Korea and the World Economy, Vol. 17, No. 3 (December 2016) 327-349

Regional Environmental Kuznets Curves and Their Turning Points for Air Pollutants in Korea*

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By using the air pollutant emissions data of 15 metropolitan cities and provinces in Korea for the period of 2000-2012, this study takes the empirical test of the Environmental Kuznets Curve (EKC) on the relationship between the air pollutants – SOx, NOx, CO, TSP – and the income per capita level. In addition to the traditional EKC model specification, this study tests the extended EKC model with additional control variables such as value added by manufacturing industry, population density etc. Furthermore, Hausman and Taylor model and Dynamic Panel System Generalized Methods of Moments (system GMM) are used to examine the robustness of the model specifications. It is found that the basic EKC exists only for NOx while the extended EKC holds for all three pollutants except for SOx. In particular, this study shows that the turning point of the EKC is 8-15 thousand US dollars of income per capita, which is in contrast to much lower values in existing studies that used the Korean data.

JEL Classification: O18, C23, Q53
Keywords: EKC, air pollutants, panel estimation, Hausman and Taylor, system GMM

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* Received November 9, 2016. Revised December 9, 2016. Accepted December 15, 2016. This work was supported by the National Research Foundation of Korea Grant funded by the Korean Government (MSIP) (2016, University-Institute cooperation program).
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1. INTRODUCTION

As the environmental pollution became more severe with the increase of the income per capita, the Club of Rome (1972) suggested a zero percent economic growth (Meadows *et al*., 1972). Many recent studies show that there is an inverse-U relationship between the environment and the stages of the economic development. The most representative study is Grossman and Krueger (1991), which present a model that supports the Environmental Kuznets Curve (EKC). Afterwards there have been several studies on the existence of the EKC. These are Grossman and Krueger (1995), Selden and Song (1994), Taguchi (2012), Roach (2013), Beck and Joshi (2015) etc.

In addition, Kim (2002) and Park (2013) are the studies on the existence of the EKC which uses the Korean data. However, they show different estimation results for Sulphur Oxide (SOx). Kim (2002) did not show the existence of the EKC, but Park (2013) shows the existence of the EKC for four areas out of six areas covered in the study. Therefore, it is necessary to investigate the sources of the differences of the estimation results. For example, the differences may exist for the time coverage of the data, the national or the regional characteristics, the assumed pollution index, or the estimation model specifications. Jung and Kim (2012) also verify the EKC, but it focuses on the relationship between Carbon Dioxide (CO_2) emissions and the income per capita.

With more fruitful data and improved robustness tests for the estimation specification, this study investigates the relationship between the environmental pollutants and the income per capita, and then calculates the level of the income per capita which reflects the turning point. The examined air pollutants are the regional data of SOx, Nitrogen Oxide (NOx), Carbon Monoxide (CO), and Total Suspended Particles (TSP), which are provided by the Ministry of Environment. The data are panel data for 15 cities and provinces in Korea from 2000 to 2012. As for the estimation methods, Hausman and Taylor model and Dynamic Panel System Generalized Method of Moments (system GMM) are employed.

The main results are as follows. First, the results show that there are EKC relationships for NOx and CO. The results of NOx and CO are similar to those from Kim (2002). However, Park (2013) shows that NOx for one region, and CO for three regions presented the EKC. This study does not support the EKC for TSP using system GMM with consideration of possible endogeneity, while Kim (2002) presents the existence of the EKC. For SOx, all the models used in this study did not show the existence of the EKC. As the EKC exists in NOx and CO, it could be stated that air pollutant policy has been successfully implemented since the early 2000s. Furthermore, as the income per capita increases, the trend of increasing pollutants is being phased out. But in the case of TSP, the nonlinear relationship with the income level across the country is not yet confirmed, but appropriate policies and measures are regardlessly needed.

Second, various model estimation results are used to calculate the income level, at which the turning point begins for each pollutant in each region. The income level of the turning point appeared different from existing domestic studies. In the case of Kim (2002), it is 3-5 thousand US dollars, and Park (2013) shows the result of 108-147 thousand Korean Won (KRW) (roughly equivalent to 100-140 US dollars). Compared with the results of international studies, these values are too low. However, the results from this study shows an income level of 8-15 thousand US dollars, consistent with other international studies. Therefore, the estimated turning point is in contrast to the existing Korean studies, but consistent with international studies.

The structure of this paper is comprised as the following. Section 2 reviews the previous studies, then section 3 explains the data and its descriptive statistics. Section 4 explains the empirical model, and section 5 presents the results of empirical analysis. Lastly, section 6 concludes with policy implications.

2. LITERATURE REVIEW

At the initial stage of the economic development, the degradation of the environmental quality and the aggravation of the environmental pollution are experienced in most of the countries due to industrialization and urbanization. However, as an economy develops, the environmental policies are implemented, and new technologies are adopted, which contribute to improving the environmental quality, and in turn, the pollution level decreases. The EKC shows an inverse-U relationship between the level of income per capita and the degree of pollutions (Grossman and Krueger, 1991, 1995; Selden and Song, 1994; Shafik, 1994; Taguchi, 2012; Roach, 2013; Beck and Joshi, 2015).

Grossman and Krueger (1991, 1995) conducted an empirical analysis on the EKC for Sulphur Dioxide (SO_2), smoke and suspended particulate matter (SPM) in urban areas of 42 countries for panel model of the year of 1977, 1982, and 1988, respectively. The estimation results show that there is an inverted U-shaped EKC in the case of SO_2 and smoke, and the turning point was around the income per capita of 8 thousand US dollars. However, the EKC did not exist in the case of SPM.

Many of the empirical results present different findings on the existence of the EKC, and the range of the turning point depends on the type of pollutants, period of analysis, pollution, environmental index and estimation methodology. However, recent studies focus more on analyzing the relationship between the air pollutants and the income per capita, and its implication instead of just verifying the existence of the EKC (Taguchi, 2012; Roach, 2013; Beck and Joshi, 2015).

By using system GMM, Taguchi (2012) analyzes the relationship of the real income per capita and the air pollutants such as sulphur and carbon for 19 Asian countries from 1950 to 2009. The empirical results show that there is an EKC for both sulphur and carbon emissions. The turning point of income level is about 10 thousand US dollars for sulphur and about 50 thousand US dollars for carbon. Roach (2013) analyzes the empirical relationship between the real per capita income and CO_2 emissions for 50 states in the United States from 1980 to 2010 with difference Generalized Method of Moments (GMM), and fixed effects models. The empirical result presents that there is an EKC between the CO_2 emissions and the real per capita income, and the turning point is at the income level of about 16-17 thousand US dollars.

Beck and Joshi (2015) select 66 OECD and Non-OECD countries with the data of CO_2 emissions (1980-2008), and applied difference GMM for estimating the relationship between the real per capita income and CO_2 emissions. The result shows that there is a N-shaped relationship between CO_2 emissions and the real per capita income among OECD countries, while an inverted U-shaped EKC curve is found among Non-OECD countries in Asia and Africa.

There are some empirical studies on the EKC with the Korean data. Kim (2002) uses random coefficient model to test the existence of the EKC in Korea's metropolitan area – Seoul, Incheon, Gyeonggi – from 1985 to 1999. The result shows that there is an EKC for TSP, CO, and Nitrogen Dioxide (NO_2). The turning point is about 3,000-5,000 US dollars, but in the case of SO_2, the EKC did not exist.

Park (2013) analyzes the relationship between the pollution emissions and the regional GDP per capita for six regions – Seoul metropolitan area, Central area, Honam area, Daegyeong area, Southeast area, Gangwon-Jeju area – from 1988 to 2008. SOx, NOx, TSP, and CO are the pollutants used to estimate the EKC. The EKC hypothesis was confirmed in one area for NOx and TSP and three areas for CO. Turning point was about 108-147 thousand KRW, which is very unrealistic.

Table 1 summarizes the literatures on the estimation of the EKC. First, it is found that every study has different objectives with different data points, and the conclusions on the EKC existence are different, depending on the types of pollutant, the objective of the study, and the methods of analysis. Second, the EKC studies have been continuously conducted since 1990s, and the econometric methods are becoming more complicated; therefore, it is necessary to select a proper estimation method, considering the characteristics

Table 1 Summary of Literature Reviews on EKC

Author (Year)	Subject and Period	Dependent Variable	Methods and Major Results
Grossman and Krueger (1991, 1995)	42 countries/ 1977, 1982, 1988	SO_2, Smoke, SPM	-Assume random effect model -Existence of EKC in SO_2, Smoke
Selden and Song (1994)	30 countries/ 1973-1984	SO_2, NOx, SPM, CO	-Fixed effect model and random effect model -Existence of EKC in SO_2, NOx, SPM
Taguchi (2012)	Asia 19 countries/ 1950-2009	SO_2, CO_2	-System GMM -Existence of EKC in SO_2, CO_2
Roach (2013)	U.S. 50 States/ 1980-2010	CO_2	-GMM difference and Fixed effect model -Existence of EKC in CO_2
Beck and Joshi (2015)	67 countries/ 1980-2008	CO_2	-GMM difference -N shape curve in OECD countries -Existence of EKC among Non-OECD (Asia, Africa)
Korean Studies			
Kim (2002)	Seoul metropolitan area/1985-1999	SPM, SO_2, NO_2, CO	-Random coefficient model -Existence of EKC in SPM, NO_2, CO -No existence of EKC in SO_2
Jung and Kim (2012)	Korea/1981-2008	CO_2	-Regression analysis using time-series data -Existence of EKC in CO_2
Park (2013)	6 areas in Korea/1988-2008	SOx, NOx, TSP, CO	-Period SUR model -Existence of EKC in 4 area for SOx, 3 areas for CO, 1 area for NOx and TSP

Source: Authors' summary with literature reviews.

of data, and the objectives of a study. Third, the studies for Korea analyze several areas within Korea, or conducted a time-series analysis but estimated a very low turning point of income per capita.

This study is different from the previous studies on Korea. First, we analyze 15 regional data, which are more detailed. Second, the emissions per capita of SOx, NOx, CO and TSP are used, which minimize the arbitrary selection of air pollutants. Third, the existence of the EKC is estimated with different models and estimation methodologies. The robustness check is conducted with additional independent variables, and various econometric methodologies, such as Hausman and Taylor model, and system GMM.

3. DATA

This study analyzes whether an inverted U-shaped EKC relationship between the income per capita and the air pollution exists using the data of air pollutants and the real per capita income for 15 cities and provinces in Korea. The air pollutants data of SOx, NOx, CO, and TSP is provided by the Ministry of Environment. Each air pollutant is divided by the registered population in each city or province, and it is used as the per capita air pollutant.

Table 2 Per Capita Air Pollutants in 15 Cities and Provinces

(unit: kg)

	SOx			NOx			CO			TSP		
	1990	2000	2012	1990	2000	2012	1990	2000	2012	1990	2000	2012
Seoul	13.2	1.1	0.4	12.3	8.8	6.2	61.1	17.2	10.7	4.7	0.7	0.2
Busan	23.7	20.3	8.5	29.8	17.3	15.9	48.2	17.3	11.0	6.5	2.2	1.0
Daegu	17.6	4.4	1.8	12.3	13.7	10.0	49.7	18.0	14.1	5.2	1.6	0.8
Daejeon	16.2	3.4	0.9	12.7	13.0	8.5	51.1	17.9	13.0	4.8	1.1	0.5
Incheon	45.6	12.6	5.7	29.4	21.6	16.4	49.1	22.2	15.4	7.3	2.0	1.0
Gwangju	13.9	1.4	0.6	12.2	9.9	8.3	56.5	16.4	10.8	5.4	0.9	0.5
Ulsan	-	113.1	52.4	-	56.3	53.6	-	33.1	30.0	-	17.7	4.8
Gyeonggi	26.2	6.5	1.4	14.6	18.0	14.0	33.2	18.2	12.7	4.5	1.8	0.9
Gangwon	67.0	28.8	14.7	33.9	42.4	51.0	50.7	24.3	33.1	27.5	20.0	6.4
Chungbuk	40.9	17.4	7.8	19.6	34.9	41.1	44.4	23.7	38.8	11.2	7.2	5.8
Chungnam	51.6	26.1	40.7	25.6	46.3	68.4	38.0	24.8	39.3	24.9	27.4	26.2
Jeonbuk	33.6	9.7	3.7	13.0	20.8	22.0	38.2	20.6	28.3	7.9	2.6	2.5
Jeonnam	78.4	54.6	44.0	35.4	62.0	58.7	31.3	24.8	40.7	19.5	17.2	18.7
Gyeongbuk	9.2	31.1	17.1	35.9	44.3	39.6	40.9	23.4	42.8	23.6	11.7	23.2
Gyeongnam	99.9	28.8	11.5	47.6	29.5	30.3	51.6	20.6	22.8	15.7	12.6	4.8
Nationwide	37.6	11.3	8.4	21.6	21.4	21.7	46.4	17.6	19.3	9.8	1.9	4.3

Source: Organize the table using data from Ministry of Environmental website “Statistics Portal” (http://stat.me.go.kr/nesis/index.jsp, retrieved on April 10, 2016).

Table 2 presents the per capita air pollutants in each city or province. Analysis period is from 2000 to 2012, but in order to figure out the emission trends, we provide data in specific year of 1990, 2000, 2012. First, it is worthwhile to note that in 1990s the SO_2 emission is reduced substantially. Reduction rates from to 2000 in almost all regions were higher than those from 2000 to 2012. Especially the emission in the metropolitan area of 2012 is lower than that in the other areas of Seoul (0.4kg), Incheon (5.7kg) and Gyeonggi (1.4kg). This is mainly due to the policies and measures to improve the air quality in the metropolitan area with the "Special Act on the Improvement of Air Quality in Seoul Metropolitan Area" of 2003.

In 2012, there is a huge gap among regions regarding the management of SOx emissions. Ulsan (52.4kg), Gangwon (14.7kg), Chungnam (40.7kg), Jeonnam (44.0kg), and Gyeongnam (11.5kg) have reduced the SOx emissions since 1990, but the SOx emissions in these regions are relatively high compared to other areas, particularly the metropolitan areas. Additional potentials to reduce SOx emissions in these regions may be available.

In the case of NOx, there is no clear improvement. NOx emissions from Gyeonggi and metropolitan cities in 2012 are lower than those in 1990s. However, NOx emissions of Gangwon, Chungnam, and Jeonbuk in 2012 are higher than those in 1990. This result means that there could be certain regional gaps regarding the management of NOx emissions among regions.

The trend of CO emissions shows a different pattern compared to those of SOx and NOx. Seoul and other metropolitan cities show distinct decreasing trends from 1990 to 2012. However, CO emissions in other regions, including Gyeonngi, has been decreased between 1990 and 2000 but it increases between 2000 and 2012. TSP emissions decreases in almost all regions except Chungnam, Jeonnam, Gyeongbuk where those emissions are relatively high compared to other areas.

There are not many indicators that could be considered to analyze the relationship between the per capita income and the pollutions, since there is a causality between the real income and the variables for economic development, which are assumed to affect the air pollutions. The key variables for this study are the industrial structure of each region and the population. For the industrial structure of each region, the share of manufacturing sector in gross value-added in the region is used. For the population, the population density of each region is used.

The shares of the manufacturing sector in Seoul, Busan, Daegu, and Daejeon have slightly changed, but those in Incheon and Gyeonggi have remarkably decreased. In comparison, the shares of the manufacturing sector in Chungbuk, Jeonbuk, Gyeongbuk have increased. The population density shows variations among regions. The list of variables is shown in table 3.

Table 3 Real Per Capita Income, Share of Manufacturing, and Population Density

	Real Per Capita Income (10,000 KRW)		Share of Manufacturing (%)		Population Density (person/km^2)	
	2000	2012	2000	2012	2000	2012
Seoul	1,012	1,811	6	6	16,659	16,502
Busan	823	1,555	20	20	4,911	4,462
Daegu	825	1,470	24	24	2,854	2,794
Daejeon	805	1,534	19	18	2,587	2,841
Incheon	776	1,421	40	29	2,614	2,676
Gwangju	798	1,447	22	29	2,759	3,013
Ulsan	971	1,883	66	72	981	1,053
Gyeonggi	886	1,479	41	35	902	1,176
Gangwon	748	1,336	13	10	91	89
Chungbuk	783	1,415	39	42	201	208
Chungnam	809	1,424	40	57	219	249
Jeonbuk	761	1,383	26	29	239	223
Jeonnam	715	1,313	32	42	170	144
Gyeongbuk	794	1,405	46	50	146	139
Gyeongnam	785	1,428	43	47	289	308
Nationwide	860	1,531	29	31	464	508

Notes: 1) Real per capita income is nominal disposable per capita income converted into real value with consumer price index of 2010. 2) Share of manufacturing is in percentage, which is converted ratio of value-added of manufacturing in gross value added in the region. 3) Nationwide data is from the Statistics Korea.

Source: The Statistics Korea website, “Korean Statistical Information Service” (http://kosis.kr/statisticsList/statisticsList_01List.jsp?vwcd=MT_ZTITLE&parmTabId=M_01_01, retrieved on April 10, 2016).

4. MODEL

The basic model for empirical analysis is as follows.

$$\ln E_{i,t} = \alpha + \beta_1 \ln Y_{i,t} + \beta_2 \left(\ln Y_{i,t}\right)^2 + e_{i,t}. \qquad (1)$$
$$t = 2000, \cdots, 2012 \qquad i = 1, \cdots, 15$$

$E_{i,t}$ is per capita air pollutants at year (t) in each city or province (i). Air pollutants are SOx, NOx, CO, and TSP. $Y_{i,t}$ means per capita income and its square is included to estimate whether an inversed U-shaped EKC exists. All variables are converted into natural log. $e_{i,t}$ is an error term which is assumed to be normally distributed.

In order to verify the robustness of the analysis, the basic model is extended to equation (2), with additional independent variables.

$$\ln E_{i,t} = \alpha + \beta_1 \ln Y_{i,t} + \beta_2 \left(\ln Y_{i,t}\right)^2 + \beta_3 X_{i,t} + u_i + \theta_t + e_{i,t}. \qquad (2)$$

$X_{i,t}$ is a set of control variables, which are the share of the manufacturing sector, and the population density. u_i reflects a regional effect and θ_t reflects a year effect. And $e_{i,t}$ is an error term. In fixed effects model, u_i is not estimated. In this case, it could be estimated by random effects model. However, since u_i as error term is assumed probability distribution in random effect model, it is necessary to verify the panel data structure. Therefore, through Hausman test, the estimation of u_i in equation (2) tests the hypothesis, $\text{cov}\left(X_{i,t}, u_i\right) = 0$. Through test results, the model specification to be either fixed effects model or random effects model is decided.

In the case of the error term u_i in equation (2), it has a correlation with the explanatory variable $X_{i,t}$, and in Hausman test, consistent estimators can be derived by fixed effects model. However, when equation (2) is applied, u_i cannot be estimated. In this case, Hausman and Taylor model with

Table 4 Definition of Variables and Sources

Variables	Definitions	Sources
Air Pollutants Emission Per Capita (kg)	SOx, NOx, CO, TSP	Statistics Portal provided by the Ministry of Environment
Real Per Capita Income (10,000 KRW)	Total disposable income of individual is an actualized form of consumer price index in 2010	Korean Statistical Information Service provided by the Statistics Korea
Ratio of Value-added of Manufacturing (%)	Ratio of value-added of manufacturing contrast to value-added of total region	
Population Density (person/km^2)	Population (person) per area (km^2)	
Seoul Metropolitan Area Dummy Variable	Seoul metropolitan area=1, else=0	
Metropolitan City Dummy Variable Except Seoul Metropolitan Area	Metropolitan city except Seoul metropolitan area=1, else=0	

instrumental variables is used to estimate u_i. [1)]

Table 4 lists the definition of variables and their sources.

There is one more factor to be considered. The current level of air pollutant could be affected by the past air pollutant level. For example, if emissions level in the past was higher, the current emissions level could be lowered with policies and counter measures. Furthermore, the characteristics of air pollutant make current level high, if the past emission was high. Therefore, analysis of dynamic panel model, which reflects the past air pollutant emissions level as a control variable, is specified. The dynamic analysis also tests the robustness of empirical results by estimating fixed effects model, random effects model and Hausman and Taylor model.

Equation (3) is the dynamic panel model, which includes lagged dependent variable as explanatory variable.

$$\ln E_{i,t} = \alpha + \beta_0 \ln E_{i,t-1} + \beta_1 \ln Y_{i,t} + \beta_2 \left(\ln Y_{i,t}\right)^2 + \beta_3 X_{i,t} + u_i + \theta_t + e_{i,t}. \quad (3)$$

1) Detailed explanation of Hausman and Taylor estimation can be referred to Cameron and Trivedi (2009), pp. 290-293, and Hausman and Taylor (1981).

In order to consider possible endogeneity of the lagged dependent variable, system GMM estimation methodology proposed by Arellano and Bover (1995) and Blundell and Bond (1998) is applied.

Adequacy of system GMM could be verified by Arellano and Bond (1991) autocorrelation test (AR test) and Sargan test. In system GMM, past variable of dependent variable is an instrumental variable, and if the use of these instrument variables become appropriate, the first autocorrelation should be present, while the second autocorrelation should not, which is AR test. In addition, the number of instrumental variables is larger than the explanatory variables in dynamic panel model, and the over-identification problem should be tested, which is Sargan test.

5. ESTIMATION RESULTS

The empirical results on the basic model are shown in table 5. The basic model is specified with a reference to Selden and Song (1994) and Grossman and Krueger (1995).[2] It specifies only the real per capita income and its square as the explanatory variables. Hausman test statistic indicates that the random effects model is appropriate for NOx, and the fixed effects model is appropriate for the rest of pollutants.

If the empirical results show the existence of the EKC, the coefficient of the income variable should be positive ($\beta_1>0$), while the coefficient of squared income should be negative sign ($\beta_2<0$). The results represent the EKC existence in NOx, and no EKC is found in the rest of air pollutant.

The basic model cannot verify the existence of the EKC precisely. It is necessary to control the time effect, and the regional effect of the pollutants. It is also necessary to verify that the estimation results are consistent regardless

[2] Selden and Song (1994) included the population density as a control variable and used year dummy variable as the control of effectiveness of year. For year dummy variable, year from 1979 to 1981 is 1, while others are 0, and 1982 to 1984 marked as 1, while others are 0. In Grossman and Krueger (1995), year dummy variable is not considered for the EKC estimation, and used the population density and dummy variable for regional characteristics as the control variable.

Table 5 Estimation Results for Basic Model

	Model 1 SOx (Fixed effects)	Model 2 NOx (Random effects)	Model 3 CO (Fixed effects)	Model 4 TSP (Fixed effects)
(Ln) Real Per Capita Income	–5.466 (5.067)	19.951*** (3.491)	2.313 (3.585)	11.492 (9.422)
(Ln) Square of Real Per Capita Income	0.343 (0.362)	–1.444*** (0.249)	–0.166 (0.256)	–0.811 (0.673)
Constant	23.659 (17.738)	–65.643*** (12.223)	–5.100 (12.548)	–39.365 (32.984)
Number of Observations	195	195	195	195
Number of Metropolitan Areas/provinces	15	15	15	15
Within *R*-Squared	0.233	0.231	0.003	0.011
Between *R*-Squared	0.037	0.011	0.033	0.390
Overall *R*-Squared	0.033	0.026	0.003	0.003
Hausman Statistics (*p*-value)	6.15 (0.046)	5.26 (0.072)	7.01 (0.030)	9.18 (0.010)

Notes: 1) Numbers in the parenthesis are standard errors. 2) Significance level is the following: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. 3) Result of Hausman test shows that in model 2, random effects model is appropriate and the rest of the models are appropriate to fixed effects model. In this table, the estimate results of adequate model are presented.

of the model specification.

In table 6, the estimation results of a model with additional control variables verify the existence of the EKC in NOx, like in the basic model. However, in the case of SOx, there is a significant U-shaped relationship between the income per capita and the emissions. If the real per capita income increases, SOx emissions decreases and the diminishing trend slows down at the high income levels.

In order to test the robustness of the estimation results above, more sophisticated econometric specifications are applied. The estimation results of different model specifications are presented in table 7, table 8 and table 9. Table 7 shows the estimation results with additional control variables. Table 8 and table 9 present the results of Hausman and Taylor method and the results of system GMM, respectively.

Table 7 shows the estimation results of the fixed effect and the random effect model with additional control variables and dummy variables. There is no

Table 6 Estimation Results with Additional Control Variables

	Model 5 SOx (Fixed effects)	Model 6 NOx (Random effects)	Model 7 CO (Fixed effects)	Model 8 TSP (Fixed effects)
(Ln) Real Per Capita Income	–10.226*** (5.050)	19.568*** (3.483)	3.042 (3.477)	6.136 (9.576)
(Ln) Square of Real Per Capita Income	0.681* (0.361)	–1.420*** (0.249)	–0.229 (0.249)	–0.437 (0.685)
Share of Manufacturing (%)	0.014*** (0.007)	0.012*** (0.004)	0.026*** (0.005)	0.030*** (0.013)
(Ln) Population Density	–2.125*** (0.532)	–0.288*** (0.056)	–0.395 (0.366)	–2.764*** (1.008)
Constant	54.147*** (19.006)	–62.564*** (12.232)	–5.329 (13.085)	–2.760 (36.038)
Number of Observations	195	195	195	195
Number of Metropolitan Areas/provinces	15	15	15	15
Within *R*-Squared	0.318	0.249	0.160	0.085
Between *R*-Squared	0.519	0.743	0.629	0.635
Overall *R*-Squared	0.497	0.708	0.483	0.492
Hausman Statistics (*p*-value)	18.85 (0.001)	7.76 (0.101)	22.87 (0.000)	21.18 (0.000)

Notes: 1) Numbers in the parenthesis are standard errors. 2) Significance level is the following: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. 3) Result of Hausman test shows that in model 6, random effects model is appropriate and the rest of the models are appropriate to fixed effects model, which only reveals the estimate result of adequate model.

EKC for SOx. The estimation results with NO, CO and TSP indicate that the EKC exist with proper signs and statistical significance for income variables.

The estimation results of the control variables are different for the pollutants. The share of the manufacturing sector is included, since the main source of pollution is the industrial facilities. The coefficient estimation for this variable is significantly positive in model 10 and model 11, which means that as the activities of the manufacturing sector increase, NOx and CO emissions also increase. The main sources of NOx are the chemical internal combustion facilities. In the case of CO, the industrial process and manufacturing process, the metal treatment process by Nitric Acid, and the transportation sector are the main sources of pollution.

Table 7 Estimation Results with Year Dummy Variables

	Model 9 SOx (Fixed effects)	Model 10 NOx (Random effects)	Model 11 CO (Fixed effects)	Model 12 TSP (Fixed effects)
(Ln) Real Per Capita Income	4.744 (6.861)	13.078*** (4.378)	17.629*** (4.032)	48.090*** (11.793)
(Ln) Square of Real Per Capita Income	–0.328 (0.465)	–0.935*** (0.303)	–1.333*** (0.273)	–3.540*** (0.799)
Share of Manufacturing (%)	0.006 (0.007)	0.012*** (0.004)	0.018*** (0.004)	0.002 (0.012)
(Ln) Population Density	–1.748*** (0.554)	–0.335** (0.138)	–0.394 (0.326)	–2.423** (0.952)
Seoul Metropolitan Area Dummy Variable (Seoul, Incheon, Gyeonggi=1, else=0)		0.133 (0.473)		
Metropolitan City Dummy Variable except Seoul Metropolitan Area (Metropolitan =1, else=0)		0.100 (0.416)		
Year Dummy (2001=1, else=0)	–0.293***	–0.037 (0.097)	–0.083 (0.064)	–0.673*** (0.057)
Year Dummy (2002=1, else=0)	–0.378***	0.024 (0.131)	–0.040 (0.081)	–0.667*** (0.077)
Year Dummy (2003=1, else=0)	–0.400**	0.070 (0.177)	0.001 (0.106)	–0.642** (0.104)
Year Dummy (2004=1, else=0)	–0.569**	0.123 (0.242)	–0.029 (0.141)	–0.682 (0.142)
Year Dummy (2005=1, else=0)	–0.585*	0.073 (0.304)	–0.012 (0.176)	–0.554 (0.179)
Year Dummy (2006=1, else=0)	–0.498	0.069 (0.348)	0.105 (0.201)	–0.493 (0.205)
Year Dummy (2007=1, else=0)	–0.591	0.018 (0.411)	0.136 (0.236)	–0.215 (0.242)
Year Dummy (2008=1, else=0)	–0.580	–0.137 (0.454)	0.060 (0.260)	–0.113 (0.267)
Year Dummy (2009=1, else=0)	–0.646	–0.166 (0.489)	0.247 (0.280)	–0.085 (0.287)
Year Dummy (2010=1, else=0)	–0.639	–0.121 (0.552)	0.246 (0.315)	0.190 (0.324)
Year Dummy (2011=1, else=0)	–0.611	–0.137 (0.593)	0.539 (0.337)	0.481 (0.348)
Year Dummy (2012=1, else=0)	–0.670	–0.087 (0.629)	0.593 (0.358)	0.589 (0.370)
Constant	–2.911 (27.229)	–40.641** (16.016)	–53.181*** (16.002)	–145.396*** (46.799)
Number of Observations	195	195	195	195
Number of Metropolitan Areas/provinces	15	15	15	15
Within *R*-Squared	0.412	0.389	0.472	0.352
Between *R*-Squared	0.508	0.764	0.543	0.578
Overall *R*-Squared	0.490	0.737	0.456	0.467
Hausman Statistics (*p*-value)	11.44 (0.022)	6.22 (0.183)	17.96 (0.001)	18.17 (0.001)

Notes: 1) Numbers in the parenthesis are standard errors. 2) Significance level is the following: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. 3) Result of Hausman test shows that in model 10, random effects model is appropriate and the rest of the models are appropriate to fixed effects model.

Table 8 Estimation Results of Hausman and Taylor

	Model 13 SOx	Model 14 NOx	Model 15 CO	Model 16 TSP
(Ln) Real Per Capita Income	5.929 (6.753)	11.940*** (4.584)	18.412*** (3.901)	51.096*** (11.432)
(Ln) Square of Real Per Capita Income	–0.380 (0.460)	–0.873*** (0.314)	–1.366*** (0.267)	–3.678*** (0.782)
Share of Manufacturing (%)	0.007 (0.007)	0.012** (0.005)	0.019*** (0.004)	0.004 (0.012)
(Ln) Population Density	–1.555*** (0.520)	–0.580* (0.336)	–0.271 (0.286)	–1.932** (0.859)
Seoul Metropolitan Area Dummy Variable (Seoul, Incheon, Gyeonggi=1, else=0)	3.053* (1.762)	0.893 (1.079)	0.758 (0.918)	4.684* (2.808)
Metropolitan City Dummy Variable except Seoul Metropolitan Area (Metropolitan =1, else=0)	3.052** (1.544)	0.772 (0.948)	0.604 (0.807)	4.383* (2.466)
Constant	–11.482 (26.038)	–34.558** (17.462)	–58.121*** (14.861)	–165.073*** (43.799)
Number of Observations	195	195	195	195
Number of Metropolitan Areas/provinces	15	15	15	15
Wald Statistics (*p*-value)	120.20 (0.000)	122.01 (0.000)	150.44 (0.000)	90.88 (0.000)

Notes: 1) Numbers in the parenthesis are standard errors. 2) Significance level is the following: *** p<0.01, ** p<0.05, * p<0.1. 3) Year Dummy variable is included in the analysis but, it is not shown in the table. 4) Share of manufacturing and population density are used as endogenous variables, which are changed by time.

The population density has significantly negative correlations with the pollutants in models 9, 10 and 12. Selden and Song (1994) shows a negative correlation between the pollution and the population density. It is because the existence of the EKC is because as the income level goes up, the demand for higher environmental quality increases and the industrial structural change in both production and consumption occur. Hence, when the population per unit area increases, the environmental quality improves, so the coefficient estimation of the population density becomes negative.

The regional dummy variable for the capital area and the metropolitan area are not significant.

Table 8 describes the estimation results for additional robustness tests through Hausman and Taylor method. The analysis with Hausman and Taylor method verifies that there is no EKC for SOx, but NOx, CO, and TSP have EKC. The difference in the estimation results with those in table 7 is that there is no EKC for TSP.

Table 9 shows the estimation results of system GMM. In the estimation specification, one-year-lagged pollutant per capita as an additional explanatory variable is included to reflect dynamic characteristic of accumulation of air pollutants. The estimation results are quite similar to those in table 7 and table 8. The only differences are that there are EKC for NOx and CO with Sargan tests and AR tests in model 17 and model 18. However, the specification tests for the estimation results for TSP are rejected.

In order to test whether the EKC hypothesis holds by regions, various econometric methodologies and specification are used. The estimation results imply that NOx supports the existence of the EKC consistently in all models. In the case of CO emission, no EKC exists in the basic models 3 and 7, but the extended models 11, 15, and 18 with additional control variables and dummy variables support the EKC. The estimation results for TSP support the EKC only for system GMM estimation, but do not support the specification tests. The estimation results for SOx do not support the EKC for all model specifications. Therefore, it can be summarized that the EKC hypothesis holds only for NOx and CO emissions.

One more important finding in the study is to derive the turning point of the EKC. The turning points of NOx, CO, and TSP are calculated, and compared with the results of various estimation specifications in table 10. In general, the turning points with system GMM seem to be higher, compared to the results of other methods. In the case of NOx, it is at about 9,330-15,670 thousand KRW, for CO it is at about 7,440-13,490 thousand KRW, and the turning point for TSP is at about 8,910 -10,390 thousand KRW. The turning point can be converted to be about 8,000-15,000 US dollars. These turning points are quite consistent with the other international studies reviewed in

Table 9 Estimation Results of System GMM

	Model 17 NOx	Model 18 CO	Model 19 TSP
(Ln) (*t*–1) Per Capita Air Pollutants	0.878*** (0.084)	0.845*** (0.060)	0.880*** (0.076)
(Ln) Real Per Capita Income	7.687* (4.019)	9.610*** (3.257)	28.216*** (9.082)
(Ln) Square of Real Per Capita Income	–0.522* (0.282)	–0.667*** (0.228)	–1.976*** (0.633)
Share of Manufacturing (%)	0.002 (0.001)	0.002** (0.001)	0.002 (0.002)
(Ln) Population Density	–0.047 (0.032)	–0.019 (0.016)	–0.044 (0.066)
Seoul Metropolitan Area Dummy Variable (Seoul, Incheon, Gyeonggi=1, else=0)	–0.029 (0.049)	–0.062 (0.039)	–0.033 (0.110)
Metropolitan City Dummy Variable except Seoul Metropolitan Area (Metropolitan =1, else=0)	–0.026 (0.044)	–0.058* (0.035)	–0.004 (0.106)
Constant	–27.392* (14.225)	–33.962*** (11.541)	–100.160*** (32.310)
Number of Observations	195	195	195
Number of Metropolitan Areas/provinces	15	15	15
AR(1) *p*-value	0.000	0.000	0.004
AR(2) *p*-value	0.211	0.989	0.228
Sargan *p*-value	0.168	0.223	0.000

Notes: 1) Numbers in the parenthesis are standard errors. 2) Significance level is the following: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. 3) Year dummy variable is included but, it is not shown in the table. 4) GMM-type instrumental variables are the lagged dependent variables, the real per capita income and square of it, with the time difference applied from $t–1$ to $t–3$. However, in the case of a small sample, the number of instrumental variables become larger than the number of observations, which means an over fitting problem could occur. Therefore, we reduce the number of instrumental variables by using the 'collapse' option in order to reduce the number of instrumental variables. 5) The share of manufacturing sector and the population density are used for the difference equation and for the level of equation, Seoul metropolitan dummy variable, metropolitan city dummy variable, year dummy variable are used as instrumental variables.

Table 10 Estimation of Turning Point of Air Pollutants

(unit: thousand KRW)

	Fixed effects, Random effects	Hausman and Taylor	System GMM
NOx	about 9,860-10,900 (Random effects)	about 9,330	about 15,670
CO	about 7,440 (Fixed effects)	about 8,450	about 13,490
TSP	about 8,910 (Fixed effects)	about 10,390	-

Notes: 1) For SOx, EKC is not derived from all the models. 2) For CO EKC is not derived from the basic model. 3) For TSP, EKC is not derived from the system GMM.

section 2, even though the results of existing studies for Korea are unrealistically low.

6. CONCLUSION

This study analyzes the empirical relationship between the air pollutants and the income per capita for 15 cities and provinces in Korea from 2000 to 2012. In order to test the robustness of the results, this study extends the basic model with additional control variables, instrument variables and some dummy variables to reflect different conditions of each region. Further to test the robustness of model estimation, various estimation methods such as Hausman and Taylor method, system GMM are applied to check the existence of the EKCs for air pollutants.

The main findings are summarized as follows. First, SOx shows no EKC with all model specifications for the period of 2000 and 2012, which reflects the successful reduction of SO_2 emissions in 1990s. Second, for TSP, there is no existence of the EKC with system GMM, while the EKC exists with fixed effects model, and Hausman and Taylor method. Third, it is found that the EKC exists with all model specifications, except the basic model for CO. Fourth, it is shown that the EKC for NOx exists with all model specifications. To sum up, the existence of the EKC could be different for different pollutants in different regions.

What is important in this study is that the turning points of the EKC for all pollutants are realistically estimated as 8,000-15,000 dollars. They are quite consistent with other international studies while the values of the studies that used the Korean data tends to be unrealistically low.

This study suggests the following policy implications.

First, it is necessary to derive an environmental policy that could meet the demand of citizens for better quality of environment. In Korea, mandatory use of clean energy was introduced from 1988. Since then, as the standard of sulfur content steadily enhanced, it is rated to achieve drastic improvement of SOx emissions. In 1990s, the “Framework Act on Environmental Policy” and “Clean Air Conservation Act” were established. In 2003, “Special Act on the Improvement of Air Quality in Seoul Metropolitan” was also established. On the other hand, emission reductions for NOx, CO and TSP are relatively insufficient. Furthermore, actions for fine particles and ultrafine particles (PM 2.5) that recently emerged as major air pollution problems are not timely managed.

Second, it is necessary to accelerate the environmental-friendly innovation in the manufacturing sectors. As the share of manufacturing increases, the emissions of air pollutants also rises, based on the empirical findings in this study. It means in order to reduce the emissions, we need to decrease the manufacturing activities. However, it is not possible to decrease them, considering the role of manufacturing activities to the regional economies. Therefore, it is necessary to bring innovative environmental policies without hurting the manufacturing activities with environmentally friendly industrial processes or improvement of technology efficiency.

Recently, ultrafine particles have been a very sensitive environmental issue. In the past, it was technically hard to measure the ultrafine particles, but with the increased awareness of air pollution and development of technology, it has become one of the serious social issues.

Still, there are some limitations in this study. First, in the process of constructing the regional panel data, available data is limited and various variables that affect the air pollutants emissions could not be included. With more reliable data and variables, a more detailed EKC analysis could be feasible.

Second, since the analysis of this study is from 2000 to 2012, the huge reduction of SOx emissions in 1990s is not included. The limitation of data series is mainly due to the data compiling from local governments. For example, in Ulsan, the air pollutants data was aggregated from 1998, and the data of the real income per capita in each province is provided from 2000. Due to the data availability, the analysis covers from 2000. Therefore, the empirical results represent the existence of the EKC between the air pollutants and the income level since 2000.

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