
| Wooldridge test | 9.329 *** | 14.021*** | 8.895*** |
| TP for GDP | 272392 | | 16498 |
| TP for Urban | | 21.58 | 27.32 |

NOTES: *, **, *** denote significance at the 10％, 5％, and 1% level respectively. TP refers to the turning point.

To overcome the problem of heteroskedasticity and autocorrelation tested by the Wald test and the Wooldridge test, I still use the fixed-effect models with correlated panels corrected standard errors to regress these three specific models for the estimation of industrial waste gas.

The first model based on the EKC hypothesis gives the results of positive and negative coefficients of GDP per capita and its quadratic term, strongly supporting the existence of the EKC hypothesis. However, it is surprising to get a fairly high turning point of the inverted U-shaped curve. 272392 yuan (US $32897 in 2001) is too high to reach for the 31 provinces and municipalities in China over the ten years from 2001 to 2010.

Differing from the inverted U-shapes curve obtained by SO2 emissions, waste gas follows a U-shaped relationship with the urbanization level according to the model 2 in table 3. This result is gained by the unexpected sign of coefficients of urbanization and it quadratic term, and the effects on the waste gas emissions are significant at the 1% level. Since the estimate of U-shaped curve turning point locates at 21.58% that is relatively low across the 31provinces and municipalities in China, only Tibet stays at the first half curve.

Model 4 further considers the impact of some other explanatory variables on waste gas emissions, which is the preferred one among the three models. The results show that the EKC hypothesis continues to hold for waste gas emissions even though more independent variables are included in the regression model, and only the turning point with respect to income level per capita correspondingly changed. More specifically, waste gas emissions begin to fall along with income level until GDP per capita reaches to 16489 yuan (US$1991 in2001). Only six provinces where the income per capita does not reach this threshold in 2010 are observed in the dataset: Tibet, Gansu, Guangxi, Yunnan, Guizhou and Ningxia. In addition, there is still remarkable evidence on the U-shaped relationship between urbanization level and waste gas emissions. The coefficients of urbanization level and its quadratic term are significantly negative and positive, respectively, and the income turning point increases to 27.32% that lead to different conclusion from model 2. Tibet, Guizhou, Yunnan, Guangxi are on the descending part of the U-shaped curve, while other areas are situated in the increasing curve over the decade from 2001 to 2010.

It must be noticed that some control variables--population size, industry structure and technology--all are in the predicted relationships with the waste gas emissions but non-significant even at the 10% level.

Now, we can focus on the trade openness to test whether the pollution haven exists in this case. Under the pollution haven hypothesis, the effect of international trade should be positive, whereas, it is observed from the table that the coefficient of trade is significant negative. It is likely to be explained by the technology spillover from developed nations to developing nations during the international trade. Foreign trade is confronted with both opportunity and challenge, and in this case technology import appear to dominate environment pollution across some areas in China.

### *6.3 Estimation results for Soot*

Table 5

Estimation results for Soot

| Variables | Model 1 | Model 2 | Model 3 |
|---|---|---|---|
| lnG | 2.498 | | 2.782 |
| | (2.38) *** | | (2.01) ** |
| $(\ln G)^2$ | -0.135 | | -0.144 |
| | (-3.73) *** | | (-2.44) ** |
| lnU | | -0.205 | -3.175 |
| | | (1.00) | (-1.18) |
| $(\ln U)^2$ | | 0.508 | 0.503 |
| | | (-0.81) | (1.24) |
| lnP | | | 0.082 |
| | | | (0.09) |
| lnI | | | 0.207 |
| | | | (2.15) ** |
| lnO | | | -0.021 |
| | | | (-0.38) |
| lnT | | | 0.171 |
| | | | (1.18) |
| Cons | -10.026 | 4.108 | -8.018 |
| | (-1.39) | (0.81) | (-0.53) |
| R Square | 0.9575 | 0.9567 | 0.9882 |
| F Test | 254.79*** | 144.30*** | 40.85*** |
| Wald test | 1458.14*** | 2026.97*** | 139997.24*** |
| Modified Wald test | 817.78*** | 568.03*** | 1551.69*** |
| Wooldridge test | 9.314 *** | 9.801*** | 9.596*** |
| TP for GDP | 10276 | | 15693 |
| TP for Urban | | | |

NOTES: *, **, *** denote significance at the 10％, 5％, and 1% level respectively. TP refers to the turning point.

The EKC hypothesis is confirmed once again due to the presence of positive and negative coefficients in the first model. And both of the variables perform efficiently even at the 1% significant level. According to the table, it is calculated that the turning point of the inverted U-shaped curve is located at RMB 10276 yuan (US$1241 in 2001). We can observe from the panel dataset that soot emissions in a majority of provinces experience two stages, firstly increasing and then decreasing along with income per capita. However, the three municipalities, Beijing ,Tianjin and Shanghai are located on the decreasing portion from 2001 due to the high level of economic growth. In contrast, for Tibet, the GDP per capita is below the thresholds until 2010.

The non-significant coefficients of urbanization level and its quadratic term show that the effect of urbanization level on soot emissions is not relevant, although the opposite sign of coefficients is a strong evidence for non-linear link. We need to further consider the estimation result after including other control variables to decide how the urbanization level affects the air pollution.

Model 3 of table 5 extends the regression model on all the variables to make the estimation results more convincing in terms of income-environment relationship and urbanization-environment relationships. It is interesting to note that only three independent variables now have explanatory power at the 5% significant level. Apparently, even though more control variables are included, the inverted relationship between the economic growth and soot emissions is robust. The turning point grows up to 15693 yuan (US$1895 in 2001), and the same conclusion associated with the threshold can be derived from model 1.

The main difference between models 1 and 3 is how the industry structure plays a role in the air pollution. Actually, industry structure is a very important factor affecting the air pollution because the industry activities mostly depend on the coal, a fuel that is the source of soot.

*6.4 Estimation results for dust*

Table 6

Estimation results for dust

| Variables | Model 1 | Model 2 | Model 3 |
|---|---|---|---|
| lnG | -0.269 | | 1.400 |
| | (-0.24) | | (1.48) |
| $(lnG)^2$ | 0.031 | | -0.080 |
| | (0.74) | | (0.024) ** |
| lnU | | -3.16 | -5.071 |
| | | (-1.19) | (0.016) ** |
| $(lnU)^2$ | | 0.413 | 0.645 |
| | | (1.02) | (2.06) ** |
| lnP | | | 1.261 |
| | | | (3.36) *** |
| lnI | | | 0.163 |
| | | | (1.16) |
| lnO | | | -0.232 |
| | | | (-3.77) *** |
| lnT | | | 0.276 |
| | | | (2.07) ** |
| Cons | 0.520 | 6.889 | -4.239 |
| | (0.944) | (1.77) | (-0.43) |
| R Square | 0.9634 | 0.9658 | 0.9832 |
| F Test | 359.05 *** | 270.87*** | 37.84*** |
| Wald test | 5645.80*** | 8523.02*** | 4268.48*** |
| Modified Wald test | 2050.46*** | 2484.51*** | 2681.38*** |
| Wooldridge test | 28.642 *** | 28.416*** | 28.571*** |
| TP for GDP | | | |
| TP for Urban | | | 50.90 |

NOTES: *, **, *** denote significance at the 10％, 5％, and 1% level respectively. TP refers to the turning point.

We get surprising results from model 1 and 2, and non-significant estimator barely provides us convincing conclusion, although the opposite sign of coefficients for the regular term and its quadratic terms indicates a non-linear relationship. It is a really special case. However, the third model yields more meaningful results according to the table.

The sign of coefficient for GDP and its quadratic term changed after including the control variables, but the coefficients remain non-significant even at 10% level. My finding is consistent with that of Shen (2006) who gives support for water pollutants but not for dust in terms of EKC hypothesis. He also uses the Chinese provincial-level data to investgate the relationship between income level and environmental pollution.

The link of urbanization level to dust emissions is non-linear, with negative estimator for urbanization level and positive one for its quadratic term. But, the increasing curve does not occur until the urbanization level reaches to 50.90% that is relatively high for lots of provinces, i.e. Fujian, Anhui, Hebei. The unexpected U-shaped relationship between the urbanization and dust emissions is difficult to explain, whereas I think it can be explained by urban carry capacity. That means there is a maximum number of individual accommodated in a city without destroying the environment for future generation. It is likely that 50.90% is an ideal urban population share to control effectively industrial dust emissions. Once the urban population exceeds this threshold, a growing size of population will pose a disadvantage on the air quality regardless of more technology applications. Similarly, the significantly positive effect of aggregated population on the dust pollution is shown in model 3.

Model 3 also presents an interesting result in terms of trade openness. The negative estimator for trade openness is somewhat unexpected but can be explained by technology spillover like I mentioned above. The pollution haven hypothesis is strongly rejected once again under the case of industrial dust.

*6.5 Discussion*

It is worthy and interesting to compare my results with some previous studies. We begin with the EKC hypothesis that is confirmed by a large number of researchers. Most of them provide us with strong empirical evidence for the inverted U-shaped relationship between economic growth and air pollution, supporting the existence of the EKC hypothesis. The main difference among these researches is the turning point of the inverted U-shaped curve. It is the turning point that determines when the provinces have access to the decreasing curve along with the economic growth. Dong (2010) believes that the turning point is RMB $3.4\times10^4$ yuan (US$4106 in 2001) for industrial waste gas emissions. This amont is much higher than 16498 yuan (US$1992 in 2001) than my results.

In terms of SO2 emissions, I get the turning point of RMB 69563 yuan (US$8401 in 2001) that is unexpectedly high compared to RMB 17293 yuan (US$2088 in 2001) obtained in the empirical study of Shaw and Pang (2010). Why does the turning points vary so much? As far as I am concerned, this is probably attributed to the different time periods, estimation strategy and the purpose of research.

Next, let me turn to the effect of urbanization on air pollution. Du and Liu (2008) found an inverted U-shaped relationship between urbanization level and SO2 emissions that is an opposite curve compared to my results. The main reason leads to the different results seems to be the inclusion of different control variables.

The pollution haven hypothesis is also rejected by Du and Liu (2008) who asserts that international trade potentially brings about more high technology instead of air pollution.

## 7. Conclusion

In this paper, I attempt to investigate the relationship between economic growth, urbanization level and air pollution, based on province-level panel data over the time period 2001 to 2010 in China. Four categories of air emissions are used in the empirical study: industrial waste gas, sulfur dioxide, dust and soot.

Firstly, an inverted U-shaped relationship between economic growth and air pollution is strongly verified in the cases of industrial waste gas, sulfur dioxide and soot, suggesting the existence of the EKC hypothesis across the 27 provinces and 4 municipalities in China. However, my finding shows that the specific income-pollution relations dramatically differ among the three types of pollutants, with SO2 emissions steadily increasing while waste gas emissions declining along with economic growth, because the turning points vary among air pollutants.

Next, our estimation results indicate that there is a non-linear relationship between urbanization level and air pollution, but it does not exist as an expected inverted U-shaped curve. Moreover, the low level of turning points make most of provinces have access to the increasing curve along with the urbanization level. Therefore, we can say the concentration of population in the urban areas positively influences the air pollution over the decade from 2001 to 2010.

Furthermore, after some other control variables are included in the model, the relationships changed Slightly. The EKC curve and non-linear relationship between the urbanization and air pollution continue to exist，and the main difference is the turning point. As a result, we can acknowledge that control variables, including population size, industry structure, trade openness and technology, play important roles in the air pollution by themselves, and, meanwhile, they make a difference in terms of the relationship between economic growth, urbanization level and air pollution.

These conclusions have some significant implications in reality for China, and some measures should be taken to protect air quality and improve economic development.

At first, more attention should be paid to speeding up technology progress instead of slowing down the economic growth. It is unlikely to impose a restriction on the economic improvement in China, because economic development still remains a priority in China. For instance, using cleaner fuel and improving the efficiency of energy use will be greatly helpful to limit air pollution. Likewise, controlling population size in the urban areas is not a wise choice, and, recently, more effort should be made to improve the quality of urbanization rather than the speed of it. At the same time, it will be helpful to encourage foreign investment and give the priority to introduce overseas advanced technology instead of promoting economy at cost of environment during the process of trade openness across 31 provinces and municipalities in China.

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