Environmental Economics and Policy Studies (2010) 12: 79–96
DOI 10.1007/s10018-010-0166-5

Environmental Economics and Policy Studies

*Article*

# Economic growth and air quality in China

**Daigee Shaw,[1,3] Arwin Pang,[2] Chang-Ching Lin,[3] and Ming-Feng Hung[4]**
[1] Chung-Hua Institution for Economic Research, 75 Chang-Hsing St., Taipei, 106, Taiwan
[2] Department of Resource Economics, University of Nevada, 1664 N. Virginia St., Reno, NV 89557-0042, USA
[3] Institute of Economics, Academia Sinica, 128 Academia Rd., Section 2, Nankang, Taipei, 115, Taiwan
[4] Department of Industrial Economics, Tamkang University, 151 Ying-chuan Rd., Tamsui, Taipei County, 251, Taiwan

Received: April 30, 2009 / Accepted: May 10, 2010

**Abstract** The relationship between economic development and air quality for mainland China is investigated by examining the environmental Kuznets curve (EKC). We compile a panel dataset comprising air quality, income, and environmental policy variables for 99 cities from 1992 to 2004 to estimate the EKC relationship. Time-specific fixed effects panel models are estimated and the instrumental variables approach is used to consider the endogeneity of income and policy variables. The regression results indicate that the EKC hypothesis is supported in the case of $SO_2$.

**Key words** Air quality · China · Environmental Kuznets curve · Latecomer

## 1 Introduction

Switching from a planned to a market economy has brought about mainland China's "economic miracle." Since implementing economic reforms in 1978, China has been experiencing rapid economic growth, as evidenced in recent years by an average annual economic growth rate of close to 10%.

On the other hand, a series of measures designed to protect the environment began to be implemented in the 1970s even though China's per capita income was very low at that time. In 1973, the Chinese government held the first national conference on environmental protection, set up a national environmental protection organization (Environmental Protection Office), and stipulated the "three synchronizations" system.[1] In actual practice, however, the three synchronizations system was said to have been rarely implemented. In general, observers

---

[1] The "three synchronizations" system entailed (1) simultaneously designing antipollution measures, (2) simultaneously constructing antipollution equipment with the construction of industrial plants, and (3) simultaneously operating antipollution equipment with the operation of industrial plants.

seem to agree that the real improvements in environmental protection started to come only after the promulgation of the Environmental Protection Law in 1979, which adopted the Environmental Impact Assessment (EIA) system and the Polluter Pays Principle (Goldman and Tsuru 1985).[2]

In 1983, environmental protection was declared one of the two Chinese "national fundamental policies."[3] More environmental laws and ambient standards were gradually established in the 1980s. In the 1990s, the cleaner production program and the discharge permit system were applied. Thus, a quite complete system of environmental management regulations and institutions was developed along with the rapid economic growth over the past 20 years.

This experience is quite different from what had occurred in the high-income countries such as Japan, the United Kingdom, and the USA during the past century. These countries by contrast all followed the pattern of "pollute first and clean up later." The fact that China has adopted the policies that emphasize both economic growth and environmental protection simultaneously from the earliest days of development arouses our interest to examine China's environmental Kuznets curve (EKC). The EKC was first pointed out by Grossman and Krueger (1991) and has generated a significant amount of literature regarding its theoretical explorations and empirical investigations (see the reviews in, e.g., Copeland and Taylor 2004; Stern 2004).

We investigate the relationship between economic growth and air quality in China using a panel dataset comprising 99 cities. The air pollution indicators used in our study are sulfur dioxide ($SO_2$), nitrogen oxides ($NO_X$), and deposited particles (DP). All of them are major local nonuniformly mixed assimilative pollutants. $SO_2$ mainly comes from burning fuel that contains sulfur, such as coal and oil. Exposure to an environment with a high concentration of $SO_2$ will damage the respiratory system and aggravate the bronchi. $NO_X$ is produced during high-temperature combustion in power generators and car engines. It has a tendency to irritate the lungs and decrease the respiratory system's resistance to infection. In the long run, it will also cause pathological changes in the lung. DP comes from roads, construction work, industrial procedures, or from the nature. The harm caused by DP to health is mostly related to respiratory problems or even long-term damage to the lung.

In recent years, the question of whether there exists an EKC relationship in China has received a lot of attention. de Groot et al. (2004) studied the EKC for China based on a sample of 30 provinces from 1982 to 1997. Their models were standard EKC regression models. The pollution (wastewater, waste gas, and solid waste) took three forms: emissions in absolute levels, per capita terms, and per unit of gross regional product terms. Poon et al. (2006) examined the roles of energy, transport, and trade in an environment–development relationship using spatial econometrics. The provincial $SO_2$ and soot emission data over the period 1998–2004 were used. Shen (2006) used a simultaneous equations model to

---

[2] The Environmental Protection Law was revised and officially enacted in 1989.

[3] The other national fundamental policy is aimed at controlling the growth of population.

examine the EKC over 1993–2002 by employing provincial emission data. Liu et al. (2007) tested the EKC hypothesis for Shenzhen (a subprovincial city of Guangdong Province in southern China) based on the concentration of pollutants in ambient air, main rivers and near-shore waters from 1989 to 2003. Brajer et al. (2008) tested the EKC hypothesis based on city-specific annual ambient levels of $SO_2$ for 1990–2004 and evaluated the benefits of tunneling through the Chinese EKC. Liu et al. (2008) estimated the relationship between economic growth and farmland conversion by country and provincial data for 1987–2005. Song et al. (2008) used panel cointegration estimation to test the EKC by employing provincial data over 1985–2005. Kaneko et al. (2009) used provincial data over 1992–2003 to estimate the relationship between income and environmental quality by means of a nonparametric approach.

In general, the EKC results for China obtained from the above studies are not consistent. They vary with the pollutant type, estimation technique, the form of the data applied, and other factors. This article differs from these studies in two respects. First, city-level and environmental-quality data are applied. In the previous literature, provincial emission data were mostly used. Although provincial-level data has the advantage in covering all of China, we consider city-level data to be more suitable for estimation purposes. This is because the cities that are centers of economic activity and population are both the sources and recipients of pollution. A province covers a large area including many cities and rural areas, and thus the environmental qualities and economic activities within it are very diverse. Average figures for provincial environmental qualities and economic activities might as a consequence produce misleading results. Besides, emissions ignore the dispersion effect that transforms emissions into ambient environmental quality, which has an impact on people's health and the economy. Furthermore, environmental protection measures and their enforcement are also diverse among cities in China. It is not possible to study these policy variables by using average provincial-level data. By using city-level data, we can discuss the effect of China's environmental protection policies.

Second, the endogeneity of the income variable is considered in this article. Whether it is from the viewpoint of the production function or the growth equation, income is quite clearly an endogenous variable. If we do not consider this endogeneity, the estimates would be biased. In addition, environmental quality also has feedback effects on the economy.[4] The abovementioned literature, except for Shen (2006), ignored this fact. Pollutants basically have two contrasting (i.e., positive and negative) effects on income. They might, on the one hand, increase income by acting as production inputs, while they might, on the other hand, also decrease income by harming human health, limiting the supply of environmental inputs, and increasing production costs when firms are asked to control pollution. In this article, we test the endogeneity of income variable first and then explore the EKC relationship by the instrumental variable approach. In addition, the endogeneity of policy variables is also tested.

---

[4] See Perrings (1987), Lopez (1994), Stern (1998), Borghesi (1999), and Hung and Shaw (2004).

In what follows, we specify the empirical model and describe the data in Sect. 2. The estimation results are presented in Sect. 3. We evaluate the performance of China's environmental policy and its implementation. Some policy implications regarding the real forces behind China's environmental performance are drawn. Section 4 presents the conclusions.

## 2 Model specification and data description

In this study, a panel dataset comprising 99 cities from 1992 to 2004 was used to investigate the relationship between urban air pollution and economic development in China. The basic model is as follows:

$$P_{it} = \alpha_t + \lambda_1 Y_{it} + \lambda_2 Y_{it}^2 + \beta \boldsymbol{X}_{it} + \gamma \boldsymbol{R}_i + \varepsilon_{it} \tag{1}$$

where subscript $i$ denotes city and $t$ denotes year. $P$ denotes air pollution including $SO_2$, $NO_X$, and DP for different pollution equations. $Y$ is per capita gross domestic product (GDP). $\boldsymbol{X}$ is a vector of additional explanatory variables that includes population density (PD), the contribution of secondary industry to GDP (TWO), and a policy variable. In the models for $NO_X$ and DP, the policy variable is CITY (i.e., the cumulative number of years that a city has been treated as a key environmental protection city).[5] In the model for $SO_2$, the policy variable is TC, which is the sum of the number of cumulative years that a city has been included in the Two Control Areas[6] and the number of cumulative years it has been treated as a key environmental protection city.

We use time-specific fixed effects to specify the model. The time-specific fixed effects ($\alpha_t$) may represent the effects of technological changes and changes in government regulatory policies in different years. This is especially true for China because the evolution of environmental protection policies for each city has been tightly controlled by the central government.

Besides the time-specific fixed effects, we also include regional dummy variables to capture the cross-regional effects. In Eq. 1, $\boldsymbol{R}$ is a vector of six regional dummies for seven regions. These regions are the North, East, South, Middle, North-East, North-West, and South-West. The South-West region is used as the reference area.[7] Because cities in the same region have similar characteristics and may affect each other, we use regional dummy variables instead of city-specific fixed effects in our model. Note that in Eq. 1, all variables are in the form of natural logarithms except for CITY, TC, and regional dummies.

---

[5] In 1989, the National Environmental Protection Agency (NEPA) began to implement a quantitative annual assessment of urban environment performances in 32 cities. These cities are municipalities directly under the jurisdiction of the Central Government (Beijing, Tianjin, and Shanghai), the provincial capitals, and three other cities (Dalian, Suzhou, and Guilin). In 1992, Qingdao, Ningbo, Xiamen, Shengahen, and Chongqing were included. More cities were covered in 1996 and the total number of these cities amounted to 46. In 2003, Lhasa was further embraced.

[6] In 1995, the NEPA marked out Two Control Areas, which included an acid rain control zone and an $SO_2$ control zone (see Appendix 2).

[7] See TEEMA (2003) and Appendix 1 for the details for each region.

Equation 1 is a quadratic model with both a linear term and a squared term of income. If the coefficients of the linear term and its squared term are positive and negative, respectively, then the EKC hypothesis holds. In addition to the quadratic model, we have also tried linear and cubic models. After close examination, we find that the most appropriate models for $SO_2$ and DP are the quadratic models and the linear model for $NO_X$.

Moreover, we estimate Eq. 1 in two different forms. The first one is a simple EKC model with just the income variables and regional dummies ($\boldsymbol{R}$). In the second form, we estimate Eq. 1 with additional explanatory variables $\boldsymbol{X}$. The first can be used to test the EKC hypothesis. The turning points are calculated based on these estimated models. The second will show whether additional explanatory variables help explain the EKC phenomenon.

Foreign direct investment (FDI), fixed capital investment ($K$), labor ($L$), government spending ($G$), and human capital ($H$)[8] are instrumental variables for income and policy variables when we use the instrumental variables approach. The definitions, descriptive statistics, and sources of all variables are presented in Table 1. In our empirical analysis, we compile a panel dataset for the 99 cities of the national monitoring network (see Appendix 1).[9] These cities are selected to represent different characteristics of Chinese cities such as per capita income, environmental quality, the amount of pollution, and location. All data we use are obtained from different sources including the *China Environment Yearbook* from 1993 to 2005, the *China Statistical Yearbook 2002*, *Cities of China 1949–1998*, and the *Urban Statistical Yearbook of China* from 1993 to 2005. Because of missing values in some cities' air quality data, the criterion for cities chosen for estimation is that those cities should have at least 10 years of data. Thus, the numbers of observations for the three pollutants for the regressions are not the same. Among all the variables, the monetary terms, $Y$, FDI, $K$, and $G$ for instance, are deflated by the indices for the gross domestic product with 2000 as the base year.[10]

Finally, in order to investigate the long-run EKC relationship in China, we consider the between estimators together with instrumental variables. Kuh (1959) and Houthakker (1965) suggested that the long-run effects can be captured by the between estimator in a static panel model. Pesaran and Smith (1995) pointed out that the between estimator can consistently estimate the long-run effects in dynamic heterogeneous panels. Pirotte (1999) further showed that the probability limit of the between estimator of a static relation converges to the long-run

---

[8] $H$ is the number of persons with a senior high school education and above as a percentage of the total population. Because the data within the numerator are obtained from China's population census that is conducted only once every 10 years, we applied a linear interpolation approach to obtain yearly figures. The two census years are 1990 and 2000.

[9] Since 1980, the China National Environmental Monitoring Center has been responsible for managing and guiding the work of the national environmental monitoring system, and providing technical support to the State Environmental Protection Administration of China in carrying out environmental supervision and management. It is the center of the network, technology, information, and training for national environmental monitoring. The center also ensures that the environmental monitoring data are reliable.

[10] Data are obtained from the *Chinese Statistical Yearbook* (2002).

Table 1. Variable statistics

| Variables | Description | Mean | SD | Minimum | Maximum | Source[a] |
|---|---|---|---|---|---|---|
| $SO_2$ (0.001 mg/$m^3$) | Sulfur dioxide concentration (annual mean) | 73.62 | 62.58 | 2 | 463 | 1 |
| $NO_X$ (0.001 mg/$m^3$) | Nitrogen oxides concentration (annual mean) | 51.37 | 24.23 | 1 | 164 | 1 |
| DP (ton/$km^2$ per month) | Average deposited particle concentration (annual mean) | 15.94 | 10.71 | 2.6 | 83.47 | 1 |
| $Y$ ($10^3$ Yuan) | Per capita gross domestic product (GDP) | 21.00 | 19.67 | 2.50 | 28.92 | 2, 3 |
| PD (person/$km^2$) | Population density | 1663.89 | 1146.92 | 147 | 9996.85 | 2, 3 |
| TWO (%) | Contribution of secondary industry as a share of GDP | 51.94 | 11.53 | 16.07 | 92.84 | 2, 3 |
| TC (years) | Cumulative number of years a city has been included in the Two Control Areas plus variable CITY | 3.73 | 3.85 | 0 | 13 | 2, 3 |
| FDI (10 US dollars) | Per capita foreign direct investment for employed persons at the end of the year | 43.73 | 68.13 | 0.02 | 588.27 | 2, 3 |
| $K$ ($10^3$ Yuan) | Per capita fixed capital investment for employed persons at the end of the year | 20.21 | 18.72 | 0.55 | 174.40 | 2, 3 |
| $L$ (%) | Employed persons as a percentage of total population at the end of the year | 45.99 | 26.13 | 5.41 | 248.49 | 2, 3 |
| $G$ ($10^2$ Yuan) | Per capita local government budgetary expenditure | 17.68 | 22.05 | 0.54 | 190.76 | 2, 3 |
| $H$ (%) | Number of persons with a senior high school education or above as a percentage of total population at the end of the year | 39.01 | 11.10 | 4.31 | 76.73 | 4 |
| CITY (years) | Cumulative number of years a city has been treated as a key environmental protection city | 5.37 | 5.48 | 0 | 16 | 5 |

The city boundaries in our sample do not include prefectures under the municipality's control. US \$1 = 8.2775 Yuan (Year 2000). Regional dummy variables are displayed in Appendix 1

SD, Standard deviation

[a] Source: 1, *China Environment Yearbook* (1993–2005); 2, *Cities of China 1949–1998* (National Bureau of Statistics of China); 3, *Urban Statistical Yearbook of China* (1993–2005, National Bureau of Statistics of China); 4, *China Statistical Yearbook 2002* (National Bureau of Statistics of China); 5, State Environmental Protection Administration of China, see http://www.sepa.gov.cn/650497467271348224/20030506/1038003.shtml

effects when the number of individual units is large, regardless of whether the true model is dynamic. Because the cross-sectional dimension of our dataset (99 cities) is large, we can then investigate the long-run EKC relationship by means of the between estimator. We consider the following between estimation:

$$\bar{P}_i = \alpha_0 + \lambda_{1L}\bar{Y}_i + \lambda_{2L}\bar{Y}_i^2 + \beta_L \bar{\boldsymbol{X}}_i + \gamma \boldsymbol{R}_i + e_i, \tag{2}$$

where $\bar{P}_i$, $\bar{Y}_i$, $\bar{Y}_i^2$, and $\bar{X}_i$ denote the over-time averages of $P_{it}$, $Y_{it}$, $Y_{it}^2$, and $X_{it}$, respectively. The instrumental variables used to control for the endogeneity of $\bar{Y}_i$, $\bar{Y}_i^2$, and the policy variables are the same as discussed before.

## 3 Estimation

In order to consider the endogeneity of the income and policy variables, we performed Hausman tests first and the results indicate that the null hypotheses of exogeneity for both these variables are rejected. Thus, we use the instrumental variables approach for the income and policy variables. Second, the results of the Hausman test show that the null hypotheses of the random-effects model are rejected for $SO_2$ and DP. Because it is the time effects in Chinese cities that we wish to examine, we therefore also adopt the fixed-effects model for $NO_X$. All test statistics are shown in Tables 2–5.

### 3.1 Estimation results

The regression results for $SO_2$, $NO_X$, and DP are presented in Tables 2, 3, and 4, respectively. The fixed-effects estimates are displayed in columns 1 and 2, while the results for the between estimators are shown in columns 3 and 4 for each pollutant model. In particular, columns 1 and 3 present the estimates of simple EKC models with just the income variables and regional dummies included,[11] while columns 2 and 4 present the estimates with all control variables included. In Tables 2–4, heteroskedasticity-consistent standard errors are reported.

We focus on the estimation results of the fixed-effects models first. In the simple EKC models (column 1), the coefficients of $Y$ and $Y^2$ are positive and negative, respectively, for $SO_2$ and DP. In particular, these coefficients are very significant for $SO_2$. The EKC hypothesis is therefore supported by the case of $SO_2$. However, the coefficient of $Y$ for $NO_X$ is significantly positive and does not support the EKC hypothesis. This result is reasonable because the control of $NO_X$ is more expensive and difficult as the economy grows with more and more vehicles in the cities. Similar results are found in Cole et al (1997), Hung and Shaw (2004), and World Bank (2001).[12]

---

[11] Regional dummies are used to capture regional effects.

[12] The World Bank (2001, p. 79) analyzed the time-series monitoring data in urban areas between 1991 and 1998 and showed similar ambient air quality trends. It stated that there are different trends among the three pollutants. First, ambient $SO_2$ levels declined significantly. Second, ambient DP levels decreased slightly, but remained high in most urban areas. Third, $NO_X$ levels worsened, reflecting the growing impact of vehicular emissions.

Table 2. Regression results for model for $SO_2$

| | Fixed effects | | Between estimator | |
|---|---|---|---|---|
| Variable | (1) | (2) | (3) | (4) |
| $Y$ | 1.733*** | 2.455* | 1.562 | 2.757 |
| | (0.552) | (1.461) | (1.577) | (2.934) |
| $Y^2$ | –0.304*** | –0.397** | –0.391 | –0.433 |
| | (0.089) | (0.199) | (0.240) | (0.405) |
| TWO | | –0.023 | | 0.342 |
| | | (0.363) | | (0.889) |
| PD | | 0.027 | | –0.218 |
| | | (0.050) | | (0.222) |
| TC | | –0.023 | | 0.011 |
| | | (0.037) | | (0.062) |
| North | 0.088 | –0.183 | –0.233 | –1.125 |
| | (0.129) | (0.392) | (0.432) | (0.786) |
| East | –0.700*** | –0.990** | –1.074** | –0.796 |
| | (0.142) | (0.403) | (0.509) | (0.856) |
| South | –1.334*** | –1.547*** | –1.616*** | –1.472 |
| | (0.153) | (0.371) | (0.569) | (0.941) |
| Middle | –0.667*** | –0.893*** | –0.891** | –0.711 |
| | (0.126) | (0.325) | (0.404) | (0.689) |
| North-East | –0.748*** | –1.033** | –1.118** | –1.032 |
| | (0.136) | (0.417) | (0.467) | (0.870) |
| North-West | –0.299** | –0.402** | –0.793* | –0.772 |
| | (0.117) | (0.172) | (0.451) | (0.500) |
| Hausman test for exogeneity | 15.86*** | 8.2** | | |
| Hausman test for random or fixed effects | 51.47*** | 84*** | | |
| No. of observations | 705 | 704 | 705 | 704 |
| $R^2$ | 0.332 | 0.248 | 0.610 | 0.640 |
| Turning point ($10^3$ Yuan) | 17.293 | | — | |

Standard errors are shown in parentheses
* Significant at the 10% level; ** significant at the 5% level; *** significant at the 1% level

The turning point, $\exp(-\lambda_1/2\lambda_2)$, for $SO_2$ is about 17293 RMB (US \$2014 in 2000). In 2004, the average per capita GDP of these cities was 21012 RMB (US \$2538 in 2000). This shows that the $SO_2$ pollution was decreasing for most cities in 2004.[13] This can be attributed to reduced coal consumption and successful promotion of the use of gaseous fuels in urban residential and commercial sectors, especially in large cities (World Bank 2001).

---

[13] Some studies presented similar results. For example, the World Bank (2001, p. 78) stated that "Overall, national pollution survey data also show that total emissions of major air pollutants as sulfur dioxide, soot, and industrial fugitive dust peaked in the mid-1990s and have been falling ever since." Poon et al (2006) indicated that $SO_2$ emissions appeared to have decreased as a result of an increase in wealth using spatial econometrics during 1998–2004. Brajer et al (2008, p. 677) summarized their data and said "the overall trend is that there have been significant improvements in urban air quality as measured by the reduced levels of $SO_2$ over a 15-year (1990–2004) time span."

Table 3. Regression results for model for $NO_X$

| | Fixed effects | | Between estimator | |
|---|---|---|---|---|
| Variable | (1) | (2) | (3) | (4) |
| *Y* | 0.359*** | 0.408*** | 0.331* | 0.305 |
| | (0.051) | (0.091) | (0.177) | (0.239) |
| TWO | | –0.088 | | 0.151 |
| | | (0.142) | | (0.435) |
| PD | | 0.136*** | | 0.123 |
| | | (0.037) | | (0.132) |
| CITY | | –0.013 | | 0.009 |
| | | (0.012) | | (0.033) |
| North | 0.141* | 0.031 | –0.007 | –0.040 |
| | (0.076) | (0.089) | (0.281) | (0.390) |
| East | 0.075 | –0.079 | –0.039 | –0.132 |
| | (0.079) | (0.101) | (0.322) | (0.413) |
| South | –0.388*** | –0.438*** | –0.364 | –0.334 |
| | (0.101) | (0.117) | (0.306) | (0.412) |
| Middle | 0.034 | –0.093 | –0.020 | –0.082 |
| | (0.071) | (0.085) | (0.239) | (0.322) |
| North-East | 0.039 | –0.006 | –0.039 | –0.199 |
| | (0.081) | (0.083) | (0.285) | (0.360) |
| North-West | 0.135* | 0.150** | 0.008 | –0.001 |
| | (0.075) | (0.073) | (0.296) | (0.309) |
| Hausman test for exogeneity | 26.6*** | 18.62*** | | |
| Hausman test for random or fixed effects | 0.38 | 0.45 | | |
| No. of observations | 670 | 669 | 670 | 669 |
| $R^2$ | 0.110 | 0.099 | 0.396 | 0.396 |

Standard errors are shown in parentheses

* Significant at the 10% level; ** significant at the 5% level; *** significant at the 1% level

In examining the effects of other variables, it is observed that the coefficients for secondary industries (variable TWO) are insignificant for all pollutants. The population density (PD) has a positive influence on all pollutants and is significant in relation to $NO_X$. This means that the more urbanization there is in a city, the more serious the pollution is.

The variable CITY denotes the cumulative number of years that a city has been treated as a key environmental protection city. It represents a policy effect on improving air quality. The coefficients of this variable are negative for $NO_X$ and DP and significant for DP. It shows that environmental protection projects that have been implemented by these key cities, including the blue sky project and the urban greening and beautification project, have improved the DP pollution. The variable TC represents the cumulative number of years that a city has been included in the Two Control Areas (Acid Rain Control Zones and $SO_2$ Control Zones) and treated as a key environmental protection city. The coefficient of this variable is negative in the model for $SO_2$, but not significant.

For comparison and analysis of the regional effects, the South-West region is used as the reference area. We find that the air quality in the North region is the worst as a whole. This may be due to the fact that coal is the primary energy

Table 4. Regression results for model for deposited particles (DP)

| | Fixed effects | | Between estimator | |
|---|---|---|---|---|
| Variable | (1) | (2) | (3) | (4) |
| *Y* | 0.405 | 1.558** | 0.160 | –1.339 |
| | (0.317) | (0.666) | (1.181) | (1.851) |
| $Y^2$ | –0.022 | –0.170* | 0.023 | 0.206 |
| | (0.055) | (0.094) | (0.192) | (0.262) |
| TWO | | –0.005 | | 1.083 |
| | | (0.200) | | (0.699) |
| PD | | 0.029 | | 0.243 |
| | | (0.432) | | (0.191) |
| CITY | | –0.046** | | 0.047 |
| | | (0.021) | | (0.048) |
| North | 0.479*** | 0.124 | 0.586 | 0.811 |
| | (0.062) | (0.150) | (0.337) | (0.521) |
| East | –0.377*** | –0.816*** | –0.409 | –0.080 |
| | (0.068) | (0.177) | (0.382) | (0.643) |
| South | –0.585*** | –0.893*** | –0.620* | –0.259 |
| | (0.084) | (0.170) | (0.362) | (0.537) |
| Middle | 0.080*** | –0.238* | 0.097 | 0.243 |
| | (0.052) | (0.128) | (0.289) | (0.430) |
| North-East | 0.345*** | –0.024 | 0.286 | 0.699 |
| | (0.075) | (0.156) | (0.335) | (0.583) |
| North-West | 0.743*** | 0.703*** | 0.715** | 0.751** |
| | (0.080) | (0.081) | (0.329) | (0.320) |
| Hausman test for exogeneity | 9.89*** | 11.17** | | |
| Hausman test for random or fixed effects | 256.3*** | 61.28*** | | |
| No. of observations | 676 | 676 | 676 | 676 |
| $R^2$ | 0.383 | 0.303 | 0.554 | 0.625 |
| Turning point ($10^3$ Yuan) | — | | — | |

Standard errors are shown in parentheses

* Significant at the 10% level; ** significant at the 5% level; *** significant at the 1% level

source in this region. The concentration of $SO_2$ in the South-West region is very high because unique geographical characteristics hinder the dispersal of emissions from coal-burning activities. In general, the air quality in the South region is the best among all the regions because it has more precipitation, more vegetation, and coal is not the major energy source in the South. All northern areas (the North, North-East, and North-West regions) have serious problems with regard to DP because of their geographical and weather characteristics. In these regions, the coverage of vegetation is lower because of less precipitation, and strong winds transport the soil from the Loess Plateau to the plains. Furthermore, coal burning is also the major source of DP pollution.

The long-run relationship obtained using the between estimation is shown in columns 3 and 4 of Tables 2–4. It is interesting to find that most of the estimates are insignificant. The insignificance of the income terms in most of the cases shows that the relationship between time-average air pollution and time-average

Table 5. Time effect estimates

| | $SO_2$ | | $NO_X$ | | DP | |
|---|---|---|---|---|---|---|
| Year | (1) | (2) | (1) | (2) | (1) | (2) |
| 1992 | 2.381*** | 1.351 | 2.796*** | 2.147*** | 1.825*** | 0.113 |
| 1993 | 0.035 | 0.016 | 0.029 | 0.036 | –0.015 | –0.053 |
| 1994 | 0.078 | 0.036 | –0.030 | –0.035 | –0.119 | –0.192 |
| 1995 | –0.067 | –0.096 | –0.051 | –0.046 | –0.167 | –0.253** |
| 1996 | –0.189 | –0.196 | –0.028 | –0.023 | –0.261** | –0.321** |
| 1997 | –0.295** | –0.280* | –0.055 | –0.052 | –0.298*** | –0.346*** |
| 1998 | –0.378*** | –0.323** | –0.035 | –0.025 | –0.310*** | –0.318*** |
| 1999 | –0.428*** | –0.335* | –0.003 | 0.017 | –0.331*** | –0.295*** |
| 2000 | –0.530*** | –0.410** | –0.085 | –0.049 | –0.389*** | –0.322*** |
| 2001 | –0.492*** | –0.338 | –0.008 | 0.040 | –0.369*** | –0.282*** |
| 2002 | –0.486*** | –0.297 | –0.001 | 0.062 | –0.453*** | –0.330*** |
| 2003 | –0.284** | –0.029 | 0.016 | 0.099 | –0.532*** | –0.348*** |
| 2004 | –0.332** | –0.065 | –0.006 | 0.076 | –0.612*** | –0.447*** |

Columns (1) and (2) report the fixed-effects estimates of the simple environmental Kuznets curve model and the model with all control variables included, respectively

*Significant at the 10% level; **significant at the 5% level; ***significant at the 1% level

per capita GDP might be very weak. This result leads us to further investigate the specific characteristics of the Chinese dataset.

It is noteworthy that China's economy grew rapidly over the study period. Our results indicate the fact that the time-average data for the cities might not be able to reflect the EKC pattern because the evolution of air pollution emissions over time in each city can be averaged out during a period of dramatic change. For example, as shown in Appendix 3, while city-average $SO_2$ gradually rises and then declines significantly as city-average GDP increases, the relationship between time-average $SO_2$ and time-average GDP per capita across cities still seems ambiguous. Consequently, the long-run pattern between air pollution and per capita income is indistinct in most of the cases.

This characteristic that Chinese pollution changes along with the time variation can also be checked by the estimated time fixed effects in Table 5. The time fixed effects of $SO_2$ and DP tend to be positive in the first few years and then become significantly negative from 1997 and 1996, respectively. This tendency partially indicates that the technology used to control air pollution in China has been improved during the study period. Similarly, while the time effects of $NO_X$ seem to change nonlinearly over time, the time effect is found to be large in 1992, and then to become negative or/and insignificantly different from zero from 1993 onward. However, we cannot observe the above changes in pollution from the time-average data and, therefore, the between estimator might not be able to reflect the EKC relationship.

Finally, some conclusions are drawn. First, we find that the EKC hypothesis is supported in the case of $SO_2$. This means that the income effect in relation to the EKC works, even though the political system in China is not yet open and democratic.

Second, the turning point in regard to the Chinese EKC occurred at an earlier stage of economic development.[14] O'Connor (1994) pointed out that there may be four reasons for a "latecomer's advantage": learning from experience, increased availability of technology, lower unit abatement costs, and increased exposure to international environmental pressures. Grossman and Krueger (1995) first pointed out that low-income countries might have a unique opportunity to avoid environmental deterioration along with economic growth by learning from history.[15] The lower value of the turning point found in the case of the Chinese EKC reveals that China has this advantage. Several other articles also support this finding (e.g., Vermer 1998; Mao 2001; World Bank 2001). Chinese environmental laws, law-making bodies, and other related regulations have been built upon the experiences of other countries. Pollution treatment techniques, clean production processes, and environmental monitoring have been mostly imported. Foreign technical and financial assistance agencies such as the World Bank and the Asian Development Bank have played important roles in improving China's environment. International conventions have also played a significant role in promoting environmental protection in China.

## 4 Conclusions

In recent years, mainland China has been successful in its economic accomplishments and has built up a fairly complete system of environmental management regulations and institutions. In this article, we use an instrumental variables approach to examine the relationship between China's economic growth and its air quality by using panel data for cities.

Through the exogeneity test, we find that the income and policy variables are endogenous. The regression results show that $NO_X$ was increasing as income increased. However, $SO_2$ confirms the EKC hypothesis. From the Chinese experience, we see that the income effect in relation to the EKC theory is still important even in a country that is under tight political control.

Compared with other countries' experiences, China entered the downward part of the EKC at an earlier stage of its development. This may be explained in terms of the "latecomer's advantage." China has learned from other countries' experiences in managing its environmental problems.

*Acknowledgments.* The authors thank the Chiang Ching Kuo Foundation for International Scholar Exchange for its generous financial contribution to the research, and Mr. Wei Cen for his outstanding research assistance.

---

[14] For example, Selden and Song (1994) estimated that the turning point for $SO_2$ exceeded $8000 in 1985 dollars by using cross-national panel data from the Global Environment Monitoring System (GEMS). Kaufmann et al (1998) estimated that the turning point for $SO_2$ exceeded $125 000 in 1985 dollars by using a dataset covering 23 countries. The turning point for $SO_2$ obtained in this article is about 17 293 RMB (US $2014 in 2000). This figure is similar to the result of another Chinese EKC study, Brajer et al (2008), which reported a value of 16 029 RMB for its quadratic model.

[15] In addition, Munasinghe (1999) stated that developing countries have gains in their economy and environment enabling them to "tunnel" through the EKC.

## References

Borghesi S (1999) The environmental Kuznets curve: a survey of the literature. In: Franzini M, Nicita A (eds) Economic institutions and environmental policy. Aldershot, Ashgate, pp 201–224

Brajer V, Mead RW, Xiao F (2008) Health benefits of tunneling through the Chinese environmental Kuznets curve (EKC). Ecological Economics 66:674–686

Cole MA, Rayner AJ, Bates JM (1997) The environmental Kuznets curve: an empirical analysis. Environment and Development Economics 2:433–450

Copeland B, Taylor M (2004) Trade, growth, and the environment. Journal of Economic Literature 42:7–71

de Groot H, Withagen CA, Zhou M (2004) Dynamics of China's regional development and pollution: an investigation into the environmental Kuznets curve. Environmental and Development Economics 9:507–539

Goldman MI, Tsuru S (1985) Economics of the environment and renewable resources in socialist systems. In: Kneese AV, Sweeney JL (eds) Handbook of natural resource and energy economics, vol 2. Elsevier, New York, pp 725–749

Grossman GM, Krueger AB (1991) Environmental impacts of a North American free trade agreement. National Bureau of Economic Research Working Paper 3914, NBER, Cambridge, MA

Grossman GM, Krueger AB (1995) Economic growth and the environment. Quarterly Journal of Economics 112:353–378

Houthakker HS (1965) New evidence on demand elasticities. Econometrica 33:277–288

Hung MF, Shaw D (2004) Economic growth and the environmental Kuznets curve in Taiwan: a simultaneity model analysis. In: Boldrin M, Chen BL, Wang P (eds) Human capital, trade and public policy in rapidly growing economies: from theory to empirics. Edward Elgar, Aldershot, UK, pp 269–290

Kaneko S, Managi S, Fujii H, Tsurumi T (2009) Does an environmental Kuznets curve for waste pollution exist in China? International Journal of Global Environmental Issues 9:4–19

Kaufmann RK, Davidsdottir B, Garnham S, Pauly P (1998) The determinants of atmospheric $SO_2$ concentrations: reconsidering the environmental Kuznets curve. Ecological Economics 25:209–220

Kuh E (1959) The validity of cross-sectionally estimated behaviour equations in time series applications. Econometrica 27:197–214

Liu L, Song M, Yokogawa H, Qu B (2008) Exploring the environmental Kuznets curve hypothesis between economic growth and farmland conversion in China. Journal of the Faculty of Agriculture, Kyushu University 53:321–327

Liu X, Heilig GK, Chen J, Heino M (2007) Interactions between economic growth and environmental quality in Shenzhen, China's first special economic zone. Ecological Economics 62:559–570

Lopez R (1994) The environment as a factor of production: the effects of economic growth and trade liberalization. Journal of Environmental Economics and Management 27:163–184

Mao Y (2001) Economic growth and environmental problems in China. In: Welfens PJJ (eds) Internationalization of the economy and environmental policy options. Springer, Berlin Heidelberg New York, pp 397–414

Munasinghe M (1999) Is environmental degradation an inevitable consequence of economic growth: tunneling through the environmental Kuznets curve. Ecological Economics 29:89–109

O'Connor D (1994) Managing the environment with rapid industrialization: lessons from the East Asian experience. OECD, Paris

Perrings CA (1987) Economy and environment: a theoretical essay on the inter-dependence of economic and environmental systems. Cambridge University Press, Cambridge

Pesaran MH, Smith R (1995) Estimating long-run relationships from dynamic heterogeneous panels. Journal of Econometrics 68:79–113

Pirotte A (1999) Convergence of the static estimation toward the long run effects of dynamic panel models. Economics Letters 63:151–158

Poon JPH, Casas I, He C (2006) The impact of energy, transport, and trade on air pollution in China. Eurasian Geography and Economics 47:1–17

Selden TM, Song D (1994) Environmental quality and development: is there a Kuznets curve for air pollution emissions? Journal of Environmental Economics and Management 27:147–162

Shen J (2006) A simultaneous estimation of the environmental Kuznets curve: evidence from China. China Economic Review 17:383–394

Song T, Zheng T, Tong L (2008) An empirical test of the environmental Kuznets curve in China: a panel cointegration approach. China Economic Review 19:381–392

Stern DI (1998) Progress on the environmental Kuznets curve? Environment and Development Economics 3:173–196

Stern DI (2004) The rise and fall of the environmental Kuznets curve. World Development 32:1419–1439

Taiwan Electrical and Electronic Manufacturers' Association (TEEMA) (2003) A survey of the environment and risk for investment in mainland China in 2003 (in Chinese). Business Weekly, Taipei

Vermer EB (1998) Industrial pollution in China and remedial policies. China Quarterly 156:952–985

World Bank (2001) China's air, land and water: environmental priorities for a new millennium. World Bank, Washington, DC

## **Appendix 1.** Regions and cities in China

Table 6. Regions and cities in China

| Region | Province or municipality | Cities |
|---|---|---|
| North | Beijing | |
| | Tianjin | Shijiazhuang, Baoding, Tangshan |
| | Hebei | Qinghuangdao |
| | Shanxi | Taiyuan, Yuncheng, Datong |
| | Shandong | Jinan, Changdao, Zibo, Qingdao |
| East | Shanghai | |
| | Jiangsu | Suzhou, Nantong, Nanjing, Xuzhou, Lianyungang |
| | Zhejiang | Hanzhong, Hangzhou, Ningbo, Wenzhou |
| South | Fujian | Sanming, Fuzhou, Xiamen |
| | Guangdong | Shenzhen, Zhuzhou, Zhuhai, Zhanjiang, Guangzhou |
| | Hainan | Haikou |
| Middle | Anhui | Anqing, Hefei |
| | Jiangxi | Jian, Pingxiang, Pingdingshan, Yichun, Yichang, Nanchang, Jingdezhen |
| | Henan | Jiaozuo, Zhengzhou, Luoyang, Kaifeng |
| | Hubei | Xiangfan, Wuhan |
| | Hunan | Hengyang, Huaihua, Changsha |
| North-East | Liaoning | Anshan, Shenyang, Anyang, Huludao, Dalian |
| | Jilin | Siping, Changchun, Jilin, Tumen |
| | Heilongjiang | Hegang, Qitaihe, Harbin, Daqing |
| North-West | Inner Mongolia | Huhehaote, Baotou, Hailaer |
| | Shaanxi | Baoji, Yanan, Xian |
| | Gansu | Jiayuguan, Lanzhou |
| | Qinghai | Geermu, Xining |
| | Ningxia | Shizuishan, Yinchuan |
| | Xinjiang | Hami, Wulumuqi |
| South-West | Guangxi | Baise, Hechi, Guilin, Nanning, Ganzhou, Wuzhou, Jiujiang, Changhai |
| | Sichuan | Zigong, Yibin, Nanchong, Leshan, Chongqing, Chengdu, Wanxian |
| | Guizhou | Guiyang, Liupanshui |
| | Yunnan | Gejiu, Kunming |
| | Tibet | Rikeze, Lhasa, Changdu |
| | Chongqing | |

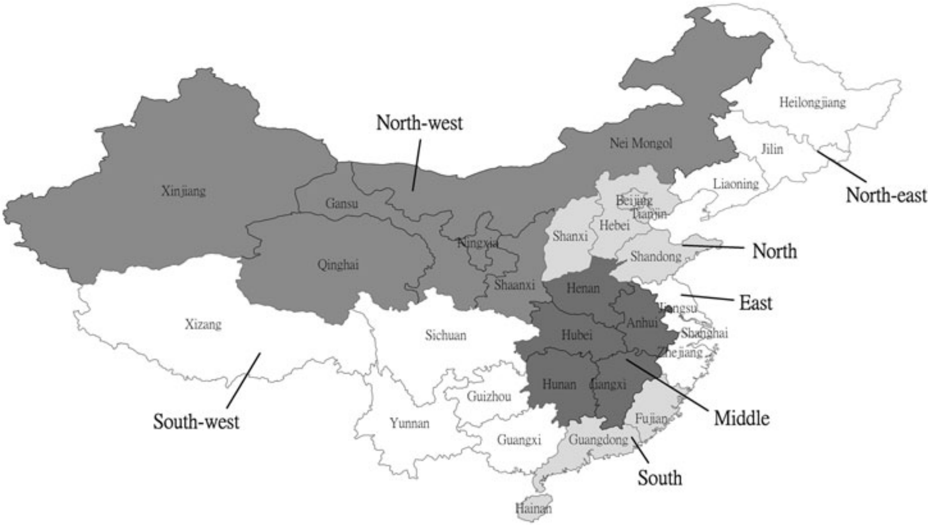

Fig. 1. Chinese regions and provinces

## **Appendix 2.** The acid rain control zone and $SO_2$ control zone

The acid rain control zone covers the areas where the pH of precipitation is lower than 4.5, sulfur deposition exceeds the critical load, and the $SO_2$ emissions are large. The $SO_2$ control zone includes areas where the average sulfur dioxide concentration exceeds the standard level. The $SO_2$ control zone is mainly located in the north and the acid rain control zone is mostly in the south.

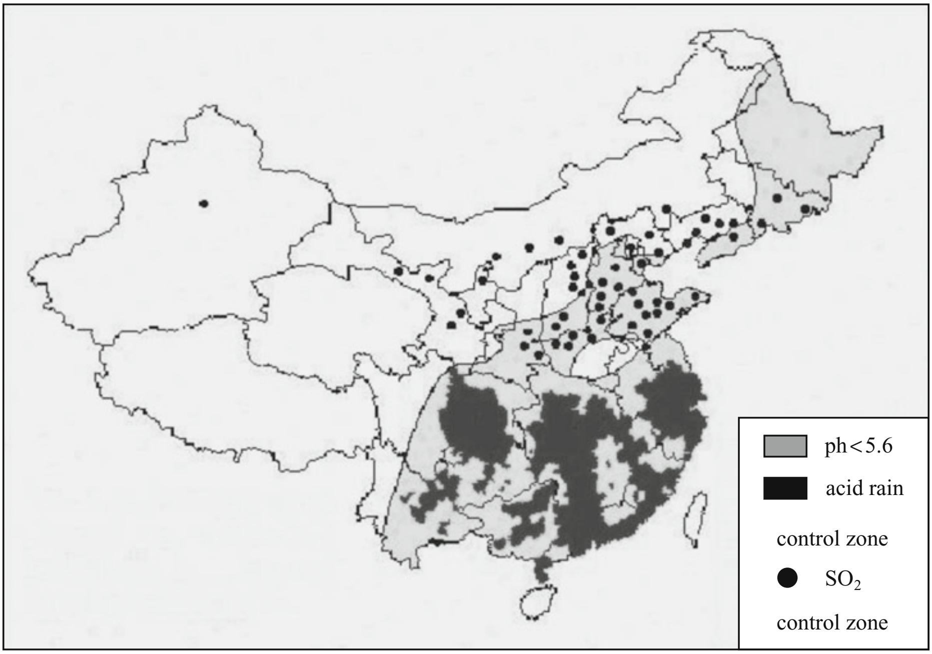

Fig. 2. The acid rain control zone and the $SO_2$ control zone. Source: State Environmental Protection Administration of China

**Appendix 3.** The city-average and time-average $SO_2$

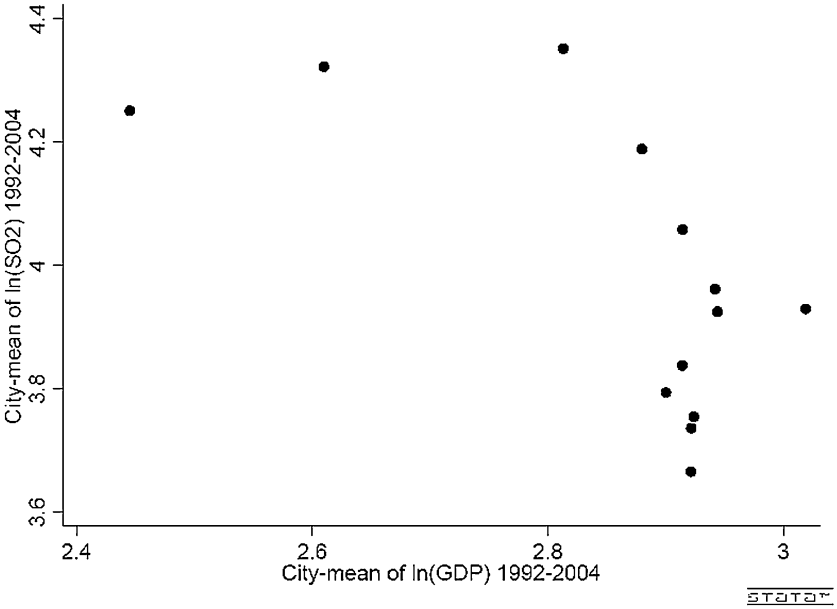

Fig. 3. Plot of city-average $SO_2$ against gross domestic product (GDP), 1992 to 2004

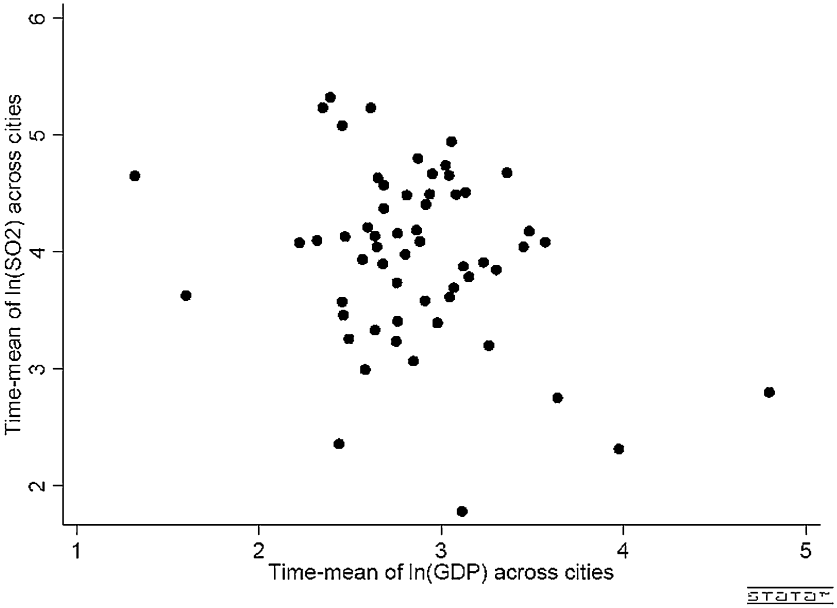

Fig. 4. Plot of time-average $SO_2$ against GDP across cities