The Effects of Economic Growth on Environmental Quality: Some Empirical Investigation for the Case of South Korea

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We explore the relationship between economic growth and environmental quality in South Korea. Economic growth is found to generate environmental pressure. Interpretation of the estimated results in association with historical changes of Korean environmental policies suggests that the problems of SO_2, NO_2, TSP and BOD and domestic waste in South Korea exhibit inverted U-shape relationship with economic growth(i.e., environmental Kuznets curve). The turning point of the curve is located around early 1980s, when the Korean environmental regulation and policies became stricter and effective in practical manner. This evidence suggests that in South Korea environmental protection requires policies and investments to be put into place to reduce environmental degradation. (*JEL* Classifications: O40, Q25, Q28)

I. Introduction

The traditional idea of "the limit to growth" developed by Meadow *et al.* (1972) shows the effect of economic growth on the environment in terms of a *trade-off.* This idea is based on two reasons: (i) the limited capacity of natural environments to receive the waste generated by the economic system; and (ii) the finite nature of exhaustible resources (Turner *et al.* 1994). The critics of the limit to growth points to a number of reasons why there may not be the

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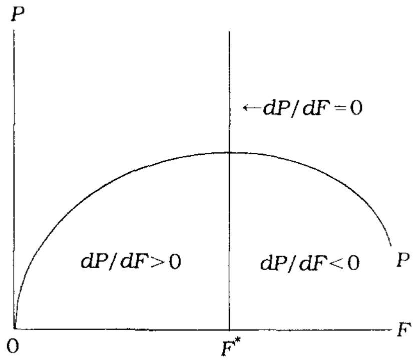

FIGURE 1
THE STYLIZED INVERTED U-SHAPE CURVE

limit to growth after all. Among these reasons are: (i) positive and increasing income elasticity for environmental quality; (ii) changes in the composition of production and consumption; (iii) increasing levels of education and environmental awareness; (iv) technological progress; and (v) more open political systems.[1] This implies that the economic growth trajectory for environmental problem is likely to depend upon both market forces and changes in environmental policies and regulations.

The emerging consensus is that at least some forms of environmental pollution exhibit the inverted U-shape relationship with economic growth. Figure 1 exhibits the stylised inverted U-shape curve with pollution level (P) graphed against income level (F). Pollution (P) increases when income level (F) is less than F^* and decreases once F^*. At the point F^*, P is not affected by F ($dP/dF=0$). There is nothing automatic about this relationship. It is not an inevitable relationship between income levels and particular environmental problems. The pattern for each environmental problem is linkely to reflect both market forces and changes in environmental policies and regulations.

López (1994) and Selden and Song (1995) focus theoretically on the impact of economic growth on environmental quality. Selden and Song (1995) re-examine the model of Foster (1973) with minor modification. They provide theoretical insights that embedded in Fo-

[1]See Radetzki(1992), Shafik(1994), World Bank(1992), Selden and Song (1994), Turner *et al.*(1994) and Common(1995).

ster's (1973) model is the possibility of the inverted U-shape curve, even if this need not occur in all cases. Treating environment as a factor of production and the direct determinant of social welfare, López's (1994) theoretical study shows that in the case of non-homothetic preferences the relationship between economic growth and pollution depends on the elasticity of substitution between conventional factors of production and pollution and on the relative degree of curvature of consumers' utility (i.e., the "relative risk-aversion" coefficient). According to López (1994), the lower the elasticity of substitution and relative curvature coefficient, increases the more likely it is that pollution increases with income. Under certain conditions,[2] an inverted U-shaped relationship between pollution and income is derived for the non-homothetic preference case.[3] However, Common (1995) points that for some impacts, irreversible damage may occur before the top of the inverted U-shaped curve is reached, and that the relationship need not hold for all impacts.[4]

Grossman and Krueger (1993, 1995), Shafik (1994), Selden and Song (1994), and Holtz-Eakin and Selden (1995) have conducted empirical studies on this issue. Grossman and Krueger (1993) explore some of the empirical evidence that bears on the likely environmental impacts of an increase in per capita GDP. By using cross-country panel data of the Global Environmental Monitoring System (GEMS),[5] Grossman and Krueger (1993) find that emission levels of sulfur dioxide (SO_2) and dark matter suspended in the air increase with per capita GDP at low levels of national income, but decrease with per capita GDP at higher levels of income (i.e., inverted U-shape relationship).[6] For the mass of suspended par-

[2]The critical assumption is the separability between income and pollution in the utility function.

[3]According to López (1994), in the case of homothetic preferences pollution is ever increasing with economic growth even if government policies are efficient and set the price of pollution to truly reflect its social marginal cost. This implies that in the long run economic growth in the absence of pollution-saving technical change would have to stop (p. 169). Even in the case of non-homothetic preference, pollution would always be increasing regardless of the degree of non-homotheticity of preferences when the elasticity of substitution between pollution and non-pollution inputs is zero.

[4]See Lim (1996) for theoretical analysis and more detailed literature survey on the relationship between economic growth and the environment.

[5]The World Health Organisation (WHO) publishes the series of air quality data in uban areas throughout the world.

ticles, however, in an given volume of air, the relationship between pollution and per capita GDP is found to be *monotonically* decreasing. Grossman and Krueger (1995) investigate the issue with more broad set of environmental indicators than their study in 1993. Grossman and Krueger (1995) find little evidence that environmental quality deteriorates steadily with economic growth. Rather, they find for most indicators that economic growth brings an initial phase of deterioration followed by a subsequent phase of improvement.

Shafik (1994) uses a wide range of environmental quality indicators.[7] He finds that environmental problems of safe water and sanitation improve with rising incomes. Others worsen and then improve (i.e., particulate and SO_2) and others worsen steadily (i.e., dissolved oxygen, solid wastes, and carbon emissions). Selden and Song (1994) focuses on emissions of four important air pollutants (i.e., suspended particulate matter, SO_2, oxides of nitrogen, and carbon monoxide). They find the inverted U-shape relationship for all four air pollutants. Holtz-Eakin and Selden (1995) examines the relationship between economic growth and CO_2 emissions. By using global panel data, they find a diminishing marginal propensity to emit (MPE) carbon dioxide as per capita GDP rises. Despite the diminishing MPE, their forecasts indicate that global emissions of CO_2 will continue to grow.

Previous empirical studies conduct econometric analysis with the cross-country panel data. The basic models used by those studies define the each pollutant as a function of per capita GDP. For example, Shafik (1994) uses various kinds of environmental indicators and tests basic models (i.e., linear, quadratic and cubic models). By using estimated results, Shafik (1994) finds which model has the best explanatory power for each environmental indicator. In addition to per capita GDP, variables of population density (Selden and Song 1994), fixed country and year effects (Holtz-Eakin and Selden 1995 and Grossman and Krueger 1993; 1995), time trend (Shafik 1994), or lagged income (Grossman and Krueger 1993;

[6]The turning point comes somewhere between $4,000 and $5,000 measured in 1985 US dollars.

[7]He tests 10 indicators: urban sanitation; safe water; annual and total deforestation; dissolved oxygen and fecal coliform in rivers; suspended particulate; ambient sulfur dioxide; municipal solid waste per capita, and cabon emission per capita.

1995) are used as exogenous variables in the estimated equations.

Analysis in respect of one country has been rare. Therefore, it is not certain whether the hypothesis of inverted U-shape relationship between economic growth and the environment holds true in *every* country. Even if it holds with some countries, it does not necessarily hold with other countries. Therefore, it is worthwhile to test the hypothesis with special focus on a specific country such as South Korea.

In Section II, we use some indicators such as the number of motor vehicles and cement production representing environmental pressure to compare these indicators with economic activity level. It will show the increasing environmental pressure along the economic growth path in South Korea. In Section III, using time series data of environmental quality indicators, environmental quality is analysed to see how it changes during the process of economic growth. This section investigates the hypothesis of the inverted U-shape curve for South Korea. Section IV summarises the results.

II. Environmental Pressure of Economic Growth in South Korea

An assessment of the environmental pressure of economic growth requires an appropriate choice of variables. In practice, the complex composition of the environment creates difficulties in measuring the change in its quality, because economic activity usually exerts pressure on many facets of the environment. There is no unobjectionable way to aggregate such impacts into a single measure of change. In explaining the environmental pressure of economic growth in Korea, we use some indicators such as total deforestation of the land area; number of motor vehicles; cement production; fertilizer production; primary energy (solid, liquid, gas and electricity) consumption; number of pigs; toilet soap production; and newsprint paper production. These indicators are generally considered as the main source of each category of environmental pollution. For example, the number of motor vehicles, cement production and primary energy consumption are considered as the main source of air pollution.

Economic growth is conventionally defined in terms of expansion of gross domestic products (GDP). Following Radetzki (1992), however,

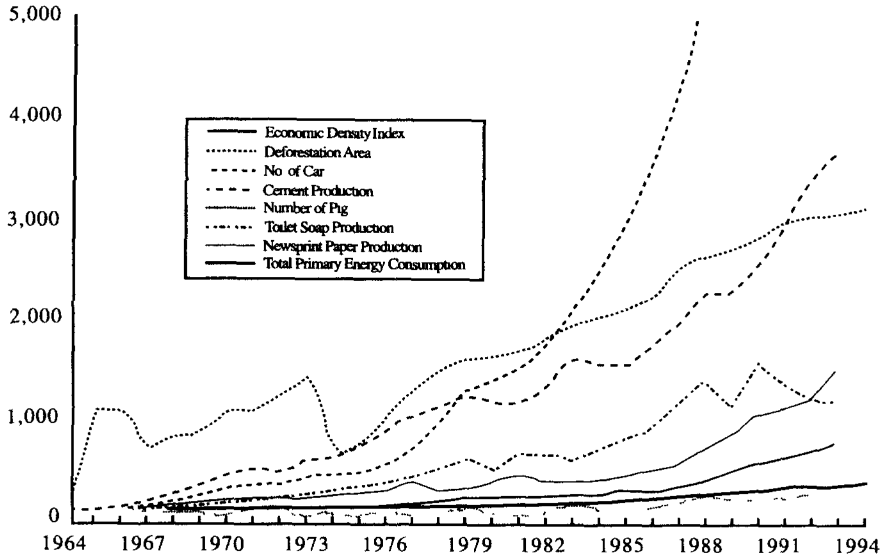

FIGURE 2

MOVEMENTS OF ECONOMIC DENSITY AND VARIOUS INDICATORS OF ENVIRONMENTAL PRESSURE

we use the concept "*economic density*" which is defined as GDP divided by population and the surface of Korea (=National Land) to measure the level and intensity of economic activity in a given area. The economic density, measured in 1985 prices, increased about 5.44% per annum between 1965 to 1994. However, data on indicators show an average annual growth rate of those indicators exceeding that of economic density (Figure 2).

As exhibited by Figure 2, economic growth have generated the environmental pressure in Korea. This is supported by the fact that the growth rates of almost and of indicators as the source of pollution are far higher than that of economic density during the periods of economic growth. This seems to support the argument for "the limit to growth". Despite the increasing environmental pressure during the periods of economic growth, however, it is commonly accepted that it is an oversimplification to see the relationship between economic growth and the environmental quality simply in terms of a trade-off. Even if the economic growth process causes environmental pressure, structural changes in industries, and stricter environmental regulations followed by the increased demand for better environmental quality can contribute to the reduction of environmental degradation. In addition, technological innovation and increased environmental awareness during the process of economic growth process can contribute to its reduction. Although evidence seems to suggest that Korean economic growth put pressure on the environment, detailed analysis is needed to find the exact environmental impacts of economic growth in South Korea.

III. Economic Growth and Its Impact on Environmental Quality in South Korea

Unlike previous studies mostly which used cross-country data, this section uses time series data relating to only one country, that of South Korea. We focus on the relationship between each indicator of environmental quality and per capita income taking into account other factors influencing environmental quality such as environmental policy and industry structure. The main difficulty of our analysis is the limitation of environmental data for the period of the 1960s and 70s. Many environmental data are available only from early 1980s onwards, therefore our regression analysis does not present a complete picture of the historical changes in environmental quality in Korea. To overcome this problem, we interpret the estimated results in association with historical changes in Korean environmental policies and environmental qualities.

A. Data and Overview

Based on *Korean Environmental Yearbook* published by the Ministry of Environment, various time-series data indicating environmental quality in South korea are used. First, the annual growth rate of deforested area is used for the extent of natural resource depletion. Second, the annual levels of SO_2, Nitrogen Dioxide(NO_2), and Total Suspended Particulate (TSP) in Seoul are used for industrial and energy-related air pollutants.[8] CO_2 emission levels from

[8]The use of SO_2, NO_2 and TSP levels of Seoul as a proxy variable of Kor-

primary energy consumption are calculated by using the CO_2 emission coefficients for different kinds of primary energy. Third, for water quality, we use the average annual Biochemical Oxygen Demand (BOD) level of *Han River* which is the largest and longest river in Korea and flows through main cities and many provinces including Seoul. We use the average BOD level of six monitoring stations (Paldang 1, Kuui, Dukdo, Pokwang, Noryangjin and Yong-dungpo) where the consistent BOD statistics are available since early 1980s. Fourth, the daily discharge volumes of domestic and industrial wastes, measured by generation source, are also used for waste management and control.[9]

As mentioned before, data for most indicators are available only after early 1980s. This limitation of data, however, indirectly means that till the early 1980s the problem of environmental degradation was left untouched. The establishment of Korean Environmental Administration (KEA) in 1980 was the starting point for the environmental conservation issue to be discussed and tackled seriously by the public sector. Thus, it is commonly accepted that environmental degradation received no public attention during 1960s, 70s and early 80s in South Korea.

Figure 3 illustrates the change of each environmental indicator along the per capita GDP.[10] The horizontal axes represent the level of per capita GDP, while the vertical axes represent the levels of various kinds of environmental quality indicators. Overall, Figure 3 indicates that the relationship between economic growth and environment cannot be simply explained in terms of trade-off or inverted-U shape relationships. For example, some indicators such as CO_2 and industrial waste worsen as per capita income increases, but other indicators such as water quality and dometic waste show the inverted U-shape relationship. Therefore, the relationship between economic growth and environment depends on each environmental quality indicators.

ean environmental indicators might underestimate or overestimate Korean environmental status. However, it does not change the quality of our estimation results in terms of the relationship between economic growth and environmental quality.

[9]The measurement method of waste by kind (general and specified wastes) is changed from 1st April, 1994, resulting in a drastic increase in generation quantity of general wastes.

[10]Different time spans are caused by the lack of data.

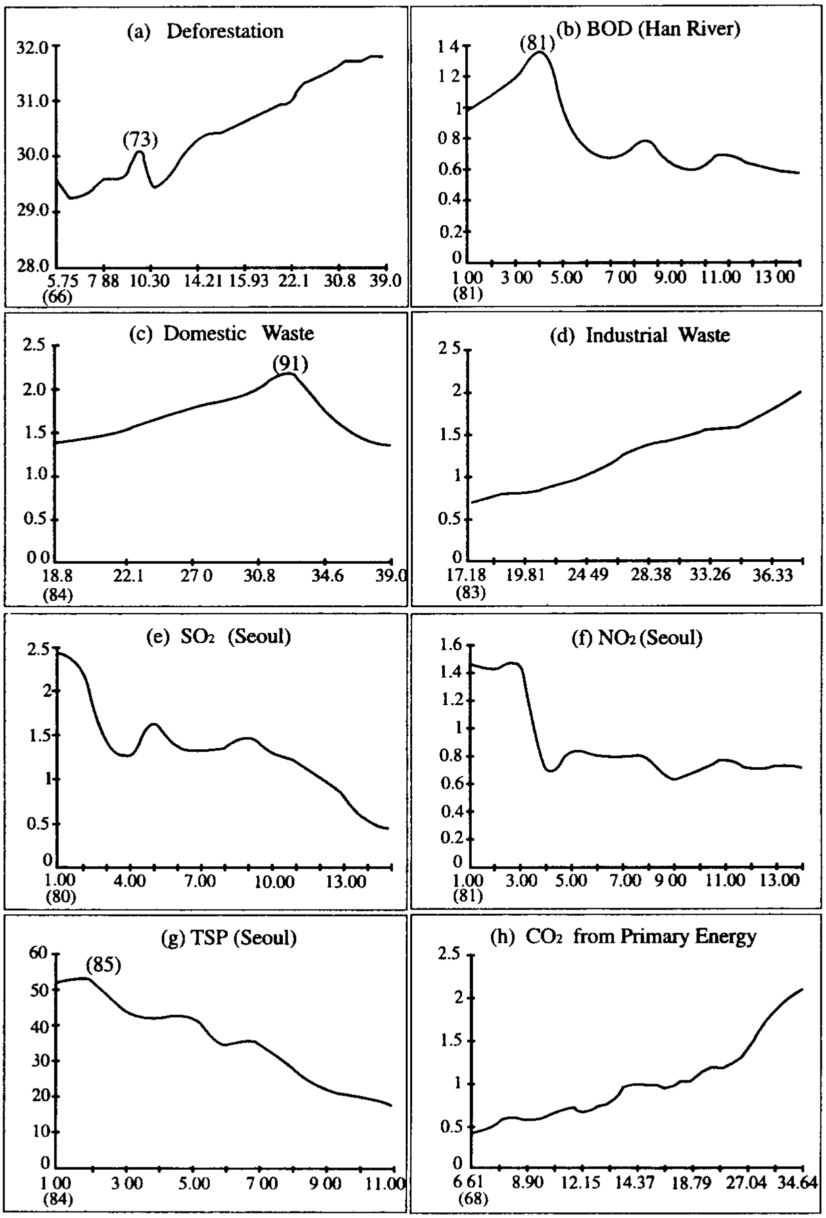

FIGURE 3

PATTERNS OF ENVIRONMENTAL CHANGE AND PER CAPITA GDP

B. Some Econometric Regressions

To assess the relationship between economic growth and environmental quality in any given country, it is improtant to consider the interrelated impacts of the following five determinants of environmental quality: (1) per capita income (e.g. per capita GDP); (2) population density; (3) technologies; (4) the level of environmental policies; and (5) endownments such as climate, geography and resource endowments. To assess the effect of economic growth on environmental quality, we should focus on the relationship between environmental quality and per capital income, taking into account these other determinants of environmental quality.

Per capital income (per capita GDP) serves to analyse directly the effect of economic growth on environmental quality. Population density is also an important factor influencing environmental quality. For technology that can affect environmental quality directly, a time trend can be used as a proxy in regression model. Treatment of environmental policies which reflect social decisions about the environment, is complicated. Since we desire to assess both the direct and indirect effect of growth on the environment, this variable that is the endogenous consequences of economic growth should be omitted from this analysis. In the case of "endowments" such as climate and location, it can be accounted for by having the intercept in regression model. Of course, there are also exogenous factors – e.g., the composition of output, regulations and taxes influencing fossil fuel consumption, the level of education, patterns of urbanization and sub-urbanization, the political structure, etc. – that will affect emissions. Those potential variables that are endogenous consequences of growth also should be omitted from the model.[11]

For specification of the model, the author tested for linear, linear-log, log-linear and double-log functions. We also tested on the significance of inclusion of time trend to take account the change of *technology*. Results of the model including time trend also showed insignificance for most cases.[12] The main focus of our analysis, therefore, is on the emission functions that are linear,

[11]The inclusion of these variables would generate multicollinearity and would undermine the objective of evaluating both the direct and indirect effects of growth. See Selden and Song (1994) and Holtz-Eakin and Selden (1995) for a similar approach in this kind of study.

[12]See the appendix available upon request from the author.

quadratic and cubic in linear-log and double-log forms. The following six basic models both including and excluding the population density term are tested to explore the relationship between each environmental indicator and per capita GDP:

(i) $E_t = \alpha_0 + \alpha_1 \ln Y_t + \alpha_2 \ln D_t + e_t$

(ii) $E_t = \beta_0 + \beta_1 \ln Y_t + \beta_2 (\ln Y_t)^2 + \beta_3 \ln D_t + e_t$

(iii) $E_t = \phi_0 + \phi_1 \ln Y_t + \phi_2 (\ln Y_t)^2 + \phi_3 (\ln Y_t)^3 + \phi_4 \ln D_t + e_t$

(iv) $\ln E_t = \gamma_0 + \gamma_1 \ln Y_1 + \gamma_2 \ln D_t + e_t$

(v) $\ln E_t = \lambda_0 + \lambda_1 \ln Y_1 + \lambda_2 (\ln Y_t)^2 + \lambda_3 \ln D_t + e_t$

(vi) $\ln E_t = \mu_0 + \mu_1 \ln Y_1 + \mu_2 (\ln Y_t)^2 + \mu_3 (\ln Y_t)^3 + \mu_4 \ln D_t + e_t$

where E_t is an indicator of environmental quality defined by i, Y is per capita GDP, D is population density (population per square meter) and e is a stochastic error term. Equations (i) and (iv) explains improvements or deterioration of environmental quality with higher per capita income. Equations (ii) and (v), on the other hand, explain the inverted U-shaped curve. To exhibit a meaningful inverted U-shaped relationship, β_1 and λ_1 must be positive and β_2 and λ_2 must be negative. Population density (D) is expected to show a negative sign, insofar as sparsely populated Korea is likely to be less concerned about reducing per capita pollution levels than more densely populated Korea. Also, pollutions associated with transportation may be lower when people live closer together (Selden and Song 1994).

We also conduct diagnostic tests on misspecification of model and correct for first-order serial correlation in the residuals. Our estimated results for all environmental quality indicators are reported in Table 1.[13] The estimated results show that the relationship between economic growth and enviromental quality varies with different kinds of environmental quality indicators. For many environmental quality indicators, the results exhibit the insignificance of inclusion of population density, except for SO_2 and TSP. We can relate these estimated results to Figure 3.

[13]Table 1 shows only significant results obtained from hundreds of experiments.

TABLE 1

ESTIMATED POLLUTION EMISSION FUNCTIONS WITH AND WITHOUT POPULATION DENSITY

Dependent variables	Specification of Model	Intercept	Income	Income squared	Income cubed	Popula Density	Adjust R^2	No of Obser
Deforestion	Linear-Log	0 106 (8 051)	0.014 (15.05)				0 964	29
	Double-log	-1.840 (-43.40)	0.046 (15 39)				0 963	29
	Double-log	63 673 (3.676)	-13.691 (-3.739)	0 959 (3 720)	-0 022 (-3 688)		0 972	29
Biological Oxygen Demand (BOD)	Linear-Log	25 153 (4 673)	-1 619 (-4.430)				0 779	14
	Double-log	20 062 (7.990)	-1 350 (-7 919)				0 826	14
Domestic Waste	Linear-Log	-751 4 (-2 342)	101.51 (2.342)	-3.420 (-2 336)			0 603	11
	Double-log	-531.57 (-3.541)	71 694 (3 535)	-2 415 (-3.525)			0 552	11
	Linear-Log	43786 (2.944)	-8927 (-2 963)	606 57 (2.982)	-13 735 (-3 001)		0 746	11
	Double-log	25443 (3.182)	-5190 3 (-3.204)	352.87 (3.226)	-7 995 (-3 248)		0 796	11
Industrial Waste	Double-log	-18.732 (-33 41)	1.278 (33.73)				0 990	12
	Linear-Log	236.47 (4.331)	-33 391 (-4.516)	1.182 (4.331)			0 987	12
Sulfur Dioxide (SO_2)	Linear-Log	23 797 (4 871)	-1.530 (-4.599)				0.793	15
	Double-log	20.773 (3 624)	-1 405 (-3 601)				0 836	15
	Linear-Log	30289 (4 632)	-6193 2 (-4 631)	422.10 (4 630)	-9 589 (-4 631)		0.888	15
	Double-Log	26423 (6 614)	-5422 8 (-6.637)	370.95 (6 661)	-8.458 (-6 687)		0 945	15
	Linear-Log	176 69 (4 896)	3 833 (3.080)			-38 382 (-4.282)	0 903	15
	Double-log	-335 89 (-3.734)	71.323 (5.267)	-2.306 (-5.137)		-35.405 (-5 439)	0 935	15

TABLE 1
(CONTINUED)

Dependent variables	Specification of Model	Intercept	Income	Income squared	Income cubed	Popula. Density	Adjust R^2	No. of Obser.
Nirtrogen Dioxide (NO_2)	Linear-Log	11.549 (3.376)	-0 723 (-3 111)				0.633	14
	Double-log	10.200 (3.294)	-0 703 (-3.342)				0 619	14
	Linear-Log	387.22 (3.594)	-51.866 (-3.538)	1 740 (3 489)			0.771	14
	Double-Log	357 59 (3 364)	-47 992 (-3 317)	1 609 (3 269)			0.763	14
Total Suspended Particulate (TSP	Linear-Log	758.60 (13.22)	-48 721 (-12 61)				0 940	11
	Double-log	24 344 (6.188)	-1 407 (-5 305)				0.924	11
	Double-log	-446.25 (-4.220)	62.238 (4 356)	-2.151 (-4 459)			0 961	11
	Double-log	145.79 (5.319)	2.128 (2 590)			-28.701 (5.319)	0.961	11
Carbon Dioxide (CO_2)	Double-log	-13.225 (-21.47)	0.923 (21 44)				0.985	26
	Linear-Log	100.27 (4.785)	-14.894 (-5.079)	0.556 (5.424)			0.987	26
	Linear-Log	-1145 (-2 653)	247 33 (2.725)	-17.834 (-2 804)	0.429 (2 894)		0.989	26

Note : *t*-statistics are reported in parentheses below the coefficient estimates.

C. Interpretation of the Estimated Results

1) Deforestation[14]

Deforestation is one of the environmental indicators that unambiguously worsens as income rises in Korea (Figure 3(a)). The double-log specification with two variables works best, although the linear-log form and the double-log specification with four variables are also significant. The association between increasing deforestation and increasing income in Korea is explained by industrialization requiring increasing areas for industrial zones and factories, and by an increase of population resulting in deforestation for

[14] The total non-forest area divided by national land is used to measure the deforestation.

construction of houses and facilities. Although Korea can point to significant reforestation efforts since the 1950s and 1960s,[15] many of those new forests are largely unmanaged. As a result, they are often harvested or more typically cleared when they stand in the way of economic growth.

Until the 1980s, the efforts for reforestation were largely controlled by the government, but more recently they have come to enjoy wide public support and participation. Today, tree planting is ongoing and is pointed to with pride by Koreans as a sign of their commitment to maintain and restore Korean natural environment.

2) Water Pollution (BOD)

The most socially controversial item in addressing environmental problem in Korea is the surface-water pollution. The water quality of the *Han River* in Seoul rarely exceeds the poor international water-quality standard of third grade. As seen by Figure 3(b), the level of BOD had increased till 1984 but then decreased as per capita GDP. The improvement of water quality is the result of huge investment by government and private sector on the waste-water discharge facilities for water quality protection. Considering the historical water pollution problems during 1970s and 1980s,[16] we may cautiously postulate an inverted U-shape relationship between economic growth and water pollution in Korea. Our estimation, however, shows that BOD decreases with income (i.e., the double-log specification with two variables fits best). This different outcome is mainly caused by the lack of data.

3) Disposal of Wastes

While water quality is clearly the single most important environmental issue in the public mind, just as complex are the challenges posed by the disposal of wastes. Unlike other pollution which affects people who step outdoors, wastes can be disposed of in isolated localities and, if disposed of properly, can have a relatively small impact on human health (Shafik 1994). The small and crowded country of Korea has had difficulty in finding landfill space to dispose of either construction wastes or ordinary domestic

[15]The New Forest Law was developed in 1961 to begin a national reforestation programs.

[16]For example, one of the most controversial issues in 1970s with respect to environment was about the polluted water in *Han River* which causes the deformed fishes and the mass and consecutive death of fishes.

wastes. In practice, landfill capacity has recently been a chronic problem in Korea, especially in the major metropolitan areas. The total disposal volume of wastes have been increasing with increasing per capita GDP.

Wastes are divided into two kinds in terms of their sources: *domestic* and *industrial*. In the case of *domestic wastes*, the estimated result follows the inverted-U shape curve. The regression for daily disposal of domestic wastes shows that the double-log and quadratic specification had most strongest explanatory power, implying that pollution from domestic wastes gets worse initially as Korea becomes richer, and then improves. Figure 3(c) also shows that domestic wastes follow the inverted U-shape curve. The steadily increased amount of domestic waste disposal began to decrease from 1992. The decreasing trend has been continuing to date. In addition, a massive national program (initiated on January, 1, 1995) of "a volume-based system" of waste disposal charge has contributed to the reduction of domestic waste by 31% in 1995. The newly launched system is expected to contribute to further decline of the disposal in the future. On the other hand, the disposal of *industrial waste* is one environmental indicator that is unambiguously increasing with rising per capita GDP (i.e., the double-log equation with two variables fits best). This is caused by the continuous increase of industrial activities (especially the progressive increase of construction wastes) in step with a rise of per capital GDP.

4) Air Pollution

Air pollution levels are high by world standards in all major Korean cities. Although some progress has been made in recent years, the citizens of major cities suffer from the effects of air pollution. For the case of domestic air quality, four indicators are tested: SO_2, NO_2, TSP, and CO_2, respectively. However, because of the lack of data for the periods of early economic growth (1960s and 1970s) for some indicators, a clear relationship between economic growth and those indicators can not be found from the regression. Considering environmental policies and industrial structures in Korea, however, we can presume indirectly the relationships of those indicators with economic growth in Korea.

In the case of SO_2 and NO_2 emissions, the regression results are inconsistent with other empirical studies. For SO_2, the double-log and cubic model fits the best. On the other hand, the linear-log and quadratic specification has the strongest explanatory power for emissions of NO_2. These results are also caused by the *lack* of environmental data. However, it is critical to note that the Korean environmental policies especially for air pollution were effective only from very early 1980s given that the permissible air discharge standard for SO_2 and NO_2 was set in 1979 and 1983, respectively. Since there was no special regulation of air pollution before that time, we can assume that the level of SO_2 and NO_2 increased since 1960s (the early stage of economic growth) to early 1980s. Therefore, the levels of SO_2 and NO_2 expressed by Figure 3(e) and 3(f) seems to represent the decreasing stage after the turning point in early 1980.[17] This downward movement is assisted by the government regulations for reduction of SO_2 level such as substitution policy toward low-sulphur and cleaner burning fuels and technologies in industrial sites and motor vehicles.

The most evident air pollution problem is the restricted visibility in most Korean major cities. The incessant construction dust, traffic jams, and industrial emissions have led to high level of suspended particulate in the atmoshpere, earning Seoul the ranking of the second-worst urban airshed in the world in 1990. However, as shown in Figure 3(g), the TSP level of Seoul has decreased since 1985. The reduction is mainly supported by the stricter regulation of TSP levels such as permissible air discharge standards of TSP set in August, 1983. Our estimation result for TSP also shows the decreasing TSP with per capita GDP (i.e., linear-log model with two variable works best). However, based on other sources such as *An Environmental White Book* (various volumes) describing environmental quality of Korea, we can clearly presume that the TSP level had increased during 1970s and early 1980s. Even if the data does not exist to support this argument, this argument is acceptable. Accordingly, the decreasing TSP expressed in Figure 3(g) represents the declining stage after the turning point (around 1985) of the inverted-U shape curve.

The CO_2 emission from primary energy consumption which is the main source of climate change shows increasing trend since early

[17]This argument is also supported by the *environmental white book* published by the Ministry of Environment in 1995 (p. 35), which shows that the level of SO_2 was top in 1980.

stage of economic growth (Figure 3(h)). The increasing dependence on liquid energy and electricity as substitute of solid energy as the result of fuel-substitution policy since the late 1980s has not supported the reduction of CO_2 emission. This increasing trend of CO_2 emission is mainly caused by the progressive increase of total primary energy consumption accompained with economic growth. Our regression analysis also shows that double-log model with two variable fits best.

Air pollutants studied in this paper such as SO_2, NO_2, CO_2 and TSP are generally regarded to be highly correlated. However, our studies show different results: SO_2, NO_2 and TSP exhibit inverted U-shape relationships with economic growth, while CO_2 emission appears to rise monotonically with income. This exceptional result on CO_2 emission which is costly to abate and has primarily global effects, however, is consistent with the recent finding by other empirical studies such as Diwan and Shafik (1992) and Holtz-Eakin and Selden (1995).

IV. Summary and Conclusion

Economic growth in Korea has clearly had an impact on the natural environment. The continuous increase of production and consumption activities in the course of economic growth have inevitably placed environmental pressures on Korea. The evidence shown in Section II has also confirmed the intensification of environmental pressures as a result of economic growth in Korea.

Section III analysed how rising economic activity (represented by per capita GDP) can cause environmental problems but can also, with the right policies and regulations, help address them. From the analysis, some very clear patterns of environmental degradation emerged. Some environmental quality indicators such as CO_2 emission, deforestation and industrial waste have worsened steadily with rising per capita GDP. However, other indicators (SO_2, NO_2, TSP, BOD and domestic waste) have worsened and then improved with economic growth. This supports the hypothesis of inverted-U shape relationship between environmental quality and economic growth. The turning points at which the relationship with per capita GDP changes varies substantially across envrionmental indicators. However, those turning points are located around early

1980s, when the Korean environmental regulation and policies became stricter and effective in practical manner. This evidence suggests that in Korea environmental improvement has required policies and investments to be put into place to reduce environmental degradation.

The increased environmental pressure and actual environmental degradation in step with economic growth have forced the Korean government to implement stricter environmental regulations and policies. Private industries also have had to expend more resources on pollution abatement and control activities to sell their products into domestic and foreign markets. With increased income following the economic growth, in addition, the civic demand for better environmental quality and awarenes of environmental problems also has forced Korean deision makers to take the problem seriously. These might have had a powerful effects on their actions in environment management.

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