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# Economic Structure, Development Policy and Environmental Quality

## An Empirical Analysis of Environmental Kuznets Curves with Chinese Municipal Data

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## Abstract

In many cases, the relationship between environmental pollution and economic development can be generally depicted by an inverted U-shaped curve, or an environmental Kuznets curve, where pollution increases with income at the beginning and decreases after a certain level of income. However, what determine the shape of an enviornmental Kuznets curve, such as the height and the turning point of the curve, have not been thoroughly studied. A good understanding of the determinants is vitally important to the development community, especially for the developing world, where income growth is a high priority and yet environmental pollution also needs to be carefully controlled. This study analyzes the impacts of economic structure, development strategy and environmental regulation on the shape of the environmental Kuznets curve with a city-level panel dataset obtained from China. The results show that economic structure, development strategy and environmental regulation can all have important implications on the relationship between environmental environmental quality and economic development but the impacts can be different at different development stages.


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# Economic Structure, Development Policy and Environmental Quality: An Empirical Analysis of Environmental Kuznets Curves with Chinese Municipal Data[1]

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## 1. Introduction

Since Grossman and Krueger (1991) and Shafik and Bandyopadhyay (1992) reported inverted U-shaped pollution-income relationships, research on the hypothesis of an Environmental Kuznets Curve (EKC) has been extensively conducted.[2] There is a good theoretical argument for the potential existence of EKC. Even though pollution reduction mechanisms can be different in different areas, the final pollution levels should be the results of trade-offs between decreasing marginal utility of consumption and increasing disutility of pollution that are associated with economic growth. Once the income reaches a certain level, the marginal disutility from pollution will surpass the marginal utility from consumption, and it is necessary to spend more resources on pollution abatement in order to maximize the utility. From then on, a dichotomy between pollution and income growth becomes possible.

Extensive empirical studies have also been conducted on the relationship between pollution and income. These studies, however, have faced a number of strong critics. The first group of critics is related to the empirical estimation strategy. Although the EKC theory describes essentially a dynamic path for a single economy's environmental quality and economic growth, most of the empirical EKC analyses have used cross-country data, implicitly assuming that the countries included in the sample follow the same pollution-income trajectories. However, the inverted-U relationship between pollution and income estimated from cross country data should not hold for specific individual countries. The often observed great sensitivities of EKC shapes with respect to time periods, country samples and functional forms also casted doubt on the appropriateness of using cross-country EKC to interpret the pollution-income relationship for an individual country.[3]

The second group of critics concerns the policy implications of EKC analyses. Most EKC studies have only described reduced-forms of the relationship between pollution and income. The different shapes of EKC found in the past can only capture the 'net effects' of income on environment, where "income growth is used as an omnibus variable representing a variety of underlying influences, whose separate effects are obscured" (Panayotou, 2003), and therefore no clear development policy implications can be directly drawn from the estimated coefficients of the polynomial income terms.

In response to the first group of critics, a small body of research has focused on country-specific EKC estimations, including Roca et al (2001) on $CO_2$, $SO_2$ and $NO_X$ emission in Spain (1973-1996), Friedl and Getzner (2003) on $CO_2$ emission in Austria (1960-1999), and Lindmark (2002) on $CO_2$ emission in Sweden (1870-1997). Several studies, like Vincent (1997) on Malaysia, Auffhammer (2002), de Groot et al (2004) and He (2009) on China, used province-level panel data in their EKC estimations; others, like Millimet et al. (2003) and Roy et al. (2004), used the US state-level data and tested the EKC hypothesis by employing the

[2] For comprehensive discussions, see Stern (2004), Dinda (2004), Dasgupta et al. (2002) and He (2007).

[3] Harbaugh et al. (2002) used the same estimation functional form and the same database as Grossman and Krueger (GK 1991). While GK (1991) confirmed the N-shape relationship, Harbaugh et al. (2000), by extending the database for another 10 years, found the estimated pollution-income relationship to become an inverted-S shape. Using only the 22 OECD countries' data, Selden and Song (1994) found an EKC with a turning point ranged at $8000-$10000. Stern and Common (2001) enlarged the database and found that the "turning point (of the EKC) becomes quite higher when the data of developing countries are included or separately estimated". The two studies based on US state-level data (Carson et al, 1997; List and Gallet, 1999) and the other two studies focusing on part of OECD and developing countries (Cole et al. 1997; Kaufman et al., 1998) also have similar findings.

non-parametric method. These studies indicated that the shape of the inverted-U form relationship between pollution and income could be attributed to technical progress, output mix changes, and variations in foreign trade and/or external shocks like oil crisis, which happened during the period of investigation.

Another body of research, while still using international or regional panel data, employed a multi-function system estimation approach which permits attributing country-specific random coefficients to the income and squared income terms (List and Gallet, 1999; Koope and Tole, 1999 and Halkos, 2003), in response to the first group of critics. These studies revealed remarkable differences between countries (or states) in their EKC forms and turning points. However, due to the complexity of this estimation method, these studies did not analyze the influence of country- or region-specific characteristics in the country- or region-specific EKC coefficients. Only some simple discussions can be made on the relationships between certain structural, population and geographical characteristics of an economy after the turning point of each different economy had been calculated from the country-specific random coefficients (List and Gallet, 1999).

Research efforts have also been made in response to the second group of critics. Height-adjustments have been widely made to the basic EKC model and can provide policy implications on pollution control. These adjustments accept the inverted U curve as an artifact for a dynamic pollution-income relationship of a single economy but suspect the credibility of a simple extrapolation from the international experiences to an individual country's dynamic process, given the heterogeneous structural and technical characters between the countries. The original reduced-form EKC is then added with other pollution determining factors, such as industrial structure, technical progress, openness degree, income distribution, population density, and political and institutional development, etc.[4] These efforts succeed in distinguishing part of the pollution variations from the income changes and providing some policy suggestions. But the characteristic variables included in the models can only switch the EKC up or down, leaving the turning points and the basic forms of EKC curves solely determined by income variation.

A small number of studies have also tried to make slope-adjustments to the basic EKC model. These studies use multiplicative terms of per capita income with other characteristic variables in EKC estimations. By doing so, the influences of characteristic variables on EKC shapes can be directly captured by the coefficients of the multiplicative terms. The first of such studies can be found in Panayotou (1997), in which the author included economic growth rate, environmental policy indicators and their multiplicative terms with income into the estimation of EKC. Antweiler et al (2001) employed multiplicative terms of openness degree with income in their pollution determinant analysis. Arcand et al (2008) employed a multiplicative term in their deforestation EKC estimation to identify the total marginal impact of the real exchange rate on deforestation. Merlevede et al (2006) added firm size as a determinant of the coefficient of income and found that firm size matters but not in a linear way: countries with bigger firms generally experience higher levels of environmental degradation than those with small firms, but only in the initial stage of economic development.

This study provides further analyses on the multiplicative EKC model with both height and slope adjustments to the basic EKC and conducted empirical estimations with Chinese

[4] Surveys on other pollution determinants included into EKC analyses can be found in Dinda (2004) and Stern (2004).

data. The determinants of EKC shapes are empirically analyzed with the multiplicative EKC models with which economic structure, development strategy and environmental regulation are considered as the determinants of both the height and the slope of EKCs. The multiplicative EKC models are estimated with a panel database of 74 Chinese cities during the period of 1991-2001. Included in the analyses are three most important pollutants in the air in China: Total Suspending Particle (TSP), Sulfur Dioxide ($SO_2$) and Nitrogen Oxide ($NO_x$). The results confirm in general a better estimation efficiency of the multiplicative EKC model and demonstrate the significant impacts of economic structure, development policy as well as environmental regulation on the relationship of pollution and income. This implies that while income growth in the long run can help reduce pollution, adjustments in economic structure, development strategy and environmental regulation in right directions can also play active roles in reducing pollution.

This paper is organized as follows. In the next section we provide an overview of the multiplicative EKC models and present the empirical models that are used in our analyses. The data and the results of the study are presented in section 3 and 4. Section 5 concludes the paper.

## 2. The Models

### *2.1 The Basic Model*

Following Panayotou (1997) and other studies, a conventional EKC model can be specified as follows:

$$E_{it}=a_0Y_{it}+b_0Y_{it}^2+Z_{k\,it}'c_k+u_i+\varepsilon_{it} \qquad (1)$$

where $E_{it}$ is a pollution indicator, such as concentration of a pollutant in the air; $Y_{it}$ is per capita income; $Z_{kit}$ are a set of control variables; a, b and c are parameters. Subscript i and t represent the economy and the time in consideration, and subscript k represents the k*th* control variable and takes numbers from 1 to K; $u$ and $\varepsilon$ are random error terms.

The control variables, $Z_{kit}$, are usually location specific and exogenous at least economically, and in our analyses they include geographical location dummies (*north:* 1=northern cities and 0=southern cities, divided by the Yangzi River; *coastal: 1*=coastal cities and 0=inland cities), population density[5] (*popden)* and land area [6](*area*).

### *2.2 The Height Adjustment*

A height-adjustment EKC model can be developed by adding relevant policy variables into the constant term of the basic EKC model (1), similar to the set of control variables ($Z_{kit}$). The height-adjustment EKC model in our study has the following functional form:

[5] As did in Shukla and Parikh (1996), Vincent (1997), Taskin and Zaim (2000), Selden and Song (1994), and Cropper and Griffith (1994).

[6] This variable can help analyze how the geographical spreading of the cities influences their environmental qualities.

$$E_{it}=a_0Y_{it}+b_0Y_{it}^2+c_1S_{it}+c_2R_{it}+c_3Open_{it}+ c_4(Open_{it}\times S_{it}) +c_5(Open_{it}\times R_{it})+Z_{k\,it}'c_k +u_i+\varepsilon_{it} \quad (2)$$

where $S_{it}$ stands for structure of an economy, $R_{it}$ for strictness of environmental regulation, and $Open_{it}$ for openness degree of an economy.

The selection of these variables is based upon previous studies, data availability as well as modeling consideration such as the multicollinearity concern. These variables were called as structural determinants of EKC in several previous studies (Grossman, 1995; Antweiler et al. 2001; He, 2009; etc.). According to Grossman (1995)'s decomposition analyses, pollution from an economy, when considered as a by-product of the productive activities, is determined by the scale effect, composition effect and technique effect of the economy. The scale effect is expected to be a pollution-increasing factor - "All else equal, an increase in output means a proportionate increase in pollution" (Grossman, 1995). The composition effect measures the influence on emission of a change in the structure of economic activities. All else equal, if the sectors with high emission intensities grow faster than the sectors with low emission intensities, the composition change will result in an increase in pollution. The technique effect measures the influences from the technical progress on pollution. The decrease in sector emission intensities, as a result of the use of more efficient production and abatement technologies, can reduce the total emission and therefore improve the environmental quality. Because of the close correlation between the scale effect and income, only the composition effect and the technique effect are included in our models.

Economic structure, denoted as $S_{it}$ in the EKC model (2) and corresponding to the composition of an economy, is very often measured by capital-abundance ratio $(K/L)_{it}$ (e.g., Copeland and Taylor, 1994 and 1997; Antweiler et al. 2001; Cole et al., 2003; Cole and Elliott, 2003 and He, 2009), and we use the same measurement in this study. A sector where the production procedure uses capital more intensively may have more pollution problems, and therefore a positive effect of this variable on the EKC shape is expected.

The role of environmental regulation ($R_{it}$) on EKC has been analyzed in the literature (Shafik, 1994; Baldwin, 1995). Environmental regulation can be significantly correlated with income (Wang and Wheeler, 2003 and 2005). In order to reduce the potential collinearity between environmental regulation and income in estimating our EKC models, we choose the percentage of environmental staff over total government staff as an approximation to the relative strictness of environmental regulation.[7] In China, municipal governments are not responsible for making environmental regulations but enforcing them. The differences in the strictness of environmental regulations in different municipalities mostly come from local enforcement (Wang and Wheeler, 2005). We therefore expect an environment-improving effect on EKC shape of environmental regulation.

Antweilet et al. (2001) further analyzed the decomposition idea through a general equilibrium model and identified the interactive role of the international trade with both the structural and technique effects. Their model suggests that international trade can actually affect emission of an economy from two aspects. Taking the example of China, on one hand, the "pollution haven" hypothesis suggests China to specialize in some pollution-intensive industries; on the other hand, considering China's extremely rich endowment in labor forces, traditional comparative advantage hypothesis also suggests its industrial structure to specialize in the less-polluting labor-intensive industries. The total effect of trade on environment in China actually depends on the relative forces between its factor endowment,

[7] We also tried to use the number of environmental staff per enterprise at the provincial level as a proxy of environmental regulation. The results are similar but less statistically significant.

also measured by $(K/L)_{jt}$, and its environmental regulation strictness. To capture the impact of trade on pollution, Antweilet et al. (2001) added three groups of openness related variables into the EKC models, which include the simple trade openness variable (to capture the direct impact of trade on environment), the multiplicative term of trade variable with the capital-labor abundance ratio $(K/L)_{jt}$ and the multiplicative term of trade variable with environmental regulation strictness (to capture the force-contrast between the pollution-haven-based and the traditional factor-endowment-based comparative advantages and their impacts on environment.

The openness degree is often measured as trade intensity in the literature, which is equal to the ratio of total export and import over total GDP. We use $Open_{it}$ to mention it in our EKC models. Unfortunately, the direct city-level export and import statistics are not available for the study period.[8] However, foreign direct investment (FDI) can be an important explanation for the fast development of China's export activities. This can be especially true during our study period of 1991-2001. During this period, attracted by China's export-promotion FDI strategies and cheap labor-force pool, the export-oriented capital from Hong Kong (SAR China) and Taiwan (China) became the most important foreign capital source for the Chinese mainland economy (Zhang, 2005). Branstetter and Lardy (2006) also pointed out that the "most exports of electronic and information products are assembled not by Chinese owned firms but by foreign firms that are using China as an export platform."[9] Considering the close relationship between FDI entry and China's export performance, we decided to use the ratio of capital stock of foreign direct investment in the total capital stock of each city to measure each city's degree of openness.

### *2.3 The Slope Adjustment*

A multiplicative EKC model can be developed by simply extending the height-augmented EKC model to include the slope-adjustment variables. While it is not feasible to include multiplicative terms for all potential policy-relevant variables in the EKC model, due to the potential strong collinearity, we only include the multiplicative terms for the first-order income variable[10]. The final multiplicative EKC model used in our estimation is as follows:

$$E_{it}=a_0Y_{it}+b_0Y_{it}^2 + Z_{k\,it}'c_k + u_i + \varepsilon_{it} \qquad \text{(Conventional EKC)}$$

$$+c_1S_{it}+c_2R_{it}+c_3Open_{it}+c_4(Open_{it}\times S_{it}) + c_5(Open_{it}\times R_{it}) \qquad \text{(Height-adjustment)}$$

$$+[a_1S_{it}+a_2R_{it} + a_3Open_{it}+a_4(Open_{it}\times S_{it})+a_5(Open_{it}\times R_{it})]Y_{it} \qquad \text{(Slope-adjustment)} \; (3).$$

The relationship of pollution $E_{it}$ with income $Y_{it}$ can be viewed as having three components: a conventional EKC, the height-adjustment terms and the slope-adjustment terms. The conventional EKC part simply records the general correlation between income and pollution which is common to all cities. Both the height- and slope-adjustment components provide adjustments in the shape of EKC of an individual city to the common correlation.

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[8] Some city-level export and import data can be found in the China Urban Statistic Yearbook only after 1999.

[9] Surely the situation has largely changed later on, more and more foreign capitals entering into China are searching for China's huge domestic market. As Zhang (2005) indicated, as China's domestic markets become more open to foreign investors, the share of Hong Kong and Taiwan investment may shrink and the importance of FDI from the EU, United States and Japan may rise.

[10] We thank one anonymous referee for the suggestion.

The derivative of pollution $E_{it}$ with respect to income $Y_{it}$ can be written as,

$$\partial E_{it}/\partial Y_{it}=a_0+ a_1S_{it}+ a_2R_{it} +a_3Open_{it}+ a_4(Open_{it}\times S_{it})+a_5(Open_{it}\times R_{it})+2b_0Y_{it} \qquad (4)$$

Equation (4) shows that the slope of EKC can be affected by those structure and policy variables and is time and city specific. Because the sign, either positive or negative, and the magnitude of the slope gives the direction of movement of a city along an EKC, estimations and analyses of equation (4) can directly provide policy suggestions. For example, as shown in equation (4), if the coefficient $a_1$ is positive, an increase in the value of S for a particular city i at a particular year t may bend the EKC upwards, and therefore policies may need to be developed to reduce the value of S. If the coefficient $a_2$ is negative, a reinforcement in environmental regulation for city i at year t may bend the EKC downwards, and an increase in the value of R is desired. Because of the existence of the multiplicative terms of S and R with openness degree, the final impacts of these two variables will also depend on the coefficients $a_4$ and $a_5$ as well as the value of openness degree.

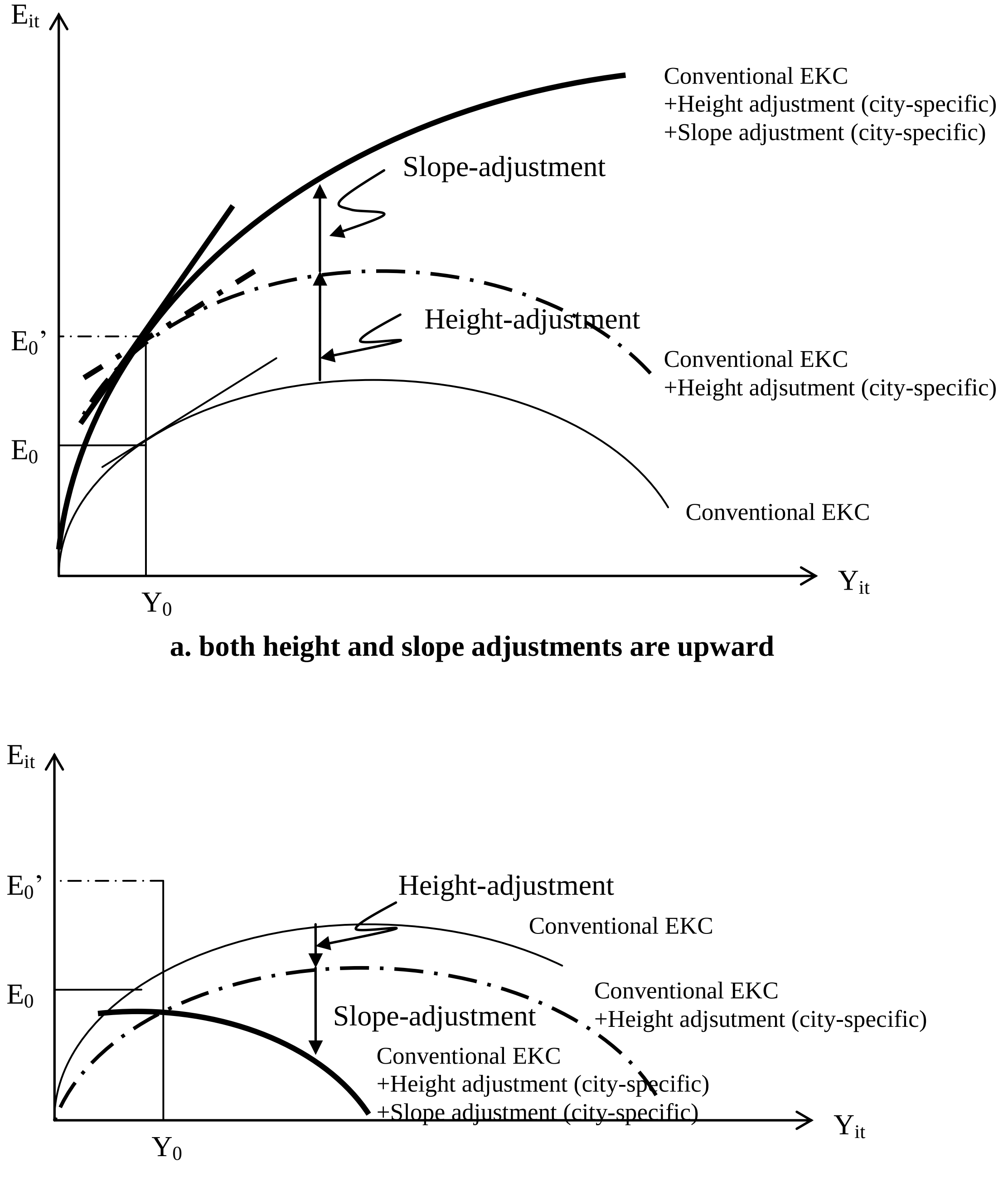
The turning points of EKCs can also be estimated and simulated by putting a value of zero to the slope equation. As shown in equation (4), the turning points are also affected by those structure and policy variables. It is also worthy to note that the pollution-income trajectory of each city is path-dependant, and the trajectories can be adjusted through reforming the economic structure, development strategy or environmental regulation. As one can see from equation (4), if two cities start from the same levels of pollution and income and if they have different economic structures, levels of environmental regulation or openness degrees, their EKC trajectories can be totally different. This is because each year these structure and policy variables change the EKC trend of a particular city, and in the following year, the new adjustment will be added to the results of the previous years.

In this study, with the empirical results of equation (3), simulations are conducted to assess both the overall impacts of the structure and policy variables on an EKC and the EKC trends of a few representative cities in China.

*2.4 The Relations of the EKC Models*

The relationship between conventional EKC, height-adjusted EKC and slope-adjusted EKC can be illustrated as in Figure 1. In figure 1, in each of the two panels, three EKC models are illustrated: the conventional EKC, height-adjusted EKC, and height- and slope-adjusted EKC. At income level of $Y_0$, on the conventional EKC, the pollution level is $E_0$, but the height-adjustment, which is city-specific, makes the height of EKC to $E_0$'. If the slope-adjustment effect is included, the EKC shape will be changed to a final city-specific one. Both the height and slope adjustments can be upward or downward. In panel a of the figure, we illustrate the situations where both slope and height adjustments to the conventional EKC are upwards (i.e. worse environmental situation) and in panel b, both slope and height adjustments are downward (i.e., better environmental situation). Surely, it is also possible that upward (downward) slope adjustment can be combined with downward (upward) height adjustment.

**Figure 1. From conventional EKC to individual pollution-income nexus**




**a. both height and slope adjustments are upward**



**b. both height and slope adjustments are downward**

## 3. Data

A panel database of 74 Chinese cities for the period of 1990-2001 is compiled in order to assess the impacts of economic structure and development policy on the relationship of pollution and economic growth in China and empirically analyze the multiplicative EKC models. Collection of city-level air quality data in China began in the 1980s when the Global Environmental Monitoring System (GEMS) started its cooperation with China's Ministry of

Health (MOH)[11]. Up to 2002, local environmental monitoring stations have been set up in almost all of the cities. In the officially published *China Environmental Yearbook*, over 90 of the largest cities have their annual daily average concentration of $SO_2$, $NO_x$ and TSP systematically reported since 1990. Our analyses will be based on the annual average air pollution concentration data published in China Environmental Yearbooks and China Environmental Statistical Yearbooks (various issues). City-level data of per capita income and other structural characteristics come from China Urban Statistical Yearbooks and China Statistical Yearbooks.

Choosing Chinese city-level air pollution concentration data to carry out our analyses has several merits: First, China is the world's largest developing country. A better understanding of the relationship between development and environment in China itself has significant policy implications. China's economic growth benefited principally from its rapid industrialization and urbanization process during the last 30 years. However the serious air pollution problem in the urban area has become a heavy burden for future industrialization and urbanization for this big country, which still has 70% of its population living in its rural area. In terms of air quality, it is reported that 16 out of 20 world's worst polluted cities are located in China (Blacksmith Institute, 2007). Diagnosing the underlying structural and institutional determinants of pollution can provide policy suggestions for sustaining its rapid economic development. In the meanwhile, for those developing countries which want to follow Chinese economic growth strategy, lessons obtained by Chinese EKC analyses can also be beneficial.

Secondly, China's unified national statistical system promises data with comparable quality on both pollution and economic variables for different cities, while international studies usually suffer from data incoherence problems between different countries. Thirdly, the use of pollution concentrations as environmental quality indicators has advantages over the use of emission information, because emission is more distant from environmental quality. Moreover, as TSP, $SO_2$ and $NO_x$ are conventional pollutants, the results of our analyses can be easily compared with those in the existing literature, such as Grossman and Krueger (1994), List and Gallet (1999), Antweiler et al. (2001) and Milimet et al (2003), where the city-level $SO_2$ and $NO_x$ concentrations were analyzed.

However, we also observe some instability and revision in Chinese urban economic statistics. Most of these problems come from the fact that the territories of the cities experienced some changes during the period of our study. Fortunately, the territory changes happened to the cities included in our study are all city-enlargement in which the smaller satellite towns around the cities were officially included as city districts. Therefore, to keep the statistics coherent during the time period, we add up the original economic statistics of the satellite towns to their associated agglomeration centers for all the years before the enlargement.

The statistics of the variables used in our estimations are reported in Table 1. From this table we can observe large disparities between the cities, not only in their income level, economic structure, environmental regulation strictness and openness degree, but also in their air pollution situation.

<Insert Table 1 about here>

[11] The environmental monitoring responsibility was fully transferred to China State Environmental Protection Administration (SEPA) in 1993.

## 4. Results

In tables 2-4 we report the estimation results of the basic EKC model, the height-adjustment model and the full model. In table 2 we summarize the results for NOx, table 3 for $SO_{2,}$ and table 4 for TSP[12]. In each table, the first two columns provide the results of both fixed and random effect estimation of the basic EKC model, where only income terms are included. The following two columns report the estimation results of the height-adjustment EKC, and the last two columns report the estimation results of the full model.

< Insert Table 2-4 about here>

For each pollutant, as expected, with the inclusion of additional structural variables, the explanation power of the model increases significantly. The adjusted R-squared increases from 0.02 for the basic model to 0.50 for the full model with the random effect estimation technique. Also as expected, the significance of the linear income terms is getting lower while additional structure variables, and especially the multiplicative terms, are included.

In tables 2-4, one can also find that environmental quality improvement is associated with time, which is indicated by the significant, negative coefficients of the variable *Year*. Higher population density (*popden*) seems positively correlated with the height of EKC. Northern and inland cities generally have more air pollution problems, particularly for the cases of NOx and TSP. The estimation results also suggest that the cities with larger total land area have more serious air pollution problems. All of these findings are reasonable ones.

Comparisons between the height-adjustment and the full EKC models give interesting findings. For the case of NOx concentration, the adjustment effects of openness degree and economic structure are statistically more significant in the height-adjustment model than that in the full model. The cases of SO2 and TSP are totally different: the statistically significant coefficients for these two variables appear only after their multiplicative terms with per capita income are included into the full-model estimation. For environmental regulation, we find significant impacts for all three pollutants.

In order to have an overall and visual comprehension on how the economic structure, openness and environmental regulation affect the shapes of EKC, three sets of EKCs are drawn for each of the pollutants and are presented in Figures 2, 3 and 4. For each of the curves, the pollution-income relationship is simulated while all other variables are kept at the mean values of the sample except for the variable under investigation, which takes the values of the mean value, the 15 percentile (15%), the median (50%) and the 85 percentile (85%) of the sample.

< Insert Figures 2-4 here>

Figure 2 depicts the adjustment effects of the three factors studied in this paper on the EKC of NOx concentration. The mean EKC is simulated by fixing the values of the height- and slope-adjustment factors at their sample mean levels. We can see from the figures that the relationship between NOx concentration and income stays as a positive one. The first panel of Figure 2 indicates that the higher the capital abundance ratio, the lower the NOx

[12] For each pollutant, the choice of cubic or quadratic model is made based on the estimation results.

concentration. This might be explained by the fact that many capital intensive sectors are also clean sectors (Dinda et al, 2000). For the case of environmental regulation, its impact on EKC changes its sign after the per capita GDP equals 3000 yuan. Given that only 13.5% of observations have an income lower than 3000 yuan and that most of these observations are from early 1990s, we believe that in general a stricter environmental regulation leads to a lower NOx concentration level. The openness degree also shows its impact change after the income level gets to 2200 yuan. We can generally say that the higher the openness degree, the higher the NOx concentration after income reaches to a certain level Another interesting finding is that in general the shape-adjustment effects of the three factors increase with income, which is indicated by the increasing gaps between the simulated curves and the initial mean curve.

Different results are found in the case of SO2 (see figure 3). For the economic structural measurement, capital abundance ratio has a negative correlation with SO2 concentration first and then the correlation becomes positive after the income reaches to the level of 8150 yuan. This finding echoes with the previous empirical findings about the ambiguity of the capital-abundance ratio as a structural measure of environmental performance for an economy. The impact of environmental regulation on SO2 concentration becomes negative after the income reaches to 4900 yuan. About 40% of the observations in our sample have an income level lower than 4900 yuan. A possible explanation for this correlation is the potential correlation between environmental regulation and income growth, which makes the possibility of having a stricter environmental regulation less effective on SO2 emission for lower income areas (Wang and Wheeler, 2003 and 2005). Another finding is that the openness degree is positively correlated with SO2 concentration and the adjustment effect of openness degree shrinks with income in the case of SO2 concentration, which is different from the case of NOx.

For the case of TSP, environmental regulation seems to have a slight pollution reduction effect only when income is higher than 4900 yuan (see figure 4). Both the capital-abundance ratio and the openness-degree are pollution increasing factors, and the increases move the EKCs upwards. Moreover, the higher the income, the larger changes the curves will have.

Comparing the curves over all three pollutants in Figures 2-4, we observe consistent positive impacts of openness degree on pollution concentration. The impacts of environmental regulation become favorable only after income reaches to a certain level, but in general, environmental regulation helped reduce pollution. For the environmental implications of capital-abundance ratio, they are favorable for NOx and unfavorable for TSP in general, and favorable for SO2 in low income areas and unfavorable for SO2 in high income areas.

The empirical results presented in tables 2-4 can not only be employed to illustrate how the structural variables affected the pollution-income trajectories in different cities in the past, such as the analyses presented in Figures 2-4, but can also be used to analyze the future directions of the trajectories for each pollutant in each city. Presented in table 5 are a few examples of such analyses. The analyses are based on the slope changes, i.e. the derivatives of the pollution concentration with respect to income. If a slope is positive, the pollution-income trajectory is increasing; if it is negative, the trajectory is decreasing. For a normal EKC, the slope should be positive at the beginning, become zero at the turning point, and be negative after income passes the turning point. The results presented in table 5 are the EKC slopes of NOx, SO2 and TSP for four cities in different years. The four cities selected are Chengdu, Dalian, Nanning and Zhengzhou, where the slopes of TSP curves changed from positive to negative.[13] The slopes are projected for each of the four cities with a 10% increase in one of the structure and policy variables – K/L, openness degree and environmental regulation, from the year of 2001, while other variables are kept at the level of 2001. We can see that the slopes are in general sensitive to the structure and policy changes. The slope-adjustment sensitivities of K/L ratio and environmental regulation are stronger than that of openness degree.

## 5. Discussion and Conclusion

Although widely studied from both theoretical and empirical perspectives, the intensive debates on Environmental Kuznets Curve (EKC) in the past decade generated more noises than answers. While the theoretical analyses can predict an inverted U curve for the dynamic relationship between pollution and income, they do not suggest a one-form-fit-all curve for the economies with different structural, technical or institutional arrangements. Researchers observed, suspected, and criticized the great sensitivity of the estimated EKC with cross-country data to the assumption of the functional forms. It is clear that the country-specific dynamic pollution-income trajectories projected from theoretical analyses should be different from the EKCs obtained from cross-country experiences. Recognizing this problem, many researchers tended to discard the EKC obtained from cross-country experiences and to focus on country-specific analyses. However, facing data availability constraints, these analyses can only be carried out in several developed countries. Their historical experiences, while certainly not optimal, offer very little implications for the developing countries, where the ways of economic growth in the future will have important strategic meanings for the global environment.

In this paper, we propose a comprehensive, multiplicative EKC model with which economy-specific structural and policy variables can be integrated into the analyses of pollution-income trajectories with cross-economy data. Comparing to the basic EKC model, the multiplicative model in general has a better explanation power with a higher flexibility in simulating an economy-specific dynamic pollution-income relationship. The direct inclusion of economic and policy characters into the estimation of pollution-income relationship can also help turn the simple coefficients into policy suggestions.

This study emprically estimated a set of multiplicative EKC models for three conventional air pollutants: NOx, SO2 and TSP, by using data from 74 Chinese cities in the years from 1991 to 2001. It demonstrated that economic structure and development polices such as the capital-labor ratio, openness degree and environmental enforcement capacity could all directly change the pollution-income relationship. The estimation results show that the impacts of these policy and structure variables can be nonlinear and the signs of the impacts can change after income reaches to certain levels. This implies that at different development stages, a certain economic structure or development policy may have different impacts on environmental quality.

The results shown that, during the period of 1991-2001 in China, the openness policy as measured by FDI ratio had increased the concentrations of almost all three conventional air pollutants. The capital abundance, as measured by the ratio of capital to labor, increased the concentration of TSP and decreased the concentration of NOx generally, but increased the

[13] The choice of these four cities is dependant on the consideration of their representativeness in geographical location and economic development level.

concentration of SO2 only in rich areas while reducing SO2 concentration in poor areas. Reinforcing environmental regulation had reduced the pollution concentrations only after income reached to certain levels.

We should also note that other development policy and structure variables which are not included in this study might also have affected the pollution-income trajectory in China during the period of 1991-2001. It is practically impossible to include all important structure and policy variables into one model, especially when higher polynomial income terms are included in a multiplicative EKC estimation.  While the multiplicative approach presented in this study should be used in future EKC analyses, this modeling strategy potentially suffers from multicollinearity problems.

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**Table 1. Sample Statistics**

| Var | Explanation | Units | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|---|---|
| **SO2** | Annual average of daily $SO_2$ concentration | μg/$m^3$ | 737 | 75.9 | 65.8 | 2 | 463 |
| **NOX** | Annual average of daily $NO_X$ concentration | μg/$m^3$ | 733 | 48.9 | 23.8 | 10 | 164 |
| **TSP** | Annual average of daily TSP concentration | μg/$m^3$ | 723 | 300.3 | 137.8 | 55 | 892 |
| **Northern city** | north/south dummy (north=1, South=0) | 1 or 0 | 737 | 0.567 | 0.496 | 0 | 1 |
| **Coastal city** | Coastal/inland dummy (costal=1, inland=0) | 1 or 0 | 737 | 0.175 | 0.380 | 0 | 1 |
| **K/L** | Capital per labor | Yuan/person | 737 | 59804.0 | 112180.7 | 204.8 | 1145325 |
| **Open** | Ratio of Foreign capital to total capital stock | % | 737 | 11.6 | 16.5 | 0.0009 | 130.9 |
| **Regulation** | Ratio of government environmental staff to total number of governmental staff | Persons / 10000 per. | 737 | 7.7 | 6.5 | 1.477 | 61.155 |
| **Population density** | Population density | persons/$km^2$ | 737 | 1630.1 | 1199.6 | 42.4 | 10482.4 |
| **Area** | City total land area | $km^2$ | 737 | 1653.8 | 2360.7 | 110 | 20169 |
| **Year** | Common time effect | | 737 | 1996.2 | 3.1 | 1991 | 2001 |
| **GDPPC** | per capita GDP | Yuan | 737 | 7606.4 | 6544.5 | 1024.1 | 65628.3 |

Note: All the variables measured by monetary values are converted into 1990 constant price of RMB.
Data source: China urban statistic yearbook (1990-2002) and China environmental Yearbook (1992-2002).

## Table 2. NOx concentration

| | Simple EKC | | Height-adjustment EKC | | Full_model EKC | |
|---|---|---|---|---|---|---|
| | RE | FE | RE | FE | RE | FE |
| **GDPPC** | -10.749 | -11.320 | -2.227 | -4.001 | 2.630 | 2.776 |
| | (2.20)** | (2.25)** | (0.45) | (0.75) | (0.48) | (0.46) |
| **GDPPC2** | 1.186 | 1.236 | 0.223 | 0.433 | -0.197 | -0.180 |
| | (2.16)** | (2.18)** | (0.40) | (0.73) | (0.32) | (0.27) |
| **GDPPC3** | -0.043 | -0.044 | -0.007 | -0.015 | 0.008 | 0.006 |
| | (2.09)** | (2.09)** | (0.34) | (0.70) | (0.36) | (0.24) |
| **Open** | | | -0.541 | -0.695 | -0.833 | -0.925 |
| | | | (1.71)* | (2.16)** | (3.33)*** | (3.39)*** |
| **K/L** | | | -0.079 | -0.103 | 0.597 | 0.462 |
| | | | (3.85)*** | (4.68)*** | (2.32)** | (1.67)* |
| **Regulation** | | | -0.048 | -0.086 | 0.503 | 0.553 |
| | | | (0.95) | (1.58) | (0.58) | (0.61) |
| **Open×K/L** | | | 0.110 | 0.137 | 0.034 | 0.045 |
| | | | (1.92)* | (2.37)** | (0.63) | (0.78) |
| **Open×(K/L)$^2$** | | | -0.006 | -0.007 | | |
| | | | (2.07)** | (2.52)** | | |
| **Open×regulation** | | | 0.005 | 0.011 | 0.021 | 0.001 |
| | | | (0.27) | (0.53) | (0.13) | (0.01) |
| **GDPPC×Open** | | | | | 0.104 | 0.113 |
| | | | | | (3.66)*** | (3.69)*** |
| **GDPPC×K/L** | | | | | -0.078 | -0.064 |
| | | | | | (2.56)** | (1.96)* |
| **GDPPC×Regulation** | | | | | -0.062 | -0.072 |
| | | | | | (0.62) | (0.69) |
| **GDPPC×Open×K/L** | | | | | -0.004 | -0.006 |
| | | | | | (0.71) | (0.86) |
| **GDPPC×Open×Regulation** | | | | | -0.002 | 0.001 |
| | | | | | (0.10) | (0.07) |
| **Year** | -0.020 | -0.019 | -0.013 | -0.010 | -0.021 | -0.025 |
| | (4.61)*** | (3.89)*** | (1.64) | (1.04) | (2.54)** | (2.36)** |
| **Northern city (dummy)** | | | 0.177 | | 0.201 | |
| | | | (2.33)** | | (2.57)** | |
| **Coastal city (dummy)** | | | -0.220 | | -0.285 | |
| | | | (2.03)** | | (2.57)** | |
| **Population density** | | | 0.314 | 0.404 | 0.311 | 0.518 |
| | | | (5.66)*** | (2.15)** | (5.47)*** | (2.65)*** |
| **Area** | | | 0.262 | 0.274 | 0.266 | 0.369 |
| | | | (6.29)*** | (2.24)** | (6.23)*** | (2.77)*** |
| **Constant** | 75.951 | 76.267 | 36.819 | 36.978 | 31.415 | 39.358 |
| | (4.16)*** | (3.95)*** | (1.62) | (1.49) | (1.32) | (1.50) |
| **R-squared** | 0.02 | 0.04 | 0.30 | 0.11 | 0.32 | 0.14 |
| **Wald test (RE)/F test (FE)** | 27.38 | 6.55 | 114.98 | 6.44 | 138.63 | 6.29 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| **Breusch-Pagan** | 1886.29 | | 1116.04 | | 1133.81 | |
| | (0.000) | | (0.000) | | (0.000) | |
| **Hausman** | 2.26 | | 27.84 | | 9.74 | |
| | (0.6875) | | (0.006) | | (0.896) | |

Number of observation 733, number of groups=72.
*significant at 10% ; ** significant at 5%; *** significant at 1%
Absolute value of t statistics in parentheses

## Table 3. SO2 concentration

| | Simple EKC | | Height-adjustment EKC | | Full_model EKC | |
|---|---|---|---|---|---|---|
| | **RE** | **FE** | **RE** | **FE** | **RE** | **FE** |
| **GDPPC** | -2.309 | -3.343 | -2.350 | -3.440 | -1.153 | -2.384 |
| | (3.01)*** | (4.21)*** | (2.71)*** | (3.48)*** | (1.00) | (1.77) |
| **GDPPC2** | 0.136 | 0.201 | 0.138 | 0.204 | 0.017 | 0.108 |
| | (3.08)*** | (4.39)*** | (2.81)*** | (3.68)*** | (0.24) | (1.28) |
| **Open** | | | -0.025 | 0.017 | 0.087 | 0.032 |
| | | | (0.19) | (0.13) | (0.24) | (0.08) |
| **K/L** | | | -0.038 | -0.033 | -0.749 | -0.584 |
| | | | (1.32) | (1.11) | (2.02)** | (1.50) |
| **Regulation** | | | -0.119 | -0.094 | 0.023 | 0.174 |
| | | | (1.63) | (1.23) | (0.02) | (0.14) |
| **Open×K/L** | | | -0.010 | -0.010 | -0.164 | -0.157 |
| | | | (1.24) | (1.22) | (2.20)** | (2.03)** |
| **Open×regulation** | | | 0.037 | 0.027 | 0.436 | 0.463 |
| | | | (1.36) | (0.95) | (2.00)** | (2.11)** |
| **GDPPC×Open** | | | | | 0.083 | 0.064 |
| | | | | | (1.91)* | (1.41) |
| **GDPPC×K/L** | | | | | -0.014 | -0.030 |
| | | | | | (0.10) | (0.20) |
| **GDPPC×Regulation** | | | | | -0.014 | -0.008 |
| | | | | | (0.33) | (0.19) |
| **GDPPC×Open×K/L** | | | | | 0.017 | 0.017 |
| | | | | | (1.98)** | (1.85)* |
| **GDPPC×Open×Regulation** | | | | | -0.044 | -0.048 |
| | | | | | (1.80)* | (1.91)* |
| **Year** | -0.081 | -0.088 | -0.080 | -0.085 | -0.081 | -0.086 |
| | (13.05)*** | (13.41)*** | (6.59)*** | (6.09)*** | (6.52)*** | (5.70)*** |
| **Northern city (dummy)** | | | 0.125 | | 0.105 | |
| | | | (1.24) | | (1.03) | |
| **Coastal city (dummy)** | | | -0.121 | | -0.104 | |
| | | | (0.81) | | (0.69) | |
| **Population density** | | | 0.091 | 0.313 | 0.073 | 0.315 |
| | | | (1.12) | (1.21) | (0.89) | (1.17) |
| **Area** | | | 0.034 | 0.128 | 0.043 | 0.152 |
| | | | (0.59) | (0.77) | (0.73) | (0.84) |
| **Constant** | 174.495 | 193.869 | 163.003 | 188.780 | 166.897 | 188.385 |
| | (13.58)*** | (14.12)*** | (7.31)*** | (6.86)*** | (7.29)*** | (6.51)*** |
| **R-squared** | 0.02 | 0.35 | 0.21 | 0.35 | 0.23 | 0.36 |
| | 333.10 | 117.50 | 366.68 | 35.96 | 383.65 | 24.73 |
| **Wald test (RE)/F test (FE)** | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| **Breusch-Pagan** | 2094.40 | | 1824.65 | | 1857.83 | |
| | (0.000) | | (0.000) | | (0.000) | |
| **Hausman** | 28.25 | | 23.10 | | 60.78 | |
| | (0.000) | | (0.0104) | | (0.000) | |

Number of observation 737, number of groups=72.

significant at 15%; *significant at 10% ; ** significant at 5%; *** significant at 1%

Absolute value of t statistics in parentheses

**Table 4. TSP concentration**

| | Simple EKC | | Height-adjustment EKC | | Full_model EKC | |
|---|---|---|---|---|---|---|
| | RE | FE | RE | FE | RE | FE |
| **GDPPC** | 2.417 | 2.202 | 2.024 | 1.976 | 3.063 | 3.878 |
| | (5.84)*** | (5.08)*** | (4.55)*** | (3.71)*** | (5.18)*** | (5.33)*** |
| **GDPPC2** | -0.144 | -0.129 | -0.120 | -0.115 | -0.168 | -0.207 |
| | (6.03)*** | (5.13)*** | (4.75)*** | (3.85)*** | (4.68)*** | (4.55)*** |
| **Open** | | | -0.068 | -0.095 | 0.016 | -0.187 |
| | | | (0.96) | (1.30) | (0.08) | (0.91) |
| **K/L** | | | 0.041 | 0.049 | -0.293 | -0.366 |
| | | | (2.63)*** | (3.00)*** | (1.49) | (1.75)* |
| **Regulation** | | | 0.035 | 0.025 | 1.617 | 2.035 |
| | | | (0.91) | (0.62) | (2.41)** | (2.99)*** |
| **Open×K/L** | | | -0.003 | -0.001 | 0.043 | 0.068 |
| | | | (0.59) | (0.16) | (1.08) | (1.65)* |
| **Open×regulation** | | | 0.029 | 0.034 | -0.140 | -0.167 |
| | | | (2.03)** | (2.27)** | (1.19) | (1.42) |
| **GDPPC×Open** | | | | | -0.011 | 0.008 |
| | | | | | (0.49) | (0.34) |
| **GDPPC×K/L** | | | | | 0.040 | 0.050 |
| | | | | | (1.73)* | (2.03)** |
| **GDPPC×Regulation** | | | | | -0.182 | -0.231 |
| | | | | | (2.34)** | (2.93)*** |
| **GDPPC×Open×K/L** | | | | | -0.006 | -0.008 |
| | | | | | (1.21) | (1.74)* |
| **GDPPC×Open×Regulation** | | | | | 0.021 | 0.026 |
| | | | | | (1.58) | (1.92)* |
| **Year** | -0.023 | -0.027 | -0.039 | -0.049 | -0.041 | -0.057 |
| | (7.02)*** | (7.40)*** | (6.17)*** | (6.48)*** | (6.34)*** | (6.97)*** |
| **Northern city (dummy)** | | | 0.457 | | 0.442 | |
| | | | (7.08)*** | | (6.81)*** | |
| **Coastal city (dummy)** | | | -0.420 | | -0.407 | |
| | | | (4.60)*** | | (4.44)*** | |
| **Population density** | | | 0.097 | 0.206 | 0.094 | 0.347 |
| | | | (2.11)** | (1.48) | (2.04)** | (2.40)** |
| **Area** | | | 0.068 | 0.103 | 0.083 | 0.226 |
| | | | (2.01)** | (1.16) | (2.41)** | (2.32)** |
| **Constant** | 42.202 | 49.342 | 72.992 | 94.092 | 71.554 | 99.002 |
| | (6.09)*** | (6.58)*** | (5.76)*** | (6.32)*** | (5.52)*** | (6.37)*** |
| **R-squared** | 0.18 | 0.25 | 0.50 | 0.27 | 0.50 | 0.30 |
| **Wald test (RE)/F test (FE)** | 222.86 | 70.91 | 333.95 | 24.16 | 351.85 | 17.82 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| **Breusch-Pagan** | 2195.05 | | 1338.63 | | 1261.57 | |
| | (0.000) | | (0.000) | | (0.000) | |
| **Hausman** | 6.27 | | 42.80 | | 68.84 | |
| | (0.0991) | | (0.000) | | (0.000) | |

Number of observation 733, number of groups=72.
significant at 15%; *significant at 10% ; ** significant at 5%; *** significant at 1%
Absolute value of t statistics in parentheses

**Table 5. Derivatives of Pollution Concentration with Respect to Income**
(Calculation based on full-model with random effect estimation)

| cityname | year | GDPPC | Structure | Open | Regulation | NOX | SO2 | TSP | cityname | year | GDPPC | Structure | Open | Regulation | NOX | SO2 | TSP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Chengdu** | 1991 | 4147.27 | 48.76 | 0.12 | 0.04 | -0.008 | -0.020 | -0.016 | **Nanning** | 1991 | 3489.05 | 44.60 | 0.26 | 0.07 | 0.087 | -0.111 | 0.210 |
| | 1992 | 4425.86 | 45.88 | 0.35 | 0.05 | 0.034 | -0.025 | -0.035 | | 1992 | 3448.09 | 42.97 | 0.75 | 0.07 | 0.135 | -0.113 | 0.208 |
| | 1993 | 4784.19 | 46.23 | 0.75 | 0.07 | 0.069 | -0.018 | -0.024 | | 1993 | 4510.90 | 43.16 | 1.46 | 0.09 | 0.173 | -0.046 | 0.130 |
| | 1994 | 6121.36 | 39.36 | 1.19 | 0.06 | 0.092 | 0.034 | -0.108 | | 1994 | 5128.48 | 39.79 | 10.02 | 0.11 | 0.273 | -0.033 | 0.074 |
| | 1995 | 6457.17 | 37.72 | 1.19 | 0.05 | 0.075 | 0.061 | -0.121 | | 1995 | 5609.33 | 38.37 | 19.11 | 0.14 | 0.297 | 0.001 | 0.050 |
| | 1996 | 7230.99 | 41.04 | 2.11 | 0.08 | 0.112 | 0.126 | -0.058 | | 1996 | 5853.87 | 34.12 | 21.05 | 0.14 | 0.298 | 0.043 | 0.051 |
| | 1997 | 8174.11 | 43.73 | 2.48 | 0.10 | 0.102 | 0.189 | -0.074 | | 1997 | 6195.90 | 32.78 | 28.39 | 0.16 | 0.301 | 0.036 | 0.009 |
| | 1998 | 8387.15 | 43.86 | 2.26 | 0.09 | 0.060 | 0.231 | -0.064 | | 1998 | 6579.64 | 31.03 | 26.96 | 0.15 | 0.270 | 0.079 | -0.015 |
| | 1999 | 8618.85 | 43.90 | 2.50 | 0.10 | 0.040 | 0.243 | -0.101 | | 1999 | 6857.42 | 30.30 | 27.27 | 0.17 | 0.250 | 0.203 | 0.024 |
| | 2000 | 8840.63 | 43.10 | 2.57 | 0.05 | 0.032 | 0.264 | -0.098 | | 2000 | 7033.14 | 30.10 | 24.59 | 0.26 | 0.234 | 0.113 | -0.049 |
| | 2001 | 10095.61 | 43.81 | 2.95 | 0.16 | 0.014 | 0.297 | -0.190 | | 2001 | 7793.03 | 28.16 | 22.06 | 0.40 | 0.193 | 0.177 | -0.089 |
| **Structure ⇑ 10%** | | 10095.61 | 48.19 | 2.95 | 0.16 | 0.006 | 0.304 | -0.186 | **Structure ⇑ 10%** | | 7793.03 | 30.98 | 22.06 | 0.40 | 0.184 | 0.188 | -0.086 |
| **Open ⇑ 10%** | | 10095.61 | 43.81 | 3.24 | 0.16 | 0.018 | 0.298 | -0.190 | **Open ⇑ 10%** | | 7793.03 | 28.16 | 24.27 | 0.40 | 0.198 | 0.178 | -0.088 |
| **Regulation ⇑ 10%** | | 10095.61 | 43.81 | 2.95 | 0.18 | 0.008 | 0.289 | -0.210 | **Regulation Ý 10%** | | 7793.03 | 28.16 | 22.06 | 0.44 | 0.186 | 0.160 | -0.103 |
| **cityname** | **year** | **GDPPC** | **Structure** | **Open** | **Regulation** | **NOX** | **SO2** | **TSP** | **cityname** | **year** | **GDPPC** | **Structure** | **Open** | **Regulation** | **NOX** | **SO2** | **TSP** |
| **Dalian** | 1991 | 6081.40 | 53.72 | 3.74 | 0.15 | 0.314 | -0.268 | -0.313 | **Zhengzhou** | 1991 | 2961.03 | 56.74 | 0.13 | 0.08 | 0.071 | -0.140 | 0.133 |
| | 1992 | 6225.29 | 53.09 | 8.05 | 0.19 | 0.324 | -0.299 | -0.272 | | 1992 | 3046.14 | 55.45 | 0.76 | 0.09 | 0.162 | -0.174 | 0.186 |
| | 1993 | 6424.23 | 53.06 | 11.84 | 0.21 | 0.298 | -0.247 | -0.230 | | 1993 | 3317.71 | 49.14 | 2.49 | 0.09 | 0.196 | -0.154 | 0.189 |
| | 1994 | 9907.98 | 47.86 | 20.57 | 0.22 | 0.318 | -0.170 | -0.387 | | 1994 | 4780.90 | 48.05 | 6.97 | 0.10 | 0.257 | -0.098 | 0.049 |
| | 1995 | 10304.86 | 45.55 | 31.59 | 0.23 | 0.312 | -0.124 | -0.361 | | 1995 | 5855.41 | 44.43 | 7.96 | 0.12 | 0.250 | -0.056 | -0.047 |
| | 1996 | 10534.80 | 43.29 | 34.36 | 0.28 | 0.339 | 0.015 | -0.282 | | 1996 | 6458.94 | 44.61 | 9.79 | 0.14 | 0.254 | -0.022 | -0.075 |
| | 1997 | 11068.36 | 42.03 | 39.34 | 0.35 | 0.322 | 0.087 | -0.279 | | 1997 | 6177.51 | 41.97 | 9.63 | 0.17 | 0.235 | -0.021 | -0.060 |
| | 1998 | 11556.02 | 41.70 | 44.47 | 0.32 | 0.241 | 0.312 | -0.232 | | 1998 | 6215.09 | 40.64 | 10.44 | 0.23 | 0.174 | 0.059 | -0.036 |
| | 1999 | 11875.52 | 42.70 | 48.13 | 0.42 | 0.180 | 0.240 | -0.310 | | 1999 | 6273.85 | 37.10 | 11.20 | 0.23 | 0.154 | 0.076 | -0.042 |
| | 2000 | 13078.71 | 43.50 | 52.38 | 0.66 | 0.166 | 0.288 | -0.348 | | 2000 | 6953.22 | 34.60 | 11.29 | 0.36 | 0.211 | 0.035 | -0.103 |
| | 2001 | 15286.96 | 44.12 | 56.31 | 0.93 | 0.179 | 0.388 | -0.384 | | 2001 | 7514.71 | 34.01 | 10.48 | 0.56 | 0.097 | 0.162 | -0.120 |
| **Structure ⇑ 10%** | | 15286.96 | 48.53 | 56.31 | 0.93 | 0.170 | 0.401 | -0.383 | **Structure ⇑ 10%** | | 7514.71 | 37.41 | 10.48 | 0.56 | 0.089 | 0.172 | -0.117 |
| **Open ⇑ 10%** | | 15286.96 | 44.12 | 61.94 | 0.93 | 0.183 | 0.389 | -0.383 | **Open ⇑ 10%** | | 7514.71 | 34.01 | 11.53 | 0.56 | 0.102 | 0.162 | -0.119 |
| **Regulation ⇑ 10%** | | 15286.96 | 44.12 | 56.31 | 1.03 | 0.172 | 0.367 | -0.396 | **Regulation ⇑ 10%** | | 7514.71 | 34.01 | 10.48 | 0.62 | 0.091 | 0.148 | -0.136 |

**Figure 2. EKCs of NOx with Different Economic Structures, Openness Degrees and Environmental Regulations**

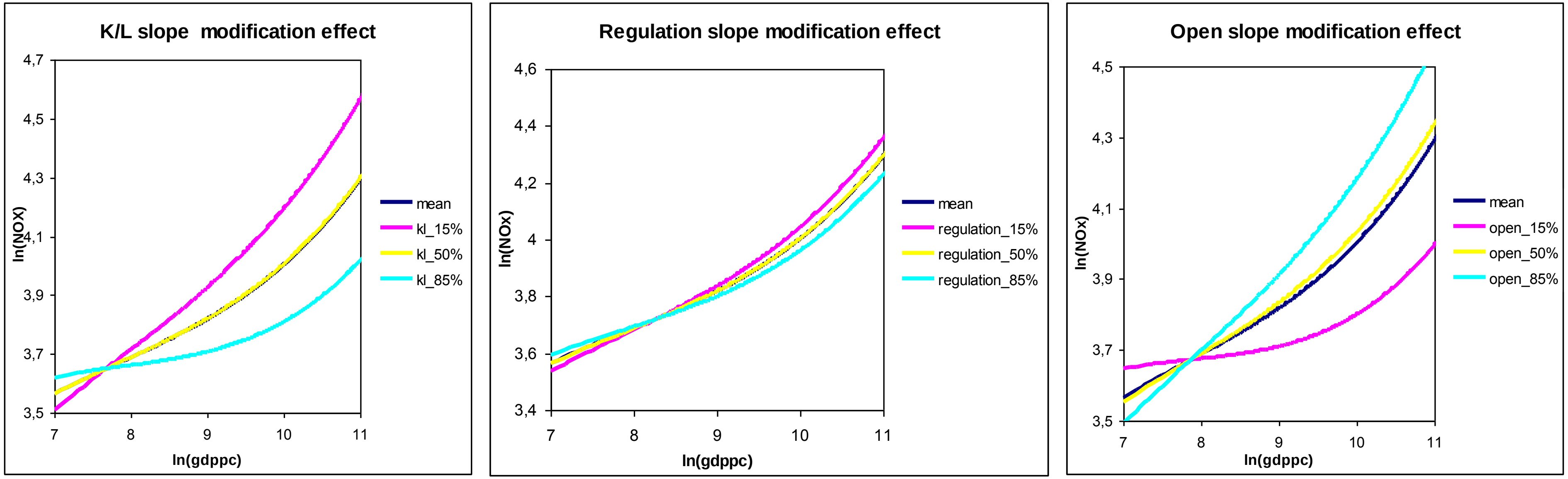

**Figure 3. EKCs of SO2 with Different Economic Structures, Openness Degrees and Environmental Regulations (quadratic model)**

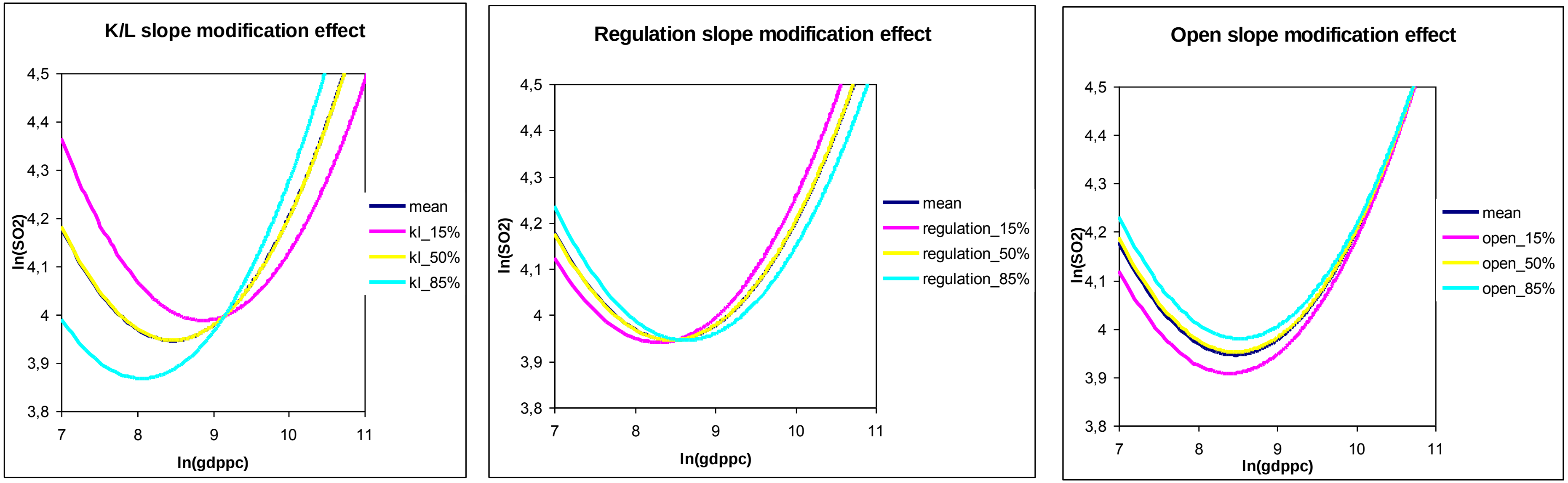

**Figure 4. EKCs of TSP with Different Economic Structures, Openness Degrees and Environmental Regulations**