Air Pollution in Japan: the Inverted U-Shaped Relation

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Abstract: In 1995 Grossman and Krueger, utilizing the data collected worldwide, discovered the inverted U-shaped relation between the per-capita GDP and air pollution level. It may be explained that the relation holds in each country. To explain the inverted U-shaped relation, however, an alternative explanation is also possible: although for each country's cross-sectional data the positive correlation holds between the per-capita GDP and pollution level, the worldwide data may exhibit the inverted U-shape. The worldwide result might be regarded as the one of time-series data, in which each country's preference relation towards environment is different depending on the stage of economic growth. First, it is shown by economic modeling that the above two explanations are possible. Next, it is examined if the inverted U-shaped relation holds for a specific country in a specific year, utilizing Japanese cross-sectional data for 1990 and 2000. Three types of pollution are dealt with: SOX, NOX, and SPM. The inverted U-shaped relation does exist for SOX case in 2000. It is the case, however, solely for SOX case in 2000. For all the other cases on NOX and SPM, only the positive correlation exists. Thus, the explanation in terms of the historical shift of preference relation towards more pollution-intolerant is more persuasive in Japan.

Keywords: *pollution, general equilibrium, Pigou, the inverted U-Shape, simulation.*

1. INTRODUCTION

In 1970s, ecologists accused Japanese firms for the "Export of Pollutions", asserting, for example, that the Japanese steel makers operated the old-fashioned blast furnaces in the developing countries. The operation was forbidden to the blast furnaces in Japan because of the pollutions they caused, while they were allowed the operation in the developing countries with less severe pollution laws (Sumi [1991]). Thus, it has been widely accepted that as a society becomes affluent, the quality of environment becomes improved. Grossman and Krueger [1995] statistically confirmed this relation and it can be attributed to income effect in microeconomics (Colstad [1999, Chapter 13]). As in the traditional microeconomic argument, in which households may select more leisure as they become affluent: backward-bending labor supply function, households may select high quality of environment as they become affluent. With the per capita GDP on horizontal axis and the smoke level on the vertical axis, Grossman and Krueger [1995] derived the inverted U-shaped regression for the data with five hundred worldwide observations on cities. They interpreted that as the per capita GDP in a society increases, the smoke level in this society rises when the society is poor, while it falls when the society is affluent. The regression may be interpreted differently. In interpreting the regression result some may assert that affluent society members are environment-conscious, while the poor members are not, and this inverted U-shaped regression is observable for a cross-sectional data in a specific country and specific time, such as, Japan in 2006. Meanwhile, others may present a different interpretation, asserting that the regression result reflects the historical economic development and it is possible that even if a positive correlation holds between the per-capita GDP and the smoke level in every country, the collection of five hundred worldwide observations may result in the inverted U-shaped regression, since affluent countries in general are relatively more environment-conscious than poor countries due to their historical experiences.

This paper examines the problem of interpretation of the inverted U-shaped regression derived by Grossman and Krueger [1995]. In Section 2 of this paper, a theoretical analysis is attempted. Thus, from the economic viewpoint we construct a general equilibrium model of competitive economy with pollution, by assuming that there are identical households and a firm, a polluter in a society, for the purpose of conducting this attempt. It is examined if this model derives the inverted U-shaped relation. In Section 3, an empirical analysis is attempted. In Japan, cross-sectional data on the atmospheric pollution for each year since 1980s are available. To be more specific, National Institute of Environmental Studies (http://www.nies.go.jp/) has published atmospheric pollution levels for each of 47 prefectures since 1980s. Types of atmospheric pollution range from SPM (Suspended Particulate Matters), SO_2, NOx, Oxidant, etc. Utilizing these data, we examine if a positive correlation holds between the per-capita GDP and the atmospheric pollution level for Japan in a particular year.

2. THEORETICAL ANALYSIS

In this section, we examine if the inverted U-shaped relation between the per capita GDP and pollution level can be derived, utilizing general equilibrium (GE) approach, which was adopted in Fukiharu [1991]. As the city size expands, usually, pollution level is expected to rise, since in accommodating the increasing population, the production expands, which may worsen the pollution. Thus, positive correlation between the per capita GDP and pollution level may be expected. Since Pigou [1920] advocated the governmental intervention in the emergence of pollution, however, Pigouvian tax became a standard method to "internalize" pollution. This internalization of pollution might produce the inverted U-shaped relation. Fukiharu [1991] constructed a primitive GE model to incorporate pollution, by adopting Pigouvian tax, or compensation for the pollution. This section extends this approach, by incorporating the expansion of a city into Fukiharu [1991]. Specifying utility function of the households by Cobb-Douglas type, or CES (Constant Elasticity of Substitution) type, we examine if the inverted U-shaped relation between the per capita GDP and pollution level can be derived by this specification. We start with the Cobb-Douglas type.

2.1 Cobb-Douglas Type

Suppose that in a city there are M identical households and each household maximizes utility under income constraint. The households with equal shares own the firm. The production of the firm causes pollution, and it compensates for the damage, through the Pigouvian tax. The compensation payment is distributed equally to each household. Specifically, each household is assumed to maximize utility under income constraint:

$$\max u[x,l,S] \quad \text{s.t. } px=w(N_0-l)+(p_sS+\pi)/M \qquad (1)$$

where $u[x,l,S]$ is the utility function, x is the quantity of the (composite) good, l is the leisure, S is the level of pollution, N_0 is the household's initial endowment of leisure hours, p is the price of the good, w is the wage rate, p_s is the compensation per one unit of the pollution paid to the government, and π is the profit distribution. We assume that the compensation, p_s, is determined by *Walrasian Tatonnement* process, as well as p and w. In other words, pollution is "internalized" following Pigou [1920]: p_s is determined in the "pollution market". In this section, the utility function of each household is stipulated by the following Cobb-Douglas type and S_0 is the maximum acceptance level of the pollution in this city:

$$u[x,l,S]=x^{a1}l^{a2}(S_0-S)^{a3} \text{ where } a1+a2+a3=1 \quad (2)$$

Income constraint is equivalent to the following:

$$px+(p_s/M)(S_0-S)+wl=wN_0+(p_sS_0+\pi)/M=I \quad (3)$$

Each household's demand function for the good, x^d, demand function for the leisure, l^d, and the demand for the pollution, S, are derived, given I and other parameters. The supply of labor, L^s is defined as N_0-l^d.

As for production, suppose that the firm produces the (composite) good using solely labor under constant returns to scale, and for simplicity suppose that one unit of good production causes one unit of pollution. Thus, the production function, $x=f[L]$, where L is the input of labor, and pollution-causing function, $S=g[x]$, is given by the following.

$$x=f[L]=L \qquad (4)$$
$$S=g[x]=x \qquad (5)$$

The firm maximizes profit with pollution compensation:

$$\max \pi=px-wL-p_s S.$$

Under the assumptions (4) and (5), the conditions of profit maximization are stipulated by

$$p=p_s+w, \quad \max \pi=0,$$

and output of the good, x^*, is determined by the demand condition:

$x^*=f[ML^s]$, $Mx^d=x^*$,

while the pollution level, S^*, is determined by

$S^*=g[x^*]=x^*$.

Thus, in this section, the GE with pollution is realized by computing $S^*(=x^*)$ and p^*, from the following equilibrium conditions.

$p_s=p^*-1$, $f[M L^s]=S^*$, and $Mx^d=f[ML^s]$,

where w=1 is assumed. In this primitive GE model with Cobb-Douglas specification, we can compute $S^*(=x^*)$ and p^* as follows.

$$S^*=[(MN_0-a_2MN_0+a_1S_0+a_2S_0-\{4a_1a_2S_0(-MN_0+S_0)+(-MN_0+a_2MN_0+a_1S_0-a_2S_0)^2\}^{1/2}]/2$$
$$p^*=[(MN_0-a_2MN_0-a_1S_0+a_2S_0+\{4a_1a_2S_0(-MN_0+S_0)+(-MN_0+a_2MN_0+a_1S_0-a_2S_0)^2\}^{1/2}]/(2a_2S_0) \quad (6)$$

When $N_0=100$, $S_0=100$, and $a_1=a_2=a_3=1/3$ and $M=500$, we have $S^*=49.975$ and $p^*=999.501$. The per capita GDP is p^*x^d and the pair of GE per capita GDP and the GE pollution level, S^*, depends on the city size, M. In what follows we construct 10000 pairs of GE per capita GDP and GE pollution level, computed as M increases from 0.1 to 1000. As shown by the solid curve in the following Figure1, as the city size increases, both the GE per capita GDP and the GE pollution level rise. Next suppose that as the society becomes more pollution-intolerant, the maximum acceptance level, S_0, falls from 100 to 95. In what follows, in the same way as in the case of $S_0=100$, 10000 pairs of the GE per capita GDP and the GE pollution level are computed when $S_0=95$ as M increases from 0.1 to 1000. They are depicted as the dashed curve in Figure1. As the city size increases, both the GE per capita GDP and the GE pollution level rise as shown by the dashed curve, while it is below the solid curve.

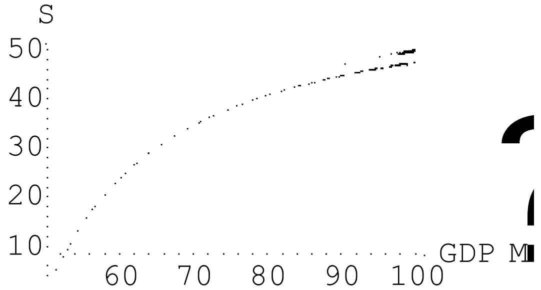

Figure1. The Positive Correlation: Cobb-Douglas Type

In the case of Cobb Douglas function, this result is rather robust. Thus, we may conclude that there is a positive correlation between the per capita GDP and the pollution level. For the details of computation and simulation, see Fukiharu [2005].

2.2 CES Type [Case I]

What would happen if the utility function is different from the Cobb-Douglas type? In this subsection, the case in which the utility function is of the CES type is examined. The CES (Constant Elasticity of Substitution) utility function is defined by

$$u[x,l,S]=\{ax^{-t}+bl^{-t}+c(S_0-S)^{-t}\}^{-n/t} \quad (7)$$

where n is the order of the homogeneity. In this subsection, the parameters are specified by

$$n=1,\ t=-1/2,\ a=b=c=1 \quad (8)$$

In exactly the same way as in the preceding subsection, with the specification of $N_0=100$, and $S_0=100$, we can compute 100 pairs of per capita GDP and the pollution level, as the city size M increases from 0.1 to 10. They are depicted as the solid curve in Figure 2. Due to the income effect, when the per capita GDP itself is sufficiently large, the GE pollution level falls as the GE per capita GDP rises, as shown by the *inverted U-shaped* solid curve in the figure. Next suppose that as the society becomes more pollution-intolerant, the maximum acceptance level, S_0, falls from 100 to 95. In what follows, in the same way as in the case of $S_0=100$, 100 pairs of the GE per capita GDP and the GE pollution level are computed when $S_0=95$ as M increases from 0.1 to 10. They are depicted as the dashed curve in Figure 2. Due to the income effect, when the per capita GDP itself is sufficiently large, the GE pollution level falls as the GE per capita GDP rises, as shown by the *inverted U-shaped* dashed curve in the figure, while it is below the solid curve.

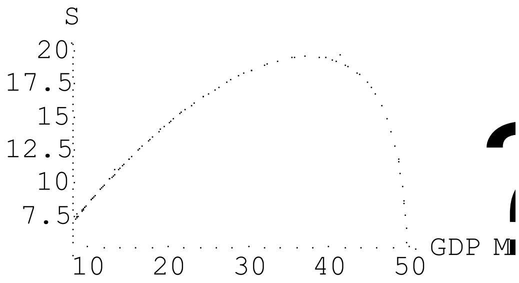

Figure2. The Inverted U-Shaped Relation: CES Type [Case I]

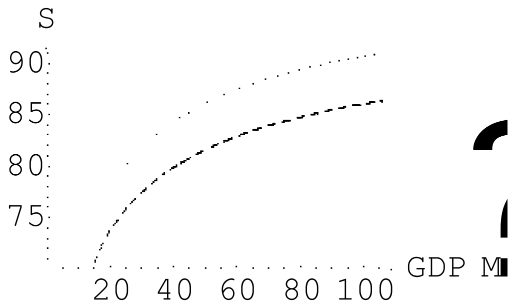

Figure3. The Positive Correlation: CES Type [Case II]

We may conclude that there is the inverted U-shaped relation between the per capita GDP and the pollution level, when the utility function is of the CES type with the parameters specified in (8).

2.3 CES Type [Case II]

When the utility function is of the CES type, as in (7), is the inverted U-shaped relation guaranteed between the per capita GDP and the pollution level, independent of the specification on the parameters? In order to examine this problem, let us assume that the utility function is of the CES type, as in (7), with the parameters specified by

$$n=1,\ t=1/2,\ a=b=c=1 \qquad (9)$$

In exactly the same way as in the preceding subsections, with the specification of $N_0=10$, and $S_0=100$, we can compute 1000 pairs of per capita GDP and the pollution level, as the city size M increases from 1 to 1000. They are depicted as the solid curve in Figure 3. Contrary to the case of t=-1/2, the GE pollution level rises monotonically as the GE per capita GDP rises, as shown in Figure 3. Next, the case of reduced acceptance level is examined. With the specification of $N_0=10$, and $S_0=95$, 1000 pairs of the GE per capita GDP and the GE pollution level are computed as the city size, M, changes from 1 to 1000. In exactly the same way as in the case of $S=100$, the GE pollution level rises monotonically as the GE per capita GDP rises, as shown by the dashed curve, which is below the solid curve, in Figure 3.

Contrary to the CES [Case I], we may conclude that there is a positive correlation between the per capita GDP and the pollution level in this CES [Case II].

3. EMPRICAL ANALYSIS

In this section, we examine if the inverted U-shaped relation between the per capita GDP and the pollution level can be depicted for the Japanese cross-sectional data, which was made available by National Institute of Environmental Studies (http://www.nies.go.jp/). The institute has published atmospheric pollution levels for observation points in each of 47 prefectures since 1980s. Types of atmospheric pollution range from SOX, NOX, SPM (Suspended Particulate Matters), to Oxidant, etc. In this paper, for each type of atmospheric pollution, the simple average of observed values in each prefecture is defined as the atmospheric pollution level of the prefecture. Starting from SOX, for each type of atmospheric pollution, we examine if the inverted U-shaped relation between the per capita GDP and the pollution level can be derived. As for the data of per capita GDP for each prefecture in 2000, they are borrowed from the Japan Statistical Yearbook 2005 (http://www.soumu.go.jp). In order to make a comparison with GDP, we use the data of per capita "income" for each prefecture in 2000. They are also borrowed from the Japan Statistical Yearbook 2005.

3.1. SOX [2000]

In Japan, SOX has been the most notorious pollutant. It was in the 1890s that farmers and ecologists demanded the alleviation of the pollution, caused by the two Japanese copper sulfide mines: Ashio and Besshi mines. This pollution was due to the discharged sulfurous acid gas from those mines (Arahata [1907]). In the 1950s, Minamata disease became the worldnotorious synonym for pollution. This disease erupted in a southern coastal city, MINAMATA, and it was the mercury poisoning, where the mercury was discharged into the sea in producing nitrogen fertilizer. At about the same time, there erupted the atmospheric pollution in Yokkaichi, a central coastal city. The disease, caused by the discharged sulfurous acid gas from petrochemical refineries and electric power plants, was called the Yokkaichi asthma. This pollution leads to the legislations of Smoke Regulation Act in 1962, the Atmospheric Pollution Prevention Act in 1968, and finally to the Revised Atmospheric Pollution Prevention Act in 1970. In this subsection, we examine if the inverted U-shaped relation between the per capita GDP and the SO2 level can be derived from the Japanese cross-sectional data, which was made available by National Institute of Environmental Studies.

We obtain better result by using per capita income, rather than using per capita GDP. The quadratic regression analysis on the data of per capita income and SO2 for 47 Japanese prefectures is conducted in Figure 4. The p-values for the coefficients of this regression function are all smaller than 0.05.

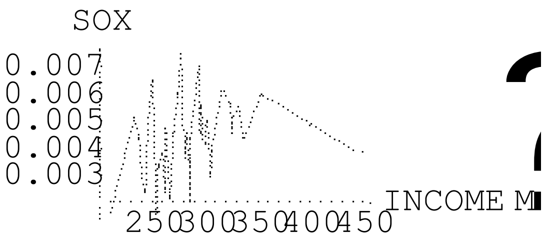

Figure4. The Inverted U-Shaped Relation: SOX in 2000

A remark is in order, however, in this case. When we conduct the linear regression analysis on the above data, the p-value for the coefficient of this regression function is also smaller than 0.05. In other words, both the positive correlation and the inverted U-shaped relation hold between the per capita income and SOX in 2000.

3.2. SOX [1990]

In this subsection, a linear regression is attempted between the per capita income and the SO2 level in 1990. In the following Figure 5, the dashed line connects the pairs of data. The solid line is the computed regression line, which shows the positive correlation between them. The p-value of the coefficient in this linear regression is smaller than 0.05. When we conduct the quadratic regression analysis on the above data, the p-values for the coefficients of this regression function are all greater than 0.48. In other words, the positive correlation holds between the per capita income and SOX in 1990, while the inverted U-shaped relation does not hold.

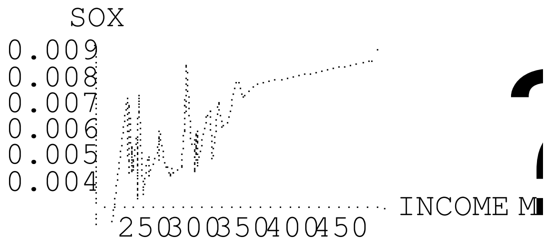

Figure5. The Positive Correlation: SOX in 1990

3.3. NOX

NOX as well as SOX cause pollution such as acid rain or respiratory diseases, and the government has attempted to reduce them. Compared with SOX, however, the reduction of NOX is more difficult. The origin of NOX is same as SOX. NOX, such as NO or NO2, is generated by the combustion of petroleum. For the purpose of distinguishing the origin of NOX and SOX, let us restrict it to the one from automobiles. SOX is generated inside the engines of automobiles: *i.e.* sulfur in petroleum is oxidized. Meanwhile, NOX is generated outside the engines of automobiles: *i.e.* the heat of engines oxidizes the nitrogen in the atmosphere. In other words, if the automobile manufacturers attempt to improve the efficiency in combustion of fuels, usually the attempt succeeds in the reduction of SOX, but it fails in the reduction of NOX. In 1992 the Automobile NOX Reduction Act was enacted in Japan.

From the regression analysis on the data for 47 Japanese prefectures, the conclusion is as follows. Both in 1990 and 2000, the positive correlation holds between the per capita income and NOX, while the inverted U-shaped relation does not hold. In Figure 6, the thick regression line is depicted for the data in 1990, where the dashed line connects those data. The (thin) solid line, in this figure, is the computed regression line for 2000. It may be said from the comparison between 1990 and 2000 that since 1990 until 2000 Japanese society became more pollution-intolerant.

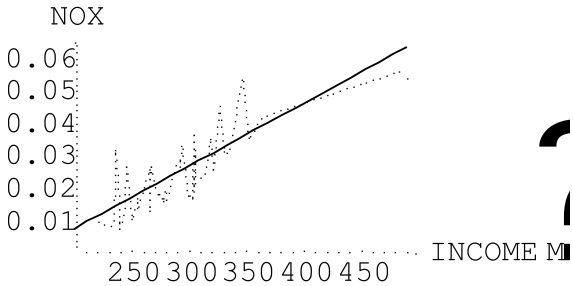

Figure 6. The Positive Correlation: NOX in 1990 and 2000

3.4. SPM

Until 1999, SPM (Suspended Particulate Matters) was almost unknown to the Japanese general public. In 1999, Governor of Tokyo, Shintaro Ishihara, abruptly announced the revision of Metropolis of Tokyo Pollution Prevention Act in a press conference, showing the reporters the black powder in a bottle at the conference. The powder, small enough to float in the air, causes respiratory diseases or lung cancer. In Japan, 43% of SPM in the air is generated by automobiles, especially, trucks with diesel engines (87% among automobiles). The revision, which took effect in 2003, made stricter regulations on the transport through trucks. Nationwide, the Automobile NOX Reduction Act, enacted in 1992, was revised into the Automobile NOX-PM Reduction Act in 2001. Regulation by Metropolis of Tokyo is stricter than the national one. From the regression analysis on the data for 47 Japanese prefectures, the conclusion is as follows. Both in 1990 and 2000, the positive correlation holds between the per capita income and SPM, while the inverted U-shaped relation does not hold. With this SPM we have a similar results as in Figure 6, so that it may be said from the comparison between 1990 and 2000 that since 1990 until 2000 Japanese society became more pollution-intolerant from the viewpoint of SPM.

4. CONCLUSIONS

The aim of this paper was to examine the inverted U-shaped relation between the per capita GDP and pollution level, discovered by Grossman and Krueger [1995]. In section 2 it was shown that when Cobb-Douglas (invariant) utility function is assumed the positive correlation holds, and under assumption of CES (invariant) utility function it is possible to depict the inverted U-shaped curve for some specification of parameters, while under assumption of CES (invariant) utility function it is possible to depict the linear positive line for other specification of parameters. Thus, theoretically, the above two explanations are possible.

In Section 3, it was examined if the inverted U-shaped relation between the per-capita GDP and pollution level holds for specific years, utilizing Japanese cross-sectional data for 1990 and 2000. In this section three types of pollution were dealt with: *i.e.* SOX, NOX, and SPM. It was ascertained that the replacement of per-capita GDP by per capita income gives rise to superior regression results for all the examinations. The inverted U-shaped relation between the per capita income and pollution level does exist for SOX case in 2000. It is the case, however, only for SOX case in 2000. Note, furthermore, that even for this SOX case in 2000, statistically, it is also possible to assert that the positive correlation exists between the per capita income and SOX level in 2000. In 1990, only the positive correlation exists between the per capita income and SOX level: *i.e.* the inverted-U shaped relation is statistically denied. For all the other cases on NOX and SPM, only the positive correlation exists, while the inverted U-shaped relation is statistically denied. It was shown that from 1990 until 2000 the Japanese society becomes more pollution-intolerant.

From the above results, we may conclude that the explanation in terms of the shift of utility function towards more "pollution-intolerant" is more persuasive in Japan.

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