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ABSTRACT

This paper examines the relationship between economic growth and environmental conditions in high performing Asian economies in the light of the South Korea's experience. We used Generalized Least Squares to regress thirteen indicators of environmental quality covering air pollution, water pollution, and industrial waste on GDP per capita and other explanatory variables. The results show that five out of the thirteen environmental quality indicators improve when per capita income increases while eight indicators show either a U-shape relationship or deterioration in environmental conditions with economic growth. Overall, the results support the claim that Korea's growth has been achieved at the cost of a reduction in some measures of environmental quality, perhaps due to delayed recognition of environmental problems associated with increased economic activities.

Keywords: Economic growth, Environment, East Asian countries, Industrialization
JEL codes: O4, O14, O53, Q2

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I.. Introduction

A sizable body of literature has emerged recently linking economic growth with the environment (e.g. Copeland Taylor, 1994; Selden and Song, 1994; Grossman and Krueger, 1993, 1995 and Radetzki, 1992). It has been argued that when the economy expands, both production and consumption increase, leading to a depletion of the resource base and environmental degradation. On the contrary, others argue that rising incomes associated with economic growth induce greater public demand for a cleaner environment and generate additional resources for greater environmental protection. The proponents of this view show that maturing industrialized countries with high incomes have greater concerns for a cleaner environment and taken widespread actions to reverse the negative impacts on environment (Radetzki, 1992).

Income growth has three distinct effects on the levels of pollution (e.g. Lopez, 1992; Holtz-Eakin and Selden, 1992, Shafik and Bandyopadhyay, 1992; Anderson, 1990). First, the `scale effect' which associates increased economic activities (higher economic growth) with increased production and consumption thereby increasing pollution. Second, the `technical effect' which associates higher levels of cleaner technology with higher income. There is an incentive for firms to look for environmentally friendly technology because there is a demand for such goods resulting from higher incomes. Third, the 'composition effect' that arises if income growth causes changes in the preferences of society from pollution-intensive goods to cleaner goods. It is argued that there is some level of income at which the composition and technical effects outweigh the scale effect, resulting in a reduction in pollution.

One popular view emerging from the empirical literature is that damage to the environment first increases at the initial stage of economic development and then decreases when the economy is at a higher level of economic growth suggesting an inverted U-shape relationship between the two. It has been shown that technical change, income effects and public pressure for cleaner environment, all associated with higher economic growth, lead to lower environmental degradation and less pollution intensity of production (O'Conner, 1994). Recently, an influential paper by Grossman and Krueger (1995) has examined this U-shape relationship between per capita income and various environmental indicators and found no evidence to suggest that environmental quality deteriorates with economic growth indefinitely.

They found that 'economic growth brings an initial phase of deterioration followed by a subsequent phase of improvement'. However, not all studies on the inverted U-shape relationship found that every measure of pollution improves with growth, even after incomes become high enough (Barrett, 1997). Some measures of environmental quality can improve with growth and others can deteriorate. It is also possible for some measures of pollution to increase, decrease and then increase again implying an 'N-shape' or (for higher income levels) 'U-shape' relationship between growth and the environment.

The empirical studies dealing with this issue are largely cross-country investigations. The conceptual and statistical problems associated with cross-country regressions on empirical linkages between economic growth and indicators of national policies have been thoroughly reviewed (Levine and Zervos, 1993). Since regression analysis assumes that observations are drawn from a distinct population, conceptually it is difficult to interpret the coefficients estimated on data from a large sample of countries which are at different levels of development with diverse economic backgrounds. They also point out that statistically, variables used in the regressions are measured inconsistently and inaccurately. These data entries do not represent what has really happened in these countries. These limitations have direct bearing on the cross-country studies of growth and the environment linkages. Apart from the problems mentioned above, location-specific factors affecting the growth-environment link cannot be taken into account in such studies. Therefore, in-depth country case studies are needed in order to shed light on the key issues of the ongoing debate,.

The purpose of this paper is to extend this analysis to a single country case. The country under investigation is South Korea where rapid industrialization and remarkable growth took place within a relatively shorter period of time. It was transformed from a very poor developing country in the 1960s to one of the fast growing industrialized countries in the world by the end of 1980s. By 1995, Korea ranked the fourteenth largest in the world in terms of value of GNP and the twelfth largest in terms of world trade.

Numerous literature have shown that Korea's rapid growth is largely due to its export-oriented growth strategy which has been taken as a development model by a growing number of developing countries[1]. However, it is equally known that the growth strategy pursued in Korea did not pay adequate attention to the environmental degradation associated with such rapid economic growth, a strategy which encourages the policy of ``develop first, clean up later''. There is enough evidence to show that Korea lagged behind in its recognition of environmental problems associated with increased economic activities (e.g. O'Connor, 1994).

The present study is expected to provide some important insights into whether the findings that have been obtained by multi-country studies carry over to a particular single country case[2]. It is interesting to investigate whether the relationships between growth and environment (e.g. the inverted U-shape) observed in the multi-country case hold for individual countries such as South Korea. In particular, the experience of Korea in managing the environment with fast industrialization is of paramount importance to the formulation of development strategies in developing countries. These countries increasingly depend on East Asian high performing countries including South Korea for lessons in formulating economic development strategies and institutional building. The study focuses on a large number of environmental quality measures covering air pollution, water pollution and industrial waste and examines the link using disaggregated data for both income and pollution indicators.

The structure of the paper is as follows. Section 2 outlines Korea's experience in rapid industrialization over the last 3 decades. Section 3 briefly reviews the previous literature. The econometric model and data are described in section 4. This is followed by the analysis of results in section 5. A comparison of results with previous studies is presented in Section 6. A summary of findings and policy conclusions are presented in the final section.

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1 See Hong(1994) for a collection of papers dealing with different aspects of Korean economic growth.

2 An important exception is the study of Grossman, Krueger and Laity (1994) who examined the determinants of air pollution in the U.S.

2. Rapid industrialization and environment in South Korea

Despite the recent dramatic turnaround in economic activities resulting from the Asian financial crisis, South Korea is well known for her remarkable record of high and sustained economic growth within a relatively short span of time, which has often been called an economic miracle. South Korea's average annual rate of growth in GNP increased from about 4 per cent during the period of 1953 to 1962 to about 8 per cent in the next two decades. It was 9.9 per cent during 1987 to 1992. The GDP per capita increased from US $150 in 1960 to well over $10,000 by the early 1996. The growth in manufactured exports which was around 8 to 9 per cent has been the major contributor to this rapid economic growth[3].

It has been claimed that this remarkable growth was achieved at the cost of the environment (Han, 1996). Pollution in major Korean cities caused by rapid industrial development has been identified as one of the major problems faced by the country (Ministry of Environment, 1995). The statistics (all for the year 1990) on key environmental indicators suggests that Korea's environment is heavily polluted and it is expected to worsen in the years to come. For instance, Korea's population density[4] (persons/km^2) is 431 persons compared with the world average of 38 persons. This is well above that of advanced developed countries such as U.S.A(25 persons), Germany(177 persons) and Japan(327 persons). Production density (GDP/area), another basic environmental indicator, is 2.4 compared with the world average of 0.16. In terms of a more direct measure of environment, pollution density (emissions/area), Korea again ranks high. Per area CO_2 emissions for Korea is 663 compared with the world average of 42, 133 (U.S.A), 176 (France) and 49 (Thailand). The share of pollution intensive industry in exports is 14 per cent in Korea compared with 12 (U.S.A), 10 (Japan) and 4 (Thailand)[5].

Korea has a relatively new history of policy making relating to environmental protection. Currently, Korea has environmental regulations covering both environmental quality

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3 The statistics on growth are from Woo-jin (1997). See also Hong (1994) and Amsden (1989) for details on Korea's economic miracle.

4 It is generally accepted that more people means more pressure on environmental resources. Population pressure has been identified as a major factor contributing to Korean environmental degradation by the Ministry of Environment.

5 All of these numbers are from Han (1996).

standards (e.g. the standards for carbon dioxides) and emission standards (e.g. sulfur dioxides). Most of the environmental regulations and economic instruments such as the Environmental Improvement Charge system and the Emission Charge System have been introduced in the mid-1980s. In addition to general policy acts covering all aspects of pollution (e.g. The Basic Environmental Policy Act and Natural Environment Preservation Act), there are a large number of Acts covering different pollution areas such as water, air and waste management and resources such as soil conservation and marine preservation which were introduced during the last decade. While most of these legislation are applicable to the whole country, there are some environmental standards which are established and enforced on a regional basis. There are distinct differences between regions in terms of environmental interests, levels of pollution and the degree of strictness of regulations. This is mainly due to the autonomy granted to local administration in enforcing environmental laws. For instance, for the purpose of management of rivers, Korea is divided into 195 areas, each of which has its own environmental regulations and standards based on the local needs for water and the level of pollution. Another example is the Air Quality Preservation Act which specifies not only nationwide emission standards but also multiple standards which take into account regional conditions (Ministry of Environment, 1995).

Measures of pollution show that recently there has been an improvement in some environmental conditions in Korea. For instance, the concentrations of sulfur dioxide (SO2) and suspended particulate are found to be declining in Korea. The levels of SO2 are now reaching not only the government's long term targets but also the standards recommended by the WHO. These improvements are mainly due to the environmental protection measures such as the expansion of the supply of clean fuels and low sulfur content oils and the introduction of low emission vehicles (Ministry of Environment). Despite these improvements, the levels of air pollution are still higher than those in advanced developed countries. Similarly, although the regulations pertaining to water pollution have been made stricter and strengthened, the levels of water pollution are high in Korea in terms of developed country standards. This has been attributed mainly to high population density and rapid expansion of industrial output (Ministry of Environment).

3. Previous Studies

Many relationships are plausible between economic growth and the environment including the possibility that there is no relationship at all (Grossman and Krueger, 1995; Shafic and Bandyopadhyay, 1992; Selden and Song, 1994). For instance, when the level of income increases the environmental conditions can improve or deteriorate overtime. It is also possible that as income increases, the levels of pollution can increase, decrease and then increase again forming a N-shape relationship. The relationship can take the form of a U-shape where pollution decreases first and after reaching a minimum, can increase again. Finally, the curve can show an inverted U-shape relationship between income and pollution, a form which has been subject to careful analysis of a number of researchers[6]. According to this view, at lower levels of income the environmental condition deteriorates, reaches a peak, and then gradually declines when the level of income increases.

Barrett (1997) identifies three major forces behind the inverted U-shape relationship. First, at lower levels of income, economic growth can expand the industrial sector at the cost of the agricultural sector and then at the higher levels of income the service sector takes the lead at the expense of the industrial sector. Second, higher income levels can accompany greater democratic freedom giving citizens an opportunity to voice 'their preferences for an improved environment'. Finally, as income rises the income elasticity of demand for environmental improvements can increase. Lopez (1992) in a study of growth/trade/environment, points out two important conditions for an inverted U-shape curve between growth and pollution. First, is the income elastic demand for cleaner goods which ensures composition effect. The second is greater elasticity substitution between inputs, which ensures technical effect. Another reason for the inverted U-shape relationship between environmental degradation and economic growth is the decline in the use of environmental resources due to the structural shifts and technological progress in the mature economies (Radetzki, 1992). After examination of time series data of individual countries, Tilton (1990) has observed that intensity of environmental resource use declined over time because of 'the material saving bias of technological progress'. It is also possible that as countries advance economically, they

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6 See Barrett (1997) for a recent survey of this literature.

tend to import environmentally sensitive goods which were previously produced locally (Grossman and Krueger, 1993)

Dua and Esty (1998) identify three distinct patterns of behavior between incomes and pollution and explain why such distinct relations exist. First, some environmental conditions such as access to clean water and sanitation conditions improve as income grows. These environmental problems are localized, easily seen by the general public and the benefits of actions solving such problems are immediately realized and readily appreciated by the voting public. Second, certain environmental problems such as particulates and sulfur dioxide follow an inverted U-shape as income increases. These environmental problems and their effects are less localized and may not be seen immediately. Therefore, the actions to ameliorate these problems are likely to be delayed. Third, some pollution indicators such as carbon dioxide emissions may not improve with increased incomes. The damage caused by these problems are largely externalized or drifts across borders so that the benefits of actions to ameliorate such environmental harm are not directly obtained by the country concerned.

The most comprehensive empirical study so far on the link between economic growth and the environment is Grossman and Krueger (1995) (hereafter GK) who used the panel data obtained from the Global Environmental Monitoring System (GEMS) to examine empirically the relationship between national income and a number of environmental quality measures using reduced-form regression models. A number of environmental indicators representing both air quality and water quality have been regressed on the current and lagged income per capita and other covariates on a selected sample of countries which varied according to the availability of data. They found that although environmental conditions can deteriorate as income rises, the environment benefits from economic growth once a certain level of income is achieved. They also found critical levels of income where high economic growth positively affects the environment. For the majority of pollutants, the turning point occurs at an income of less than US $8000.

GK have identified two important limitations of their study. Firstly, they only cover two dimensions of environmental quality (air pollution and water pollution). The other aspects of environmental conditions such as industrial waste were not examined because data were not available from GEMS. Secondly, even under air and water pollution, some important pollutants were omitted for the same reason. The important omissions under air pollution included nitrogen dioxide, carbon monoxide and ozone. Obviously, these problems are due to the nature of the study as it is hard to obtain data for all these pollutants for a reasonably large sample of countries. Apart from obvious difficulties of data, as described in section 1, there are also conceptual and statistical problems associated with cross-country regression studies.

The present study is a longitudinal investigation of an individual country and thus avoids many pitfalls in the cross-country approach. It is also more comprehensive in terms of the coverage of various dimensions of environmental conditions such as industrial waste as well as more environmental quality indicators than used in GK. Our study is also capable of taking care of location-specific factors affecting the link, which cross-country studies cannot take into account in their models.

It closely follows the methodology used in GK. However, we use disaggregated data on both income and pollution rather than national averages. As noted above while most environmental regulations are set nationally in Korea, there are some environmental quality and emission standards which are established and enforced on a regional basis. There are also distinct differences between regions in terms of environmental interests, levels of pollution, the degree of strictness of regulations. This justifies the use of regional income and pollution data in the investigations of the link between economic growth and the environment. Further support to the use regional disaggregated data is given by Grossman, Krueger and Laity (1994) who found that local differences in pollution levels do sometimes depend on local differences in incomes for the U.S, a country which sets environmental regulations and standards nationally.

4. Econometric Model and Data

In order to examine the link between economic growth and the environment, following GK, we regress pollution on income as:

$$P_{it} = C_i + I_{it}a_1 + I_{it}^2 a_2 + I_{it}^3 a_3 + \bar{I}_{it}a_4 + \bar{I}_{it}^2 a_5 + \bar{I}_{it}^3 a_6 + Z_{it}'a_7 + \varepsilon_{it} \quad (1)$$

where P_{it} is a measure of environmental quality of region i in year t, C_i is a region-specific constant, I_{it} is per capita gross regional domestic product of region i in year t, $\bar{I}_{it}$ is lagged average of per capita gross regional domestic product of previous three years, Z_{it} is a vector of other variables (strictness of environmental authority, population density, number of registered vehicles and time), and ε_{t} is an error term. Following Grossman and Krueger (1995), we used Generalized Least Squares (GLS) as the appropriate estimator of the above equation. The GLS procedure produces a more efficient estimator by minimizing a weighted sum of squared residuals. This method is more appropriate than simple OLS in the presence of heteroscedasticity and temporal correlation in the error term due to omission of relevant independent variables affecting pollution in our equation.

In the estimation of the above equation, disaggregated data at regional level for both dependent variable (environmental quality indicators) and independent variables (income and other location-specific variables) were used. The period of analysis varies depending on the availability of data. Generally, it covers the period of 1985 to 1995. The annual panel data for major regions of South Korea over this period were obtained mainly from the Korean Ministry of Environment and Statistical Year Books of different regional councils. The variables, their measurements and the samples used in the above equation for each pollutant are briefly described below (see Appendix 1 for details).

(a) Air Pollution

The sample consists of the six biggest cities in Korea: Seoul, Pusan, Taegu, Inchon, Kwangju, Taejon. The period of analysis is 1985 to 1995. In the case of new-born cities (Kwangju, Taejon) analytic period is shorter than other cities.

Five different indicators of air pollution are used as dependent variables. These are Carbon Monoxide, Nitrogen Dioxide, Ozone, Sulfur Dioxide and Total Suspended particles. All these pollutants have severe effects on human health and natural ecosystems. For example, sulfur dioxide and total suspended particles have been recognized to cause respiratory diseases.

There are two types of independent variables: (a) the variables representing different aspects of growth of income and (b) other variables. We used per capita income, lagged per capita income, squared value of both current and lagged per capita income, and cubed value of both current and lagged per capita income as independent variables. Income is measured at 1990 constant prices. The average income of the previous three years[7] is used as a measure of permanent income.

Secondly, the other covariates affecting environmental quality which include population density, per capita registered vehicles, strictness of environmental authority, lagged strictness and time trend are used. In comparison to GK, unavailability of data prevented us using some variables such as the location of the monitoring station and the nature of the land use near the station. We have used two new variables. One is per capita registered vehicles as an indicator of air pollution caused by the use of motor vehicles. The other is the strictness of enforcement of environmental regulations measured as the ratio of number of facilities strictly controlled to number of total facilities controlled. Strict controls are accusations, license withdrawals, transfers, and temporary suspensions[8]. We expect a negative relationship between indicators of pollution and the strictness of enforcement. Following GK, we used time trend as a separate regressor.

(b) Water Pollution

In the analysis of water pollution, five regions were included in the sample: Seoul-Kyonggi, Pusan-Kyongnam, Taegu-Kyongbuk, Kwangju-Chonnam and Taejon-Chungnam. The region is the combination of city and province in which the city is located. The period of analysis is from 1987 to 1994. The rivers that are the objects of analysis are Han River for Seoul-Kyonggi, Naktong River for both of Pusan-Kyongnam and Taegu-Kyongbuk, Yongsan River for Kwangju-Chonnam, and Kum River for Taejon-Chungnam[9].

Five indicators of water quality are used. These are Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Coliform, Dissolved Oxygen and Suspended Particles . When there are high concentrations of these indicators, the water can no longer be used for drinking, fishing or swimming. Water pollution can come from various sources such as domestic sewage, industrial waste water and livestock waste water.

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7 The first lagged income data of each region or city is the average of income over previous two years.

8 An example of weak controls is warning given to the people who violate environmental laws. .

9 In the case of Pusan-Kyongnam and Taegu-Kyongbuk, the water pollution is measured in the same river. Naktong River goes through first Taegu-Kyongbuk and then Pusan-Kyongnam.

In addition to the variables representing income as described above under air pollution, we used persons per household, households per squared kilometer, annual average temperature of river water, current strictness of environmental authority, lagged strictness and time trend as independent variables. Compared with GK, the three new variables used in the equation for water pollution are the strictness of environmental authority, the number of persons per household and the number of households per square kilometer. The latter two measures are expected to have negative relationships with the indicators of water quality.

(c) Industrial Waste

In the estimation of industrial waste equation, data from six cities and eight provinces were used. These are Seoul, Pusan, Taegu, Inchon, Kwangju, Taejon, Kyonggi, Kangwon, Chungbuk, Chungnam, Chonbuk, Chonnam, Kyongbuk, Kyongnam. The data are for the period of 1985 to 1995.

We used 3 indicators of industrial waste, i.e. acides & akali, waste oil, and waste synthetic resin as dependent variables. All these are considered to be hazardous industrial waste which have severe impact on human life and environmental resources. In 1994, they accounted for 67.5 per cent of all hazardous waste in Korea.

The independent variables were per capita income, squared income, cubed income, lagged income, squared lagged income, cubed lagged income, population density, number of plants emitting pollution and time. The extent of different types of industrial waste is expected to increase as the number of plants emitting pollution increase.

5. **Results**

The regression results linking economic growth with each of the pollutants mentioned above, estimated using GLS are reported in Appendixes 2-4. Environmental quality indicators representing each pollutant are regressed on current income, lagged income and other relevant explanatory variables. All equations have high R^2 indicating that the independent variables explain most of the variations in environmental quality indicators. As pointed out by GK, although nothing much can be said about the individual coefficients, given high multicollinearity between income variables, in a majority of equations (e.g. carbon monoxide, total suspended particles, dissolved oxygen and waste acid and akali), the coefficients of either the current income variables or lagged income variables, in some cases both, are statistically significant at least at the 10 per cent level. The joint significance tests combining current and lagged income (P-values) confirm that income is an important variable in those equations. However, in a number of equations (e.g. nitrogen dioxide, ozone, sulfur dioxide and total coliform), income is not a significant variable indicating that economic growth has nothing to do with such pollutants in South Korea. Of other explanatory variables, the major influencing factors are number of vehicles and population density (air pollution), the strictness of environmental authority and population density (water pollution) and the number of facilities (industrial waste).

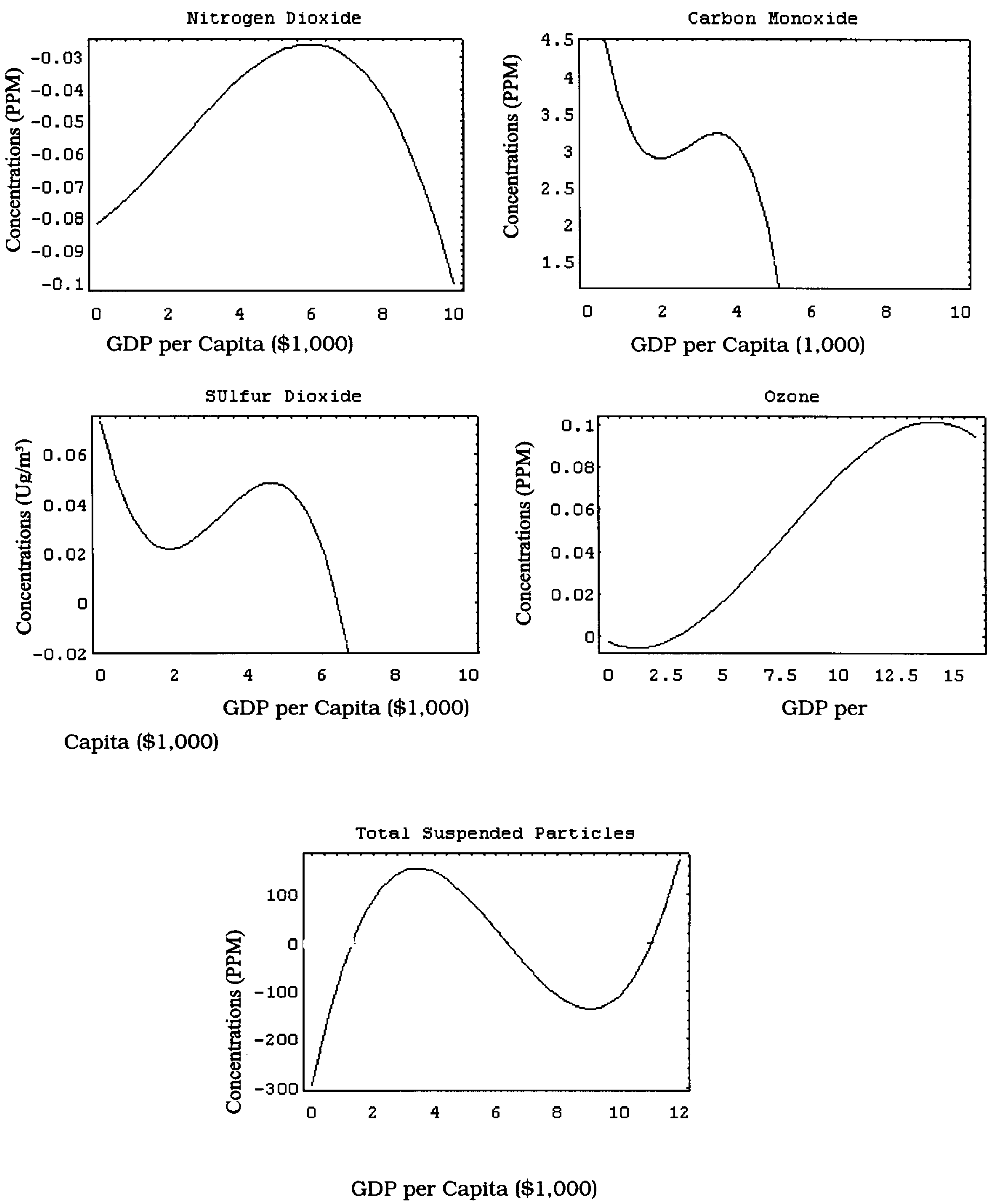
The graphs showing the relationships between GDP per capita and each pollutant are given in Figure 1 (air quality), Figure 2 (water quality) and Figure 3 (industrial waste). Following GK, we constructed the graphs using the following equation.

$$\hat{P}_{it} = I_{it}(\hat{\alpha}_1 + \hat{\alpha}_4) + I_{it}^2(\hat{\alpha}_2 + \hat{\alpha}_5) + I_{it}^3(\hat{\alpha}_3 + \hat{\alpha}_6) + \overline{Z}'\hat{\alpha}_7 \qquad (2)$$

where $\hat{P}_{it}$ is the estimated value of each pollutant or predicted level of pollution and $\hat{\alpha}$'s are the estimated coefficients corresponding to equation (1), where each income variable is multiplied by the estimated coefficients of current and lagged GDP per capita. $\overline{Z}$ is a vector of mean values of other variables multiplied by their corresponding coefficients. The graphs show the estimated relationships between GDP per capita and each pollutant.

We begin the analysis with the air pollution diagrams (Figure 1) where 5 indicators of air quality are linked to economic growth. An inverted U-shape relationship between GDP per capita and indicators of air quality is displayed by nitrogen dioxide. It shows that at lower levels of per capita income, air pollution rises and then after reaching a peak, gradually declines when income increases. However, it should be noted that the relationship between this pollutant and income is statistically insignificant (Appendix 2). Two air quality indicators, carbon monoxide and sulfur dioxide show that at lower levels of income pollution declines, then rises over a middle income range and eventually declines again (inverted N-shape). These curves show that environmental conditions improve with economic growth. On the contrary, ozone displays a positive relationship with income with a possible turnaround at a higher level of income. Total suspended particles first increase then decrease, and then increase again. This N-shape relationship indicates that some environmental conditions continue to deteriorate even at high levels of income. In South Korea, one major reason for increasing air pollution levels is increasing number of automobiles on the roads. According to estimates produced by the Korean Ministry of Environment, in Seoul, automobiles account for 71.6% of all air pollution (Ministry of Environment, 1995). Our regression results (Appendix 2) support this claim. The coefficient of the number of registered vehicles is statistically significant in all equations of Carbon Monoxide, Nitrogen Dioxide, Ozone and Total Suspended Particles.

Figure 1: The Relationship between per Capita GDP and Urban Air Pollution



With regard to water pollution (Figure 2), Total Coliform displays negative relationships with GDP per capita. Advancements in environmental conditions occur when environmental services such as sanitation services and access to clean water are improved. All other indicators of water quality (Biological Oxygen Demand, Chemical Oxygen Demand, Dissolved Oxygen and Suspended Particles) show an increasing trend in pollution when income increases. This trend is almost monotonic in the case of Suspended Particles while there are sharp drops in two other indicators over a middle income range. None of the curves display inverted-U relationship between GDP per capita and indicators of water quality. According to the Korean Ministry of Environment, some of the reasons for increasing water pollution are increased populations in major cities, lower sewage treatment ratios, less facilities for cleaning up livestock and industrial wastewater and outdated treatment facilities[10]. Our regression results (Appendix 3) appear to support some of these claims. For example, the coefficient of population density is statistically significant in equations of two major indicators of water pollution (Biological Oxygen Demand and Suspended Particles). Unfortunately, we could not test the impact of number of treatment facilities due to unavailability of data. However, strictness of environmental authority seems to have been influential in ameliorating the situation.

Turning to the relationships between the indicators of industrial waste (Figure 3), the curve for Waste Synthetic Resin shows that environmental conditions deteriorate at lower income levels and then improve towards the higher income range. The curve for waste oil shows an increasing trend in pollution levels when income rises. This may be partly attributed to the fact that although population and industrial output continued to grow at a rapid rate over the last 20 years generating an enormous amount of household and industrial waste, the number of waste treatment facilities did not grow as fast as industrial production[11]. The diagram for waste acid shows an N-shape relationship between the growth in GDP per capita income and pollution.

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[10] As of the end of 1994, the existing sewage facilities were able to handle only 42% of total sewage generated in the country. Therefore a substantial part of sewage flows into rivers directly without being treated.

[11] Per a day, Korean households generate 58,118 tons of waste and industry generates another 88,931 tons of which 3,702 tons are considered to be hazardous. Majority of the treatment facilities are small in size and of all wastes treated only 60% is subject to sanitation treatment.

Figure 2: The Relationship between per Capita GDP and Water Pollution

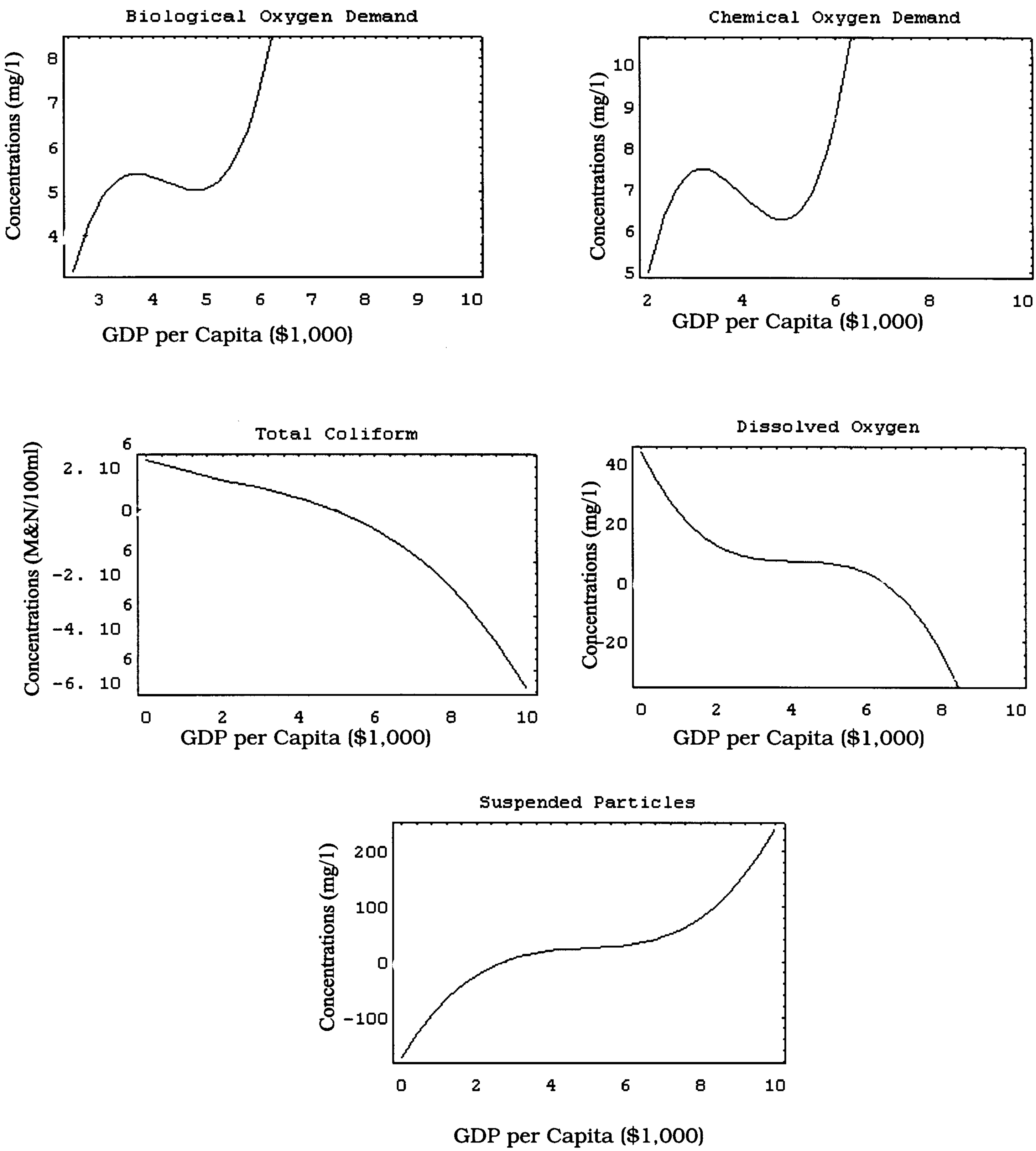
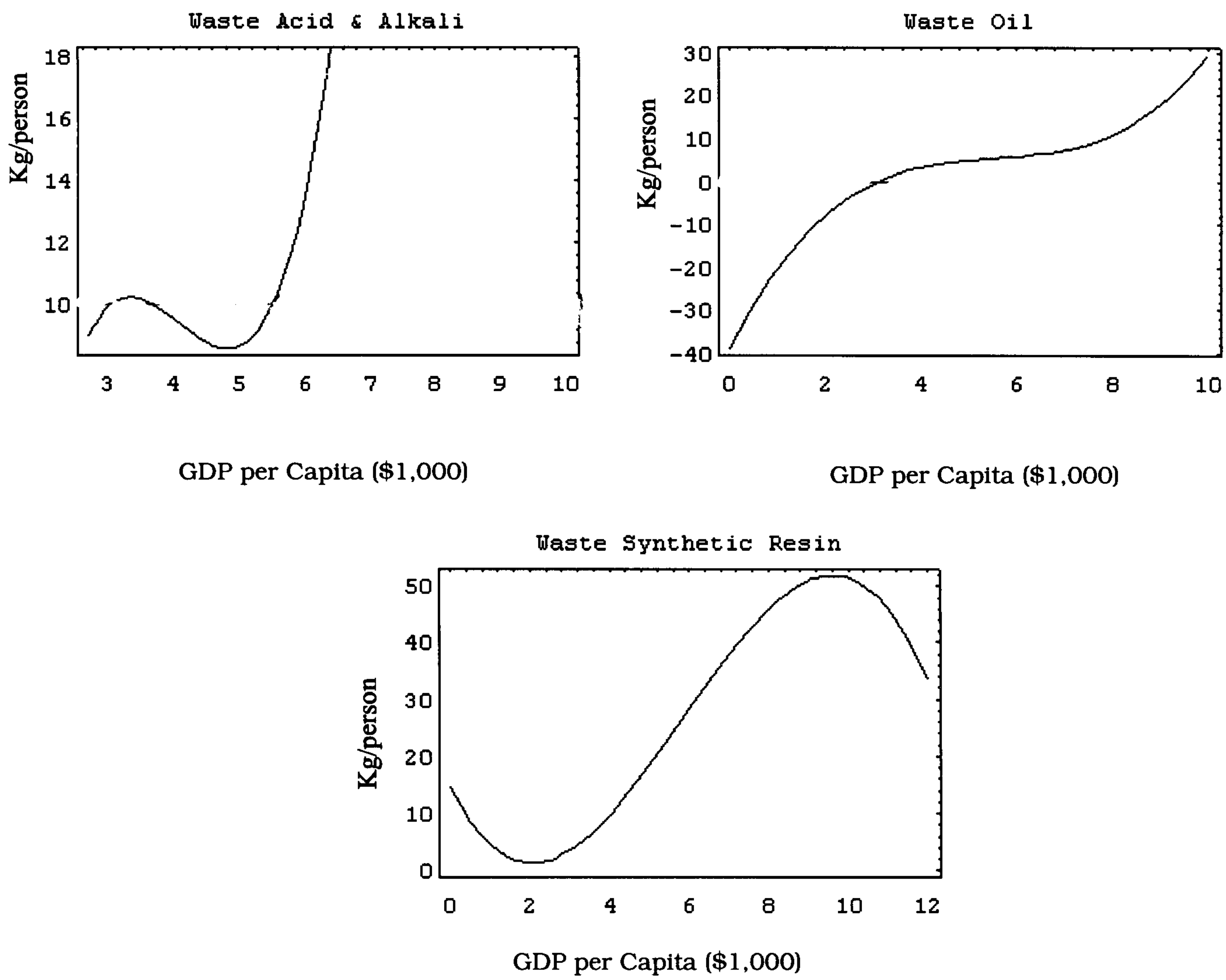


Figure 3.:The Relationship between per Capita GDP and Industrial Wastes



Having examined the relationships between levels of income and pollution, next we turn to investigate the turning points of income when the level of each pollutant is at its highest point (Table 1). We have excluded the results of ozone, nitrogen dioxide, Total Coliform and biological oxygen demand from the table as their relationship with income (both current and lagged) is statistically insignificant (Appendix 2 and 3). The earliest turning point in terms of GDP per capita is for concentrations of Chemical Oxygen Demand (at $3157), a measure of water quality while the latest is for waste synthetic resin (at $9614). Generally, the turning points for water quality indicators occur at relatively lower levels of income than those for air pollution and industrial waste.

Column 2 of Table 1 shows the estimated derivatives of the levels of pollution with respect to income (estimated slopes of the relationship) at 3 different levels of GDP per capita income ($4000, $6000 and $9000). These estimates can be used to see the relationship between income and pollution at different levels of income. For example, if the environment improves when the country reaches a certain level of income, we expect a negative sign for the derivative. The estimated relationship between pollution and per capita GDP is negative at all income levels for Carbon Monoxide indicating that the concentrations of these pollutants decrease when the levels of income increase. For Sulfur Dioxide, the relationship is negative at relatively higher income levels. There are other pollutants such as Suspended Particles and Waste Oil where higher incomes are not associated with lower concentrations of such pollutants. For the majority of them, there are no peak income levels at which the environment improves as can be seen in column 2 of Table 1.

Table 1: The Turning Points of Incomes at Highest Levels of Pollution and the Derivatives of Pollution with Respect to GDP Per Capita

Variable	Peak GDP (US dollars)	Derivatives		
		$ 4000	$6000	$9000
Carbon Monoxide	3467	- 0.6267	- 5.8743	- 22.3182
Sulfur Dioxide	4627	0.0101	- 0.0427	- 0.2344
Total Suspended Particles	3427	- 28.2078	- 76.821	- 4.5753
Chemical Oxygen Demand	3157	- 1.0776	4.9268	36.5234
Dissolved Oxygen	NA	- 0.2387	- 5.6761	- 37.0027
Suspended Particles	NA	7.2884	8.7732	79.6839
Waste Acid & Akali	3342	- 1.6458	9.4914	71.7507
Waste Oil	NA	2.4828	0.9312	9.1428
Waste Synthetic Resin	9614	7.6621	9.9933	2.9871

NA = Not applicable (because relationships are monotonically increasing or decreasing.

6. A Comparison of the Results with Previous Studies

We have shown above that some of the environmental indicators improve when the level of income rises in Korean cities. Some indicators exhibit inverted U-shape relationships and decreasing trends between economic growth and pollution. However, more than half of the indicators (eight out of thirteen) show environmental conditions deteriorate when income increases. Some of these indicators display an N-shape relationship with income while others show a U-shape, but all are showing environmental degradation with economic growth.

Table 2: A Comparison of Results with Grossman & Krueger (GK)

	GK Study		Our Study	
Indicators of Environmental Quality	**Nature of the Relationship**	**Peak Income $**	**Nature of the Relationship**	**Peak Income $**
Air Pollution				
Sulfur Dioxide	Inverted U	4053	Inverted N	4627
Smoke	Inverted U	6151	-	-
Heavy Particles	Decreasing	N/A	N-shape	3427
Carbon Monoxide	-	-	Inverted N	3467
	-	-		
		-		
Water Pollution				
Dissolved Oxygen	U shaped	2703	Decreasing	N/A
COD	Inverted U	7853	N-shape	3157
Nitrates	Inverted U	10524	-	-
Coliform	N-shape	3043	Decreasing	N/A
Lead	Decreasing	1887	-	-
Cadmium	Decreasing	11632	-	-
Arsanic	Inverted U	4900	-	-
Mercury	N-shape	5047	-	-
Nickel	N-shape	4113	-	-
Suspended Particles	-	-	N-shape	N/A
Industrial Waste				
Waste Acid	-	-	N-shape	3342
Waste Oil	-	-	Increasing	N/A
Waste Synthetic Resin	-	-	Inverted N	9614
			I	

N/A = Not applicable, - = Not available

A comparison of our results with previous studies is difficult because of the differences in data used and the different measurements of dependent and independent variables. For example, some studies use concentrations of SO2 in the air while others use SO2 emissions to represent environmental quality. Despite these difficulties, the previous studies (9 studies) on the relationship between pollution and economic growth have been surveyed and compared in Barrett (1997) according to which 'evidence for the inverted-U relationship exists but it is fairly shaky'. This relationship appears to hold only for some measures of environmental quality. As pointed out by Dua and Esty (1998: 78), these different relationships may depend on "the geographical scale of the harm and, to a lesser extent, on the visibility, severity, and temporal immediacy of the injury".

In this study, we compare our results with those of GK although there are differences in data and measurement of variables as mentioned above. However, we have used exactly the same methodology as GK in our estimations. The nature of the relationship (inverted U-shape, U-shape, N-shape, increasing and decreasing) between GDP per capita and various indicators of environmental quality and the peak levels at which the levels of pollution reach the highest point are reported in Table 2.

None of the indicators have exactly matching curves in the two studies. The pollution indicators which show an increasing trend as income rises (N-shape) in our study (e.g. sulfur dioxide and COD) have inverted U-shape relationship in GK. Dissolved oxygen which shows a decreasing trend in our study has a U-shape curve in GK. The closest result is for sulfur dioxide where an inverted N-shape relationship is found in our study while GK shows an inverted U-shape relationship. In GK, 9 out of 13 indicators (about 70%) show either decreasing trend or inverted U-shape relationship between income and pollution. In our study, 6 out of 13 indicators (about 45%) show a similar pattern. Differences in results may be partly attributed to the use of disaggrgated data and location-specific factors used in the estimation. It appears that more country-based case studies are needed before any sweeping conclusions are made about the relationship between economic growth and the environment.

7. Summary and Policy Implications

In this study, we have examined the relationship between economic growth and environmental conditions using data from South Korea where fast economic growth through rapid industrialization has taken place within a short span of time. We used Generalized Least Squares to regress 13 indicators of environmental quality covering air pollution, water pollution and industrial waste on GDP per capita and other explanatory variables.

In a number of equations (e.g. carbon monoxide, dissolved oxygen, and waste acid) the coefficients of either the current income variables or lagged income variables, and in some cases both, are statistically significant indicating that levels of income have some influence in determining the levels of environmental quality. However, in a majority of cases (e.g. nitrogen dioxide, ozone, sulfur dioxide and total coliform), income is not a significant variable indicating that economic growth has nothing to do with such pollutants in South Korea. Of other explanatory variables, the major influencing factors are number of vehicles and population density (air pollution), the strictness of environmental authority and population density (water pollution), and the number of facilities (industrial waste).

The results show that five out of thirteen environmental quality indicators improve when per capita income increases. One indicator shows inverted U-shape relationships between income and environmental conditions and some show decreasing trends in pollution when income rises. However, eight indicators show either a U-shape relationship, N-shape or an increasing trend in pollution indicating that environmental conditions deteriorate when economic activities increase. With regard to these environmental quality indicators, the turning points at which the composition and technique effects begin to outweigh the scale effect, appear to come later than sooner. In this highly performing economy, rapidly increasing economic activities have translated directly into increased pollution levels in relation to some environmental resources. These results support the claim that the superior growth in Korea has been achieved at the cost of some measures of environment which may be attributed to Korea's late recognition of environmental problems associated with increased economic activities.

Some important policy implications arise from the preceding analysis. Firstly, the relationships between economic growth and environmental conditions can take different forms (i.e. different shapes), possibly reflecting different policy priorities based on the geographical scale, 'visibility, severity and temporal immediacy of the injury'. For example, it is quite possible for policy makers to focus first on local or regional environmental problems, effects of which are seen and felt immediately by their supporters and then move onto the other problems which are less important in terms of the same criteria. The environmental problems which have across border effects need to be resolved through international negotiations and co-operation.

Secondly, in terms of Korean experience, there is no assurance that economic growth always contributes positively to the environment. Increased economic activities can lead to increased pollution and environmental damage. Thirdly, the high levels of pollution in South Korea point to the need for early recognition of environmental problems associated with increased economic activities and the adoption of preventive measures in time. The adverse effects of increased economic activities on the environment can be reduced or minimized if proper environmental protection measures are introduced in time. Although countries are expected to undergo significant changes in the composition of their industrial structure favoring more environmentally friendly production when income increases, it is possible that the developing countries will continue to specialize in dirty industries due to a lack of well-imposed environmental regulations as has been the case in South Korea. For instance, as mentioned in section 2, pollution-intensive industry share in Korean exports is relatively higher than advanced developed countries such as the U.S and Japan. Developing countries can exploit market opportunities for environmentally friendly products in both domestic and international markets by introducing proper environmental management systems within their national boundaries. The export-oriented development model used by South Korea and other newly industrializing countries (East Asian Model) may be adopted by other developing countries with proper modifications, taking into account environmental effects of such policies. Overall, it is important for developing countries to assess carefully the consequences of the strategy- "develop first and clean up later'' before embarking upon any model of development.

Appendix 1. Variables, Measurements and Data Sources

Dependent Variables

Air Pollution

Carbon monoxide (CO), measured in ppm (parts per million)

Nitrogen dioxide (NO_2), measured in ppm

Ozone (O_3), measured in ppm

Sulfur dioxide (SO_2), measured in ppm

Total suspended particles measured in $\mu g / m^3$

Water pollution

Biological Oxygen Demand, measured in milligram per liter

Chemical Oxygen Demand, measured in milligram per liter

Coliform, measured in MPN per 100 milliliter

Dissolved Oxygen, measured in milligram per liter

Suspended Particles , measured in milligram per liter

Industrial waste

Waste acides & akali, waste oil, waste synthetic resin. Total amount emitted in a region divided by the population of that region (kilograms per person).

Independent Variables

Air Pollution

I , Gross regional domestic product (GRDP) per Capita measured in thousand US dollar

$\bar{I}$, Lagged average of incomes over previous three years measured in thousand US dollar

Strictness of Authority, the strictness of the environmental authority in the enforcement of the air pollution standards

Population Density, measured in 1000 Persons per Km^2

Registered Vehicles, per capita

TIME, time trend set 1980 to 0

Water Pollution

I and $\bar{I}$, as defined above

Persons per household, number of persons per household

Households per area, per sq. Kilometer

Temperature of water, measured in centigrade

Strictness of Authority, the strictness of the environmental authority in the enforcement of the water pollution standards

TIME, as defined above

Industrial Waste

I and $\bar{I}$, as defined above

Number of plants, the number of plants in a region that emit air pollutants divided by the area of that region (# per sq. kilometer).

Population density, as defined above

Sources of Data

Seoul, "Seoul Statistical Yearbook", various issues

Pusan, "Pusan Statistical Yearbook", various issues

Taegu, "Taegu Statistical Yearbook", various issues

Inchon, "Inchon Statistical Yearbook", various issues

Kwangju, "Kwangju Statistical Yearbook", various issues

Taejon, "Taejon Statistical Yearbook", various issues

Kyonggido, "Kyonggi Statistical Yearbook", various issues

Kyongsangnamdo, "Kyongnam Statistical Yearbook", various issues

Kyongsanbukdo, "Kyongbuk Statistical Yearbook", various issues

Cholanamdo, "Chonnam Statistical Yearbook", various issues

Chungchongnamdo, "Chungnam Statistical Yearbook", various issues

Ministry of Environment, "Korea Environmental Yearbook", 1988 - 1996

National Statistical Office, "Korea Statistical Yearbook", 1993, 1994, 1996

The Bank of Korea, "Monthly Bulletin", January 1997

Appendix 2: The determinants of Air Quality

(t-statistic in parenthesis)

Variable	Carbon monoxide	Nitrogen dioxide	Ozone	Sulfur dioxide	Total suspended particles
Income	24.5955 (1.7686)	.0195 (.1539)	- .0486 (- .5444)	.0751 (.4501)	1069.352 (2.4470)
Squared Income	- 5.7260 (- 1.7451)	- .0025 (- .0824)	.0124 (.5937)	- .0161 (- .4107)	- 247.9763 (- 2.3807)
Cubed Income	.4192 (1.6889)	.0002 (.0804)	- .0010 (- .6209)	.0010 (.3275)	17.9752 (2.2557)
Lagged Income	- 26.6032 (- 2.0766)	- .0069 (- .0553)	.0377 (.4367)	- .1617 (- 1.0636)	- 683.8788 (- 1.6913)
Sq. Lagged Income	6.8502 (2.1378)	.0040 (.1277)	- .0093 (- .4353)	.0445 (1.1639)	169.1300 (1.6501)
Cub. Lagged Income	- .5780 (- 2.1630)	- .0004 (- .1498)	.0008 (.4686)	- .0038 (- 1.1755)	- 13.7884 (- 1.5892)
Population Density	.6442 (2.7672)	- .0044 (- 2.7225)	- .0006 (- .5082)	- .0021 (- .9034)	8.4174 (1.3793)
Registered Vehicles	18.5099 (1.7840)	.2942 (3.3237)	.1082 (1.6294)	.0570 (.4707)	240.0609 (.7848)
Strictness of Authority	.4124 (.3790)	- .0309 (- 3.3344)	- .0006 (- .0828)	.0037 (.3052)	16.7040 (.6011)
Lagged Strictness	1.1771 (1.1235)	- .0127 (- 1.5148)	.0007 (.1071)	.0058 (.5284)	80.6412 (3.1351)
Time	0.3659 (1.0350)	- .0085 (- 3.0797)	- .0027 (- 1.2891)	- .0044 (- 1.1768)	- 3.9274 (- .4070)
R-square No. of Obs.	.9354 42	.9529 42	.8197 42	.9412 42	.9745 42
P-value (Income and Lagged income Combined)	0.0128	0.2467	0.9412	0.0900	0.0594
P-value (Income only)	0.2240	0.2296	0.8381	0.2370	0.0360
P-value (Lagged Income Only)	0.1690	0.5003	0.7711	0.0733	0.3308

Appendix 3: The determinants of Water Quality

(t-statistic in parenthesis)

Variable	Biological Oxygen Demand	Chemical Oxygen Demand	Total Coliform	Dissolved Oxygen	Suspended Substances
Income	11.6190 (.6679)	- 8.6941 (- .5448)	35970.23 (.0155)	- 2.7630 (- .2677)	71.7310 (1.0193)
Squared Income	- 4.1653 (- .9552)	.6495 (.1632)	- 42872.84 (- .0742)	.5217 (.1996)	- 18.7621 (- 1.0712)
Cubed Income	.4120 (1.2004)	.0389 (.1256)	4556.709 (.0998)	- .0277 (- .1338)	1.4207 (1.0375)
Lagged Income	25.8471 (1.8492)	28.2943 (2.3027)	- 423474.4 (- .2770)	- 22.5923 (- 3.0929)	37.9866 (.7174)
Squared Lagged Income	- 5.5510 (- 1.4662)	- 6.5556 (- 1.9624)	129767.3 (.2890)	5.5273 (2.6732)	- 5.9268 (- .4112)
Cubed Lagged Income	.3381 (.9782)	.4635 (1.5652)	- 12478.47 (- .2933)	- .4724 (- 2.4491)	.3276 (.2559)
Population Density	- 8.1060 (- 1.0035)	-11.3369 (-1.9095)	- 934261.7 (- .3867)	- 4.3656 (.8923)	16.5586 (.6203)
Temperature of water	- .0639 (- .2549)	.2185 (.9940)	797.8197 (.0316)	- .2764 (- 2.719)	- .5916 (- .6262)
Strictness of authority	- 3.9015 (- 1.2161)	- .6350 (- .1808)	176148.9 (.3710)	- .0034 (.0017)	- 15.0244 (- 1.0331)
Lagged strictness	- 2.0730 (- 1.5095)	- 2.5293 (- 2.1841)	- 8771.920 (- .0602)	.7975 (1.0940)	6.0474 (1.2043)
Time	.2534 (.2544)	.4677 (.5334)	21185.24 (.2579)	.9010 (1.8316)	.4568 (.1398)
R-square (No. of obs.)	.9296 (40)	.9220 (40)	.3302 (40)	.9793 (40)	.7059 (40)
P-value (Income and Lagged income Combined)	0.6531	0.1398	--	0.0014	0.1796
P-value (Income only)	--	0.0596	--	0.9512	0.4620
P-value (Lagged Income Only)	--	0.0997	--	0.0082	0.1836

Appendix 4:The determinants of Industrial Waste

(t-statistic in parenthesis)

Variable	Waste Acid & Akali	Waste Oil	Waste Synthetic Resin
Income	-39.9312 (-.9472)	-1.9594 (-1.2005)	-34.9671 (-1.1028)
Squared Income	7.0673 (.8527)	.7629 (.3572)	7.8902 (1.2949)
Cubed Income	-.3588 (-.6848)	-.0544 (-.3633)	-.5981 (-1.5710)
Lagged Income	88.8966 (1.8422)	24.4078 (1.9860)	21.1620 (.6145)
Squared Lagged Income	-19.4675 (-1.8221)	-4.6638 (-1.6164)	-3.8064 (-.4919)
Cubed Lagged Income	1.3711 (1.7962)	.2886 (1.3045)	.3647 (.6503)
No of Facilities	-2929.684 (-.6574)	-704.1628 (-.8464)	14244.68 (4.9787)
Population Density	-2.3114 (-.9430)	-.2210 (-.7249)	.4030 (.3364)
Time	.0377 (.0330)	-.7798 (-3.4454)	-1.7216 (-1.8284)
R-square (No of obs.)	.8721 (78)	.9209 (80)	.8436 (80)
P-value (Income and Lagged income Combined)	0.0073	0.0003	0.0003
P-value (Income only)	0.1747	0.0596	0.0006
P-value (Lagged Income Only)	0.0395	0.0747	0.0004

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