Beyond the Environmental Kuznets Curve:

A Comparative Study of SO_2 and CO_2 Emissions

between Japan and China *

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Abstract: This study is the first systematic attempt to test statistically the contrasting hypotheses on the emission of SO_2 and CO_2, and energy consumption in Japan and China for the last few decades. We postulate the hypotheses that local governments have incentives to internalize the local external diseconomies caused by SO_2 emissions, but not the global external diseconomies caused by CO_2 emissions. To substantiate our hypotheses, we decompose emissions of SO_2 and CO_2 into two factors: the emission factor (i.e., emission per energy use) and the energy consumption. The results show that the prefectures where the past energy consumption was high tend to reduce the emission factor of SO_2 significantly in Japan, while we do not find such a tendency in China. There is also evidence that neither per capita income nor the past energy consumption affects the CO_2 emission factor and the energy consumption significantly in both Japan and China implying that an individual country has little incentives to reduce CO_2 emissions.

1. Introduction

The majority of developing countries do not participate in the Kyoto Protocol, at least partly because of the belief that environmental protection cannot be achieved without sacrificing economic development to a significant extent. This is probably why the majority of developing countries prefer industrial development to environmental protection. On the other hand, those who believe in the environmental Kuznets curve (EKC) hypothesis consider that environmental protection becomes active only after economic development is achieved to some extent (World Bank 1992). For them, the post-war high growth era in Japan is a favorable example (OECD 1977, 1994; Weidner 1995), in which high economic growth lasted from the 1950s to the 1980s and sulfur dioxide (SO_2) emissions decreased drastically in the 1970s and 1980s.

China has experienced rapid economic growth and serious environmental deterioration in the last two decades (National Bureau of Statistics, China 2001). The Chinese government, however, has not paid serious attention to its environmental deterioration such as air pollution caused by SO_2 emissions until recently. As a result, over one hundred thousand Chinese people still suffer from and even die of respiratory diseases annually (World Bank 1997). Because Japan did not act decisively on reducing SO_2 emissions until the late 1960s after a period of intense growth, it may not be surprising that China is taking action only now. A question, however, arises as to what the major factors are that induce the government to take such action. While the EKC hypothesis highlights the stages of economic development, seminal studies have also acknowledged and discussed other potential factors, such as abatement technology change, the pre-abatement concentration of pollution, concern for the unfavorable effects of abatement efforts on industrial development, and whether pollution is local or global (e.g., Shafik 1994; Stern 1998). It seems important to further explore the idea empirically.

This paper is an attempt to extend the EKC analysis in this vein based on a comparative study of the SO_2 and carbon dioxide (CO_2) emissions between Japan and China. External diseconomies arising from the emissions of SO_2 and CO_2 are markedly different: While the emission of SO_2 causes immediate and severe damage to the health of the residents near the pollution sources, CO_2 gas itself is non-toxic to human bodies but may cause global warming in the long run[1]. Furthermore, while desulfurization is technically feasible to reduce the SO_2 emissions, there is no practical technology to abate the emissions of CO_2 without reducing fossil energy use. We hypothesize that while local communities have strong incentive to internalize the local external diseconomies arising from SO_2 emissions, they have little incentive to reduce the use of energy as it is

[1] CO_2 emissions may also cause local or regional externality, such as ocean acidification that damages coral and carbon fertilization that disturbs ecosystems.

likely to have unfavorable effects on the production activities of local industries. In other words, local communities are interested in adopting abatement technology which enables them to reduce SO_2 emissions without reducing energy consumption. We also hypothesize that local communities have little interest in reducing CO_2 emissions because of the global nature of the external diseconomies arising from CO_2 emissions. These hypotheses are consistent with the findings of the existing empirical literature (World Bank 1992; Shafik and Bandyopadhyay 1992; Shafik 1994; Selden and Song 1994, 1995; Grossman and Krueger 1995; Stern 1998, 2004a). For example, Stern (1998, 2004a) cogently argues that while the EKC is monotonic for both sulfur and carbon, technical change in abatement which lowers the EKC is greater for sulfur than for carbon. With respect to local and global externalities, our hypothesis is consistent with the insight provided by Shafik (1994, p. 770):

> Local air pollution, which imposes external costs locally but is relatively costly to abate, tends to be addressed when countries reach a middle income level. This is because air pollution problems tend to become more severe in middle income economies, which are often energy intensive and industrialized, and because the benefits are greater and more affordable. Where environmental problems can be externalized, as with solid wastes and carbon emissions, there are few incentives to

incur the substantial abatement costs associated with reduced emission and wastes.

This study is the first systematic attempt to statistically test the hypotheses on the contrasting incentives to reduce SO_2 and CO_2 emissions and energy consumption. To substantiate these hypotheses, we decompose the emissions of SO_2 and CO_2 into energy consumption and emission per energy consumption, and then examine the determinants of each component of the emission of each air-pollutant, as our hypotheses imply that local communities are interested in reducing SO_2 emission per energy but not energy consumption or CO_2 emission. We believe that this formulation of the hypothesis testing represents a novel methodological approach in the field of environmental studies.

This paper is organized as follows. Section 2 briefly presents estimation results on the EKC for sulfur and carbon in Japan and China. Section 3 postulates hypotheses regarding the determinants of the environmental degradation and protection, and then discusses the data and methods used to estimate the reduced-form functions that explain energy consumption and emission per energy. The estimation results are presented in Section 4. The final section summarizes the findings and discusses their policy implications.

2. Estimation of the Environmental Kuznets Curve (EKC)

We begin our analysis by estimating the EKC for SO_2 and CO_2 emissions in Japan and China. Although there are a wide variety of specifications of the EKC (Shafik and Bandyopadhyay 1992; Grossman and Krueger 1995; Stern 1998; Stern *et al*. 1996), the basic model uses an indicator of emissions of environmental pollutants as the dependent variable, and per capita income (or GDP) and its squared term as the explanatory variables as follows:

$$(1) \quad \ln EM_{it} = \beta_0 + \beta_1 \ln y_{it} + \beta_2 [\ln y_{it}]^2 + \lambda_t + u_i + \varepsilon_{it} ,$$

where ln EM_{it} is the natural logarithm of the emission of SO_2 or CO_2 per area, $\ln y_{it}$ stands for the natural logarithm of per capita GDP, β's are regression parameters, λ is the time effect, u is a province/prefecture effect, ε is an error term, and i refers to the i-th area and t refers to the t-th time period[2]. If the relationship between an environmental indicator and income is of the inverted U-shape, as is supposed in the EKC hypothesis, β_1 is positive and β_2 is negative. Since the Chinese economy is currently at the low- to middle-income stage, it is possible that China is on the rising portion of such a curve while Japan is on the declining portion, if the EKC hypothesis is valid in both countries.

We constructed prefecture-level data for Japan and province-level data for China

[2] The specification, in which the dependent variable is emission per capita and explanatory variables include population density, leads to similar results.

based on the statistical data compiled by the respective governments (National Bureau of Statistics, China various years; Agency of Environment, Japan various years; Economic Planning Agency of Japan various years; Institute of Energy Economics, Japan 2002). The data sets cover 47 prefectures in Japan and 29 provinces in China[3], and the period from 1975 to 1999 (1975, 1980, 1985, 1990, 1995 and 1999) for Japan and from 1985 to 1999 (1985, 1991, 1995 and 1999) for China. Since the CO_2 emission data at the provincial or prefectural level are not available, we estimated them using the data on the use of various fuels[4].

Table 1 shows the summary statistics of the environmental and energy use indicators from the industrial sector in China and Japan. The emissions data and the energy consumption data are taken from stationary sources, such as power plants and factories, in Japan. They are taken from industrial sectors in China.[5] China increased its real GDP 3.5 times and energy consumption 2.1 times in the period from 1985 to 1999. Corresponding to these changes, the emissions of SO_2 and CO_2 doubled in the same period. On the other hand, Japan increased energy consumption only by about 38% and reduced

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3 The data from Tibet are not available.

4 A more detailed discussion on this estimation procedure is provided in Yaguchi (2003).

5 Streets *et al*. (2000) and Carmichael *et al.* (2002) show quite a different pattern for sulfur emissions in the Chinese economy as a whole. This is most likely due to the fact that we use basically industrial data, whereas those authors use aggregate economy-wide data.

SO_2 emissions by 75% in the period from 1975 to 1999. As a result of this decrease in SO_2 emissions, the level of the atmospheric SO_2 concentration rapidly improved over the last 30 years in Japan, as illustrated in Figure 1, which plots the measured pollution of SO_2 in the same 17 locations over time. It is interesting to observe that the solid curve showing the average pollution level resembles the downward-sloping part of the inverted U-curve. By contrast, CO_2 emissions increased by 73% from 1975 to 1999 in Japan, when the real GDP of the country almost doubled. Thus, the trends of both emissions and energy use were highly different between the two countries.

Table 2 presents the estimation results of the EKC for SO_2 and CO_2 emissions in Japan, using both the fixed and the random-effects model. In columns (1) and (2) for sulfur, coefficients β_1 and β_2 are negative and positive, respectively, indicating the existence of an inverted U-shaped curve. The sulfur EKC has a turning point around 3.6 million yen in 1990 constant prices. The Hausman test indicates that the random effects are not correlated with the explanatory variable. Following Stern and Common (2001) and Perman and Stern (2003), we conducted the tests on the autocorrelation of residuals and did not find significant serial correlation. However, it is worth emphasizing that the coefficients of the time dummies for SO_2 emissions are negative and their magnitudes increased in absolute value over time. In other words, there are factors, besides GDP, that had time trends and contributed to lowering SO_2 emissions commonly in all prefectures. These results are consistent with the recent literature (Stern and Common 2001; Perman and Stern 2003; Stern 2002, 2004b). While panel unit root and cointegration tests are employed by Perman and Stern (2003) in their analysis of the EKC, such tests are not applicable here because of the sheer paucity of data.

In columns (3) and (4), coefficients β_1 and β_2 suggest the existence of an inverted U-shaped curve in the CO_2 case as well. Of the 282 observations in total, however, only three observations have higher GDP per capita than the implied turning point, i.e., 4.4 million yen in 1990 constant prices. Thus, the EKC for CO_2 is essentially monotonic, which is also consistent with the findings of Stern (1998, 2004a). The Hausman test indicates that the random effects are not correlated with the explanatory variable. While none of the time dummies have a significant effect on CO_2 emissions, the autocorrelation test detects significant autocorrelation, suggesting significant variables for CO_2 emissions are omitted from this basic EKC model or/and CO_2 emissions show significant persistence over time. Following the lead of Stern and Common (2001), we estimated the first-difference version using OLS and the fixed-effect model. Because the Breusch-Pagan (1979) test indicates the existence of heteroskedasticity in the OLS estimation, we corrected it with White's (1980) robust variance estimator. As shown in columns (5) and (6), the estimation results imply that the turning point is as small as 2.1 million yen, but they should be taken with caution because the residuals exhibit negative and significant autocorrelation.

Table 3 presents the estimation results of the EKC for SO_2 and CO_2 emissions in China. According to the Hausman test, the random effects are correlated with the explanatory variables in the case of SO_2, so that the random-effect model is not estimated consistently. In the first column, neither β_1 nor β_2 is significantly different from zero, and all the time dummies have positive and significant effects on SO_2 emissions, even though their magnitudes are similar. Thus, there is no relationship between SO_2 emissions and GDP per capita, and SO_2 emissions increased from 1985 to 1991 and then become stable. In the case of CO_2, where both fixed- and random-effect models are consistently estimated, coefficient, β_1 is positive and significant but β_2 is insignificant, which suggests that CO_2 emissions increased monotonically with GDP per capita. These results are consistent with the arguments of Stern (1998, 2004a). The positive and significant effects of the time dummies indicate that given GDP per capita, CO_2 emissions increased from 1985 to 1991. For both SO_2 and CO_2, the residuals are not serially correlated.

To summarize these results of the estimation of the basic EKC model, the EKC has an inverted-U shape only in the case of SO_2 emissions in Japan, even though it is possible that China is on the flat turning portion of the EKC in the case of SO_2 and both Japan and China are on the rising portion in the case of CO_2. More importantly, however, the results suggest that there are variables other than GDP per capita that affect SO_2 and CO_2 emissions. They are likely to have time trends or serial correlation at least in the case of Japan. We therefore identify them and examine how they affect air-pollutant emissions in the following sections.

3. Determinants of Atmospheric Environmental Quality

3.1 Overview

In order to reduce the emissions of pollutants, either energy use or an emission factor (i.e., emission per energy) must be reduced. It is likely that the determinants of energy use and emissions per energy use are different, because their reductions impose different costs upon society. Indeed, living conditions are directly affected by the reduction of energy use but not by the reduction of the emission factor. Thus, we will examine the determinants of energy use and emission factor separately below. For this purpose, we constructed data on each component.

The emission of air-pollutants (*EM*) is the product of energy consumption (*EN*) and an emission factor (*EF*) based on the following engineering relationship[6]:

(2) $EM = EN \times EF$

In the case of SO_2 *EF*, we computed it from officially published data of *EM* and *EN*. SO_2 emissions per energy use can be reduced by desulfurization, such as oil desulfurization and exhausted gas desulfurization, as well as the conversion towards low-sulfur fuels such as natural gas. As mentioned earlier, since the information on *EM* of CO_2 is not available, we computed CO_2 *EF* based on the fact that each type of fossil fuel (i.e. coal, crude oil, gasoline, heavy oil, and natural gas) contains a fixed amount of potential energy and a certain amount of carbon per weight, the latter of which is transformed to CO_2 after burning. For China in 1985, however, the data on the composition of energy use are not available.

Let us return to Table 1. The SO_2 emission factor in China did not visibly change over time, while Japan reduced it by 75% over the 20-year period by strengthening regulatory policies. In addition, the SO_2 emission factor in China in 1999 is three times as high as that for Japan in 1975, when Japan tightened the control of the SO_2 emissions. It appears that China has not attempted to reduce the SO_2*EF* to a significant extent.[7]

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[6] Using the decomposition formula as identified, Stern (2002, 2004a) assesses the relative contributions of various components such as emission related technical change and energy intensity, to total change in emissions.

[7] The emission factor increased from 1985 to 1991. This was presumably due to a

Regarding the CO_2*EF*, not only China but also Japan failed to reduce it appreciably over time. This is likely to reflect not only the technical difficulty in reducing CO_2 emissions but also the political factors. Due to the abundant availability of coals and the low energy price policy with ample subsidies by the central government, Chinese enterprises seem to have had little incentive to save energy.[8] It is, however, true that the energy consumption per GDP improved considerably during the period under study, suggesting that China has slowly started to conserve energy use. Still, there remains a huge gap between China and Japan in energy consumption per GDP.

Table 4 shows the contrasts in the emission factors between urban areas and non-urban areas in Japan. Although urban regions use more energy, the SO_2*EF*s in these areas have been lower and declined more significantly, reflecting the fact that environmental regulations are tightened particularly in the urban and industrialized areas in Japan (Weidner 1995). It is said that China pays serious attention to pollution problems in urban areas, where the law enforcement and ordinances are tightened (Kojima 1993). Table 5 compares the average *EF*s between East Coast provinces, which are more

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temporary increase in coal consumption, which emits more sulfur than liquid fuels.

[8] Energy consumption per GDP in China is over twenty times higher than that of Japan, even though this difference will not be as great when it is measured in the purchasing power parity adjusted exchange rates.

urbanized, and the other provinces.[9] The levels of the SO_2EF in the East Coast have declined over time unlike the rest of the country. It is likely that East Coast provinces have effectively strengthened anti-SO_2 regulations in the 1990s.

3.2 Hypotheses and estimation methods

3.2.1 Case of Japan

It is important to note that the local (or prefectural) governments in Japan implemented their own anti-pollution measures since the end of the 1960s. Since Japan had already achieved high income status, its economic goals no longer rested primarily in income growth, but more in the improvement of the quality of life. Thus, the energy-intensive industries, which were considered to be major polluters, were more carefully regulated by the local governments than other industries. Based on this argument, we postulate the following hypothesis:

Hypothesis 1-J: The reduction in the SO_2EF is greater in prefectures which experienced severer pollution, enjoyed higher income, and developed more

[9] East Coast Provinces include Liaoning, Beijing, Hebei, Tianjin, Shandong, Jiansu, Shanghai, as Municipalities according to the administrative classification in China. However, we regard those regions as 'Provinces' in this study. Zhejiang, Fujian, Guangdong, and Hainan. Among them, Beijing, Tianjin and Shanghai are classified as Municipalities according to the administrative classification in China. However, we regard those regions as 'Provinces' in this study.

energy-intensive industries in the past.

Since CO_2 gas itself is not toxic, there is little incentive to abate the CO_2 emissions from the viewpoint of individual prefectures as well as Japan as a whole. Thus, we advance the following hypothesis:

Hypothesis 2-J: Since there is little incentive to reduce the CO_2 emissions, the reduction in the CO_2EF is not affected by the past pollution level, the past income level, and the development of energy-intensive industries.

Since the reduction in the energy use of industries is likely to have negative effects on industrial development and, hence, on the employment and income of local residents, local governments would not be willing to reduce the energy consumption as part of the environmental policy. Therefore, it seems reasonable to advance the following hypothesis:

Hypothesis 3-J: Because of the weak incentive to save energy, the past pollution level and past income did not negatively affect the energy consumption. [10]

[10] As is well-known, with increasing per capita income, the composition of output shifts among sectors which differ in their pollution intensity of output. For instance, the service sector, which is less energy-intensive, grows relative to the manufacturing sector, resulting in a negative income effect on energy consumption. Such a composition effect may not affect the validity of Hypothesis 3 significantly, because we use energy use data of the manufacturing sector. We cannot deny, however, that the composition effect within the manufacturing sector may affect our hypothesis testing to the extent that the industrial structure shifts towards less energy-using sectors. In order to control for such an effect, we will use a variable that reflects the importance of energy-using industrial sectors in the analysis of the Japanese case, where the relevant data are available.

3.2.2 Case of China

In addition to the determinants considered for the case of Japan, the following considerations seem to be relevant for a proper understanding of the environmental policies in China. First, in enforcing its environmental policy, the government can supervise and monitor state-owned enterprises (SOEs) more effectively than other enterprises (Kojima 1993). Second, productive coal mines in China are concentrated in the northern region, where mines produce higher quality coal containing less sulfur and having higher thermal efficiency than coals produced in other regions. Since coal accounts for over 70% of China's total energy production in 1999 (see Figure 2), the northern region tends to emit less SO_2 than the other regions. Since the political system of China is considerably different from that of Japan, it is questionable whether the preferences of residents for improved environmental quality are reflected in local environmental policies in China. For comparison, however, we postulate a hypothesis similar to Hypothesis 1-J as follows:

> Hypothesis 1-C: The reduction in the *EF* of SO_2 is greater in provinces which experienced severe pollution, enjoyed higher income, and were dominated by SOEs, and were endowed with poor quality coals.

Judging from Table 1, China does not appear to have made serious attempts to reduce the CO_2 emissions or save energy during the period under study. Thus, similar to the case of Japan, it seems reasonable to postulate the following hypotheses:

Hypothesis 2-C: The reduction in the *EF* of CO_2 is not affected by the past pollution level, the past income, and the past business activities by SOEs.

Hypothesis 3-C: Because of the weak incentive to save energy, the pollution level and income in the past do not negatively affect the energy consumption.

3.3 Methodology and data

In order to test the hypotheses postulated above, we conduct regression analyses using the changes in SO_2*EF*, CO_2*EF*, and the energy consumption per area as the dependent variables. Unlike the standard analysis of environmental deterioration, we use energy consumption per area, because the severity of pollution is more closely related with energy use per area rather than per capita. For the change in the SO_2 *EF*, denoted as ϕ, we consider the following relationship:

$$(3) \quad \ln\phi_{it} - \ln\phi_{it\text{-}N} = \alpha_0 + \alpha_1 \ln SOEM_{it\text{-}N} + \alpha_2 \ln\phi_{it\text{-}N} + \alpha_3 \ln y_{it\text{-}N} + X_{it\text{-}N}\alpha_4 + \eta_t + \varepsilon_{it},$$

where $\ln SOEM$ is the natural logarithm of SO_2 emission per area; $\ln(y)$ is the natural logarithm of GDP per capita; X is a vector of exogenous variables; α's are regression parameters; subscripts i refers to the i–th area, t and $t–N$ refer to the t-th year and the ($t–N$)th year, respectively; η_t is the time effect, and ε_{it} is an error term.[11] We basically used a five-year lag (i.e., N=5),[12] but the results remain unchanged qualitatively even if we used a 10-year lag. Since $SOEM_{t-N}$ is a measure of pollution in the past, its coefficient α_1 is expected to be negative if the government reduced the emission factor in response to the severe pollution. In practice, it will be technically difficult to reduce the current *EF*, if the *EF* in the past is already low. Thus, we expect that α_2 is negative. The negativity of α_2 is interpreted as conditional convergence, to use a terminology in the recent growth literature (e.g., Barro and Sala-i-Martin 1992).[13]

Since *SOEM* (SO_2 emission per area) is defined as the product of ϕ and *EN* (energy use per area), we transform equation (3) into the following estimable form:

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[11] The squared term of per capita income is not included because our trial regressions have shown that it has no significant effects.

[12] For China, year t-N for 1991 is 1985, 1991 for 1995, and 1995 for 1999. For Japan, year t-N for 1980 is 1975, 1980 for 1985, 1990 for 1995, and 1995 for 1999.

[13] As criticized in the more recent literature (Friedman 1992; Quah 1993), however, this terminology is misleading: while the common usage of the word, conversion, carries a connotation that the variance of the variable in question decreases over time, the conversion as a concept in the growth literature may or may not be accompanied by decreasing variance. Mean reversion may be an apt word. This issue has been discussed also in the recent literature on economic geography (Henderson 2003; Dumais *et al.* 2002).

(4) $\ln\phi_{it} - \ln\phi_{it-N} = \alpha_0 + \alpha_1 \ln EN_{it-N} + (\alpha_1 + \alpha_2)\ln\phi_{it-N} + \alpha_3 \ln y_{it-N} + X_{it-N}\alpha_4 + \eta_t + \varepsilon_{it}$,

As Hypotheses 1-J and 1-C assert, we expect that the coefficient of $\ln EN_{t-N}$, α_1, is negative. The sign of the coefficient of $\ln\phi_{t-N}$, $(\alpha_1 + \alpha_2)$, is expected be negative and larger than α_1 in absolute value.

It is possible that ln(y), lnEN, and ln ϕ are integrated of order one in the time series dimension. If this is the case, it is intriguing to ask whether these variables have a stable relationship over time. As Perman and Stern (2003) argue in their pioneering work, the EKC variables must be cointegrated if the EKC is to be interpreted as a long-run equilibrium relationship. Their results of conintegration tests cast doubt on the existence of such a relationship. Although the direct tests of integration and cointegration are not applicable to our small-sample data set, a model of cointegration can be envisaged, in which increases in ln$y$ are accompanied by increases in lnEN and decreases in lnϕ. Indeed, equation (4) can be rewritten as

(4') $\ln\phi_{it} - \ln\phi_{it-N} = \alpha_0 + (\alpha_1 + \alpha_2)(\ln\phi_{it-N} - \kappa_1 \ln EN_{it-N} - \kappa_2 \ln y_{it-N}) + X_{it-N}\alpha_4 + \eta_t + \varepsilon_{it}$,

which describes the variation in lnϕ around its long-run trend in terms of the equilibrium error correction in the model of cointegration and a set of stationary exogenous variables X.

We examine whether or not the relationship among the three variables is stable over time, by estimating equation (4) separately for different time periods. If the coefficients for these variables change significantly over time, it suggests that cointegration does not exist.

Analogous to equation (4), we assume the following function for explaining the CO_2 *EF* (Φ):

$$(5) \quad \ln\Phi_{it} - \ln\Phi_{it-N} = \beta_0 + \beta_1 \ln EN_{it-N} + \beta_2 \ln\Phi_{it-N} + \beta_3 \ln y_{it-N} + X_{it-N}\beta_4 + \theta_t + v_{it},$$

where β's are parameters, θ_t is the time effect, and v_{it} is an error term. Since we do not anticipate the conscious efforts of local governments to reduce the CO_2 *EF*, we expect to observe that $\beta_1 = 0$.

We consider the following function for the energy use per area:

$$(6) \quad \ln EN_{it} - \ln EN_{it-N} = \gamma_0 + \gamma_1 \ln EN_{it-N} + \gamma_2 \ln\phi_{it-N} + \gamma_3 \ln y_{it-N} + X_{it-N}\gamma_4 + \mu_t + u_{it},$$

where γ's are regression parameters, μ_t is the time effect, and u_{it} is an error term. Note that we use ϕ (SO_2*EF*) rather than Φ (CO_2*EF*) as an explanatory variable, because we expect a priori that the energy use would respond, if at all, to local air pollutions represented by SO_2 emissions in the past, but not to CO_2 emissions. Since we do not expect conscious governmental efforts to reduce the energy use in response to air pollution in the past, we expect to observe that $\gamma_1 = 0$.

In the regression functions for Japan, vector *X* includes the share of energy intensive industries in prefectural GDP (Energy-Int Industry, hereafter) and an urban dummy which is equal to 1 if the prefecture is regarded as an urban and industrial area and 0 otherwise.[14] In the regression functions for China, the value-added share of SOEs (SOE Ratio, hereafter), an East Coast dummy, and a North dummy are included. We use the ordinary least square (OLS) method to estimate functions (4), (5), and (6) separately for each year. In order to test the robustness of such estimations as well as to control for the effects of unobservable location specific factors, we also estimated pooled OLS regressions and the fixed-effects models. As will be seen, there are large consistencies between period-by-period regressions and the pooled regressions.

4. Estimation Results

4.1 Case of Japan

The estimation results for the SO_2*EF* in Japan are presented in Table 6. Notably,

[14] Energy intensive industries include the pulp, petroleum chemistry, chemical, cement, steel, and nonferrous metal industries, and public utilities.

the past energy consumption per area has negative and statistically significant coefficients in 1975-80 and 1980-85. This finding parallels with the findings of Stern (2004b) that the adoption of emission abating technology was positively correlated with the pre-abatement concentration of pollution. Thus, prefectures that consumed a larger amount of energy, and which also emitted a larger amount of SO_2 seem to have stronger incentive to reduce the pollution through a reduction in the emission factor. The past per capita GDP also had a negative impact on the change in *EF* in 1975-80 when Japan tightened its anti-air pollution policy. These results generally support Hypothesis 1-J, even though the Energy-Int Industry has no significant effects. In the 1985-90 period, while the effects of the past energy use and per capita GDP are insignificant, the effect of the past SO_2EF is negative and highly significant. These results indicate that the desulfurization technology was diffused from previously polluted and/or high-income areas to other areas by the end of the late 1980s, so that SO_2EF exhibited a clear tendency towards the convergence. In the 1990s, SO_2EF was already low in all prefectures, and, hence, no explanatory variables had significant effects. The changing effects of energy consumption, GDP per capita, and SO_2EF clearly indicate that the relationship among these variables is not stable over time, which is consistent with the finding of Perman and Stern (2003) that the EKC variables are not cointegrated.

The estimation results of both the pooled OLS (column 6) and the fixed-effects regression (column 7) are qualitatively the same as those of the period-wise regressions (columns 1 to 5). In addition, two points are noteworthy. The pooled OLS estimate of the effect of ln*Energy*/*Area* is highly significant even though the coefficient, -0.161, is more moderate than those in columns 1 and 2. This is simply because the greater sample size inflates the *t*-statistics in the case of the pooled OLS. The same argument applies to the pooled OLS estimate of the effect of SO_2*EF*, which is highly significant in column 6. More conspicuous, however, is the fixed-effects estimate of this effect, as shown in column 7. Presumably the large negative coefficient, -1.075, comes from the well-known problem of applying the fixed-effects estimator to dynamic panel data models, in which the disturbance term after the Within transformation is inevitably correlated with the lagged dependent variable, i.e., lnSO_2*EF* in the past in this case, on the right-hand side of the regression equation (e.g., Baltagi, 1995, pp. 125-126). In column 7, the downward bias in the estimation of the effect of the lagged dependent variable seems to have caused upward biases in the estimation of the effects of the time dummies. The same comments on the relatively large *t*-statistics in the pooled OLS results and the possible biases in the fixed-effects estimation results hold true for the tables that we will discuss below.

The estimation results on the CO_2*EF* are shown in Table 7. Therefore, these results support Hypothesis 2-J that the current *EF* of CO_2 is not affected by the past pollution level, the past income level, and the past economic activities by energy-intensive industries. The coefficients of the past CO_2*EF*s are negative and significant at the 1% level. These negative impacts can be due to the energy policy by which the government of Japan promoted fuel energy conversion from oils to gases by implementing the Law Concerning Promotion of the Development and Introduction of Alternative Energy in 1980 (Government of Japan 1980). In order to confirm that the factors affecting the CO_2*EF* also influenced such a change in the fuel energy conversion, we estimated the function explaining the change in the proportion of oil to total fossil energy use.[15] As shown in Table 8, the coefficients of the past CO_2*EF* are all negative and four of them are significant. In other words, prefectures with high CO_2*EF* substituted gas for oil, thereby reducing CO_2*EF* in the subsequent period. These results indicate that the negative effect of the past CO_2*EF* on the current CO_2*EF*, as shown in Table 7, comes from the energy policy of the government but not necessarily from its environmental policy. Indeed CO_2*EF* did not decrease over time as we saw in Tables 1 and 4. As in the case of SO_2*EF*,

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[15] The function for the determination of the fuel conversion to liquid fuels is:

$$OIL_{it} - OIL_{it\text{-}N} = \delta_0 + \delta_1 \ln EN_{it\text{-}N} + \delta_2 \ln \Phi_{it\text{-}N} + \delta_3 \ln y_{it\text{-}N} + X_{it-N}\delta_4 + w_{it},$$

where δ's are regression parameters, *OIL* is the share of oil and Φ is the *EF* for CO_2, and w_{it} is an error term.

the pooled OLS estimate of the effect of CO_2*EF* has a high significance level, and the fixed-effects estimation of the same effect produces a large negative coefficient, as shown in columns 6 and 7, respectively.

Table 9 shows the estimation results for the determinants of energy use in Japan. The coefficients of past energy use per area are significantly different from zero only in column 4 for the 1990-95 period and in column 7 for the fixed-effects estimation. The significantly negative coefficient in column 4 is likely to reflect the change in the fossil fuel composition, and that in column 7 is likely to be biased for the reason discussed above. In other words, the results shown in Table 9 as a whole indicate that decisions on energy consumption has been made almost irrespective of the past energy consumption in Japan. Moreover, few other variables are significant determinants of energy use. Overall, the estimation results are consistent with Hypothesis 3-J.

4.2 Case of China

The estimation results for the SO_2*EF* function in China are shown in Table 10. The coefficients of the past SO_2*EF* for the period 1985-91 is negative and significant but not for the 1991-95 and 1995-99 periods. Since the nationwide average of SO_2*EF* increased from 1985 to 1991 (see Table 1), it is unlikely that the convergence in SO_2*EF* during this period came from the diffusion of the desulfurization technology. Although evidence is insufficient, it seems plausible to argue that provinces highly dependent on oil reduced the use of oil in favor of coal.

The estimated coefficients of the past energy use per area are not significantly different from zero, indicating that provinces that consume larger amounts of energy did not effectively reduce the level of the emission factor. Although the coefficients of per capita GDP are negative, they are not statistically significant. These results do not support Hypothesis 1-C, in contrast to the results in the Japanese case.

The East dummy is significant with a positive coefficient in 1990-95, which turns negative in 1995-99. The North dummy, on the other hand, is not significant in all periods. The SOE Ratio is statistically significant with a positive coefficient in 1991-95 and a negative coefficient in 1995-99. These results indicate that provinces where industry developed and SOEs actively operated have finally begun to reduce the emission factor in recent years.

The estimation results of the CO_2*EF* function are presented in Table 11[16]. The effects of energy consumption per area, income levels, and SOE ratios in the past are

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[16] As we find the data on the provincial CO_2 emission in China in 1985 are unreliable, we do not report the estimation results of CO_2 *EF* function for 1985-91 which uses the data for 1985. There is no evidence that the past energy use led to the reduction in the CO_2 *EF* in the current year.

insignificant in columns 1 and 2. They are significant in the pooled OLS estimation but not in the fixed effects estimation, indicating that these effects are week. These results are consistent with Hypothesis 2-C. The estimates of the effects of CO_2*EF* in the past are negative in columns 3 and 4 for the same reasons that we discussed above. But they are also negative and highly significant in columns 1 and 2, indicating strong conditional convergence. The source of the convergence is not the abatement efforts. The lack of abatement efforts is manifested in the rapidly increasing energy consumption, the rapidly increasing CO_2 emission, and the virtually constant CO_2*EF* in China as shown in Tables 1 and 5. A possible explanation for the convergence in CO_2*EF* is that the composition of fuels as well as fuel quality became similar across provinces. A puzzle, however, remains as to why there is conditional convergence for CO_2*EF* but not for SO_2*EF*.

Finally Table 12 shows the estimation results of the energy use function. The effect of past energy consumption per area is negative and significant effect in the 1985-91 period, in the pooled regression, and the fixed-effects estimation.[17] This effect, however, is not significant in the recent periods, indicating that any significant energy saving measures have not been adopted in response to the large energy consumption in the 1990s. In addition, both the past SO_2 *EF* and GDP per capita are generally insignificant with a

[17] The fixed-effects estimate of this effect is likely to be biased downward due to the correlation between the lagged dependent variable and the disturbance after the Within transformation.

few exceptions. These results are consistent with Hypothesis 3-C that the past pollution level and income level do not negatively affect the current energy consumption.

5. Concluding Remarks

In this study, we hypothesize that while SO_2 emissions may be reduced by means of reducing its emission factor responding to the deterioration of local environment, the CO_2 emissions do not respond to such local conditions. We found evidence for the EKC hypothesis in Japan, particularly for the SO_2 emissions, but not in China, even though there is a possibility that China is on the rising portion of the curve. Since income is not the sole determinant of the environmental quality, we estimated more elaborated functions. The estimation results on Japan show that the local governments do not react to CO_2 emissions, which cause global externalities, whereas they do react to SO_2 emissions, which cause local externalities. The latter finding explains why we observe an inverted U-shaped relationship between per capita income and SO_2 emissions in Japan over time to the extent that an increase in income leads to the increased emissions of SO_2 when its level is low. Furthermore, the Japanese case illustrates that the reduction in SO_2 emissions is possible without the significant sacrifice of economic development by reducing its emission factor. In contrast, the SO_2 emissions have kept increasing in China, which is consistent with the findings of recent works (Stern 2002, 2004b; Stern and Common 2001). Stern (2004a) argues that "the recent studies that used more representative samples find that there is a monotonic relation between sulfur emissions and income just as there is between carbon dioxide and income". Our analysis suggests that this is likely to be attributable to the fact that local governments have not taken initiatives in solving the local SO_2 pollution problem under the current political regime in China. There is, however, the possibility that such a difference in government behaviors can be attributed to the differences in the income level between the two countries.

Consistent with the above inference, there is an indication that the SO_2 emission factor began declining in the coastal region of China where income levels are higher (see Table 5). Such decline, however, was overwhelmed by rapidly increasing energy use associated with high economic growth rate, thereby leading to the increasing emission of SO_2. An important observation is that the emission factor in China was twenty times as high as in Japan in 1999, which indicates that there is the huge potential to reduce the emission factor in this country so as to reduce the overall emission of SO_2. If the EKC hypothesis is valid, the SO_2 emission in China is likely to decline in near future owing to the induced reduction in the emission factor.

The finding that per capita income is not a significant factor affecting the emissions of CO_2 in both Japan and China is also consistent with the findings of the recent literature (Stern 2002, 2004b; Stern and Common 2001). This implies that individual governments have little incentive to reduce CO_2 emissions. Therefore, an international arrangement, such as the Kyoto Protocol, is indispensable to diminish them globally.

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Table 1 SO_2 and CO_2 Emissions, and Final Energy Consumption from Industry Sector in China and Japan

	China				Japan			
	1985	1991	1995	1999	1975	1985	1995	1999
SO_2 Emission (10^4 ton)	7,197	11,642	14,050	14,600	865	278	248	220
Final Energy Consumption (Million TOE)	362	486	671	732	185	182	230	255
CO_2 Emission (Million t-C)	533	702	946	1,034	112	139	182	194
SO_2 Emission Factor	19.9	24.0	20.9	19.9	4.7	1.5	1.1	0.9
CO_2 Emission Factor	14.7	14.4	14.1	14.1	6.1	7.6	7.9	7.6
GDP ($ billion, 1995 price)	274	433	700	964	2,608	3,814	5,137	5,356

Data Sources: Agency of Environment, Japan, General Surveys on Emissions of Air-pollutants (Taiki-osen-busshitsu Haishutsu-ryou Sogo-chosa), various years; National Bureau of Statistics, China, *China Statistical Yearbook,* various years.

TOE: tons of oil-equivalent = 10^7kcal

t-C: carbon tons

Table 2 Estimation Results of the Environmental Kuznets Curve in Japan (SO_2 and CO_2)

	SO_2 Emission per Area		CO_2 Emission per Area			
					First-difference	
	(1)	(2)	(3)	(4)	(5)	(6)
	Fixed effects	Random effects	Fixed effects	Random effects	OLS	Fixed effects
GDP per capita	17.33**	17.36**	23.96**	24.96**	15.29**	13.58*
	(5.05)	(5.17)	(4.95)	(5.21)	(2.74)	(1.89)
[GDP per capita]^2	-1.06**	-1.06**	-1.43**	-1.49**	-0.99**	-0.89*
	(-4.95)	(-5.05)	(-4.77)	(-4.96)	(-2.74)	(-1.89)
Time dummy at 1980	-0.99**	-0.99**	-0.13	-0.17	-	-
	(-11.29)	(-12.13)	(-1.06)	(-1.46)		
Time dummy at 1985	-1.42**	-1.41**	-0.20	-0.27	-	-
	(-11.36)	(-12.62)	(-1.12)	(-1.62)		
Time dummy at 1990	-1.76**	-1.74**	-0.29	-0.40	-	-
	(-9.25)	(-10.52)	(-1.06)	(-1.63)		
Time dummy at 1995	-1.76**	-1.73**	-0.06	-0.19	-	-
	(-8.41)	(-9.60)	(-0.21)	(-0.71)		
Time dummy at 1999	-2.03**	-2.00**	-0.18	-0.34	-	-
	(-8.21)	(-9.43)	(-0.53)	(-1.06)		
Intercept or mean time effect	-68.45**	-68.42**	-77.62**	-82.34**	0.19**	0.20**
	(-4.96)	(-5.11)	(-3.99)	(-4.30)	(3.30)	(3.38)
Adjusted R^2	0.308	0.308	0.167	0.173	0.023	0.173
ρ	0.038	0.035	0.208#	0.199#	-0.181#	-0.389#
AR(1)	0.61	0.57	3.52	3.40	-2.72	-6.11
Hausman test		0.1		2.16	-	-
		(1.000)		(0.951)		
Breusch-Pagan heteroskedasticity test	-	-	-	-	6.92	-
					(0.085)	
Inflection point of EKC (Million Yen)	3.6	3.6	4.4	4.3	2.3	2.1

Notes: Numbers in parentheses are *t*-values and significance levels for the Hausman and Breusch-Pagan test statistic. AR(1) is a *t*-test on the residual autocorrelation coefficient ρ . All variables except dummies are in natural log.

** statistically significant at 1% level (single-side test)
* statistically siginificant at 5% level (single-side test)
# statistically siginificant at 1% level (double-side test)

Table 3 Estimation Results of the Environmental Kuznets Curve in China (SO_2 and CO_2)

	SO_2 Emission per Area		CO_2 Emission per Area	
	Fixed effects	Random effects	Fixed effects	Random effects
GDP per capita	0.08	0.31	0.38*	0.62**
	(0.32)	(1.25)	(2.00)	(3.08)
[GDP per capita]^2	-0.06	-0.04	-0.00	0.01
	(-0.82)	(-0.52)	(-0.02)	(0.20)
Time dummy at 1991	0.50**	0.52**	0.40**	0.43**
	(7.99)	(8.03)	(8.18)	(8.07)
Time dummy at 1995	0.61**	0.55**	0.51**	0.45**
	(7.36)	(6.57)	(7.91)	(6.55)
Time dummy at 1999	0.53**	0.40**	0.55**	0.42**
	(4.02)	(3.12)	(5.47)	(4.02)
Intercept	2.74**	3.06**	7.41**	7.78**
	(9.06)	(8.13)	(31.36)	(25.03)
Adjusted R^2	0.109	0.190	0.284	0.385
ρ	0.063	0.062	-0.267	-0.265
AR(1)	0.42	0.42	-1.38	-1.40
Hausman test		73.1		0.0
		(0.000)		(1.000)
Inflection point of EKC (10^8 Yuan)	2.04	48.18	3.27E +95	2.71E-12

Notes: Numbers in parentheses are *t*-values and significance levels for the Hausman test statistic. AR(1) is a *t*-test on the residual autocorrelation coefficient ρ . All variables except dummies are in natural log.

** statistically significant at 1% level (single-side test)
* statistically siginificant at 5% level (single-side test)

Table 4 SO_2 and CO_2 Emission Factors in Urban Regions and Others, Japan (Averages)

Japan

	Urban Prefectures				Others			
	1975	1985	1995	1999	1975	1985	1995	1999
SO2 Emission Factor	4.1	1.1	0.8	0.6	6.3	3.0	2.0	1.8
CO2 Emission Factor	6.3	7.6	7.9	7.6	5.4	7.5	7.8	7.5

Data Sources: Agency of Environment, Japan, General Surveys on Emissions of Air-pollutants (Taiki-osen-busshitsu Haishutsu-ryou Sogo-chosa), various years.

Table 5 SO_2 and CO_2 Emission Factors in Coastal Regions and Others, China (Averages)

China

	East Coast Provinces				Others			
	1985	1991	1995	1999	1985	1991	1995	1999
SO2 Emission Factor	17.8	21.4	17.4	14.7	23.0	27.7	25.5	27.8
CO2 Emission Factor	15.0	14.2	14.0	14.0	14.3	14.7	14.5	14.4

Data Sources: National Bureau of Statistics, China, *China Statistical Yearbook,* various years.

Table 6 Determinants of SO_2 Emission Factor in Japan, 1975-1999

ln SO_2 EF (difference)	(1) OLS 1975-80	(2) OLS 1980-85	(3) OLS 1985-90	(4) OLS 1990-95	(5) OLS 1995-99	(6) Pooled OLS 1975-99	(7) Fixed effects 1975-99
ln Energy/Area	-0.223*	-0.204*	-0.032	-0.049	-0.041	-0.161**	-0.171*
	[-1.98]	[-1.70]	(-0.42)	[-0.49]	(-0.36)	[-3.46]	(-1.85)
ln SO_2 EF	-0.144	-0.278	-0.267**	-0.193	0.027	-0.271**	-1.075**
	[-0.82]	[-1.30]	(-2.76)	[-1.12]	(0.17)	[-4.07]	(-12.81)
ln per capita GDP	-1.049**	0.140	0.134	-0.187	0.019	-0.163	0.051
	[-2.92]	[0.28]	(0.53)	[-0.52]	(0.05)	[-0.96]	(0.13)
Energy-int Industry	0.996	0.786	-0.516	0.710	-0.042	0.486	-0.593
	[0.65]	[0.93]	(-0.66)	[0.79]	(-0.04)	[1.04]	(-1.85)
Urban	0.060	-0.016	-0.179*	0.024	-0.044	-0.031	-
	[0.41]	[-0.14]	(-1.81)	[0.19]	(-0.30)	[-0.56]	
Time dummy at 1980	-	-	-	-	-	-0.252	1.004**
						[-1.56]	(3.97)
Time dummy at 1985	-	-	-	-	-	0.111	0.752**
						[1.05]	(4.57)
Time dummy at 1990	-	-	-	-	-	-0.011	0.428**
						[-0.14]	(3.65)
Time dummy at 1995	-	-	-	-	-	0.062	0.238**
						[0.80]	(3.88)
Intercept	7.081*	-1.080	-0.932	1.287	-0.367	1.127	-0.113
	[2.57]	[-0.28]	(-0.48)	[0.45]	(-0.12)	[0.84]	(-0.04)
B-P Statistics	4.78	4.54	0.04	6.66	0.00	5.70	-
Adjusted-R^2	0.430	0.113	0.282	0.138	0.050	0.355	0.070

Notes: ** statistically significant at 1% level (single-side test).
* statistically siginificant at 5% level (single-side test).
Values in ( ) are t-values; [ ] are t-values based on White standard errors.
SO_2 EF: SO_2 Emission Factor, Urban: Urban regional dummy,
Energy-int Industry: Share of GDP for Energy-intensive Industries,
B-P Statistics: Breusch-Pagan statistics.

Table 7 Determinants of CO_2 Emission Factor in Japan, 1975-1999

ln CO_2 EF (difference)	(1) OLS 1975-80	(2) OLS 1980-85	(3) OLS 1985-90	(4) OLS 1990-95	(5) OLS 1995-99	(6) Pooled OLS 1975-99	(7) Fixed effects 1975-99
ln Energy/Area	0.081	0.047	-0.019	0.012	-0.028	0.022	0.197**
	[0.68]	[0.84]	[-0.67]	[0.42]	(-0.79)	[0.85]	(3.08)
ln CO_2 EF	-0.548**	-0.422**	-0.350**	-0.266*	-0.311**	-0.419**	-0.811**
	[-3.12]	[-2.27]	[-3.81]	[-2.32]	(-2.62)	[-5.49]	(-13.07)
ln per capita GDP	-0.018	0.044	0.069	0.048	-0.065	0.007	0.299
	[-0.05]	[0.20]	[0.69]	[0.37]	(-0.33)	[0.08]	(0.91)
Energy-int Industry	-0.246	-0.917	0.775	-0.353	-0.266	-0.263	1.052
	[-0.16]	[-1.03]	[1.50]	[-0.85]	(-0.47)	[-0.79]	(1.34)
Urban	-0.035	-0.057	-0.046	-0.030	0.048	-0.029	-
	[-0.24]	[-0.58]	[-0.64]	[-0.53]	(0.64)	[-0.68]	
Time dummy at 1980	-	-	-	-	-	-0.034	0.094
						[-0.34]	(1.22)
Time dummy at 1985	-	-	-	-	-	0.080	0.099
						[1.37]	(0.91)
Time dummy at 1990	-	-	-	-	-	0.029	0.062
						[0.70]	(0.39)
Time dummy at 1995	-	-	-	-	-	0.031	0.006
						[0.79]	(0.18)
Intercept	11.233**	8.489**	6.568**	5.144*	6.879*	8.529**	14.01**
	[2.19]	[2.09]	[3.48]	[1.86]	(2.31)	[1.86]	(2.67)
B-P Statistics	16.24	47.91	23.55	13.60	0.55	91.33	-
Adjusted-R^2	0.337	0.373	0.531	0.174	0.232	0.385	0.161

Notes: ** statistically significant at 1% level (single-side test)
* statistically siginificant at 5% level (single-side test)
Values in ( ) are t-values; [ ] are t-values based on White standard errors.
CO_2 EF: CO_2 Emission Factor, Urban: Urban regional dummy,
Energy-int Industry: Share of GDP for Energy-intensive Industries,
B-P Statistics: Breusch-Pagan statistics.

Table 8 Determinants of Fossil Fuel Composition in Japan, 1975-1999

Oil/Energy (difference)	1975-80	1980-85	1985-90	1990-95	1995-99
ln Energy/Area	-0.037	-0.025	-0.021*	-0.016	0.006
	(-1.23)	[-0.96]	(-1.75)	[-0.66]	[0.31]
ln CO_2 EF	-0.133*	-0.107*	-0.041*	-0.105**	-0.017
	(-2.11)	[-2.35]	(-2.11)	[-2.61]	[-0.82]
ln per capita GDP	0.008	0.053	0.033	-0.000	-0.084
	(0.04)	[0.31]	(0.50)	[-0.00]	[-0.70]
Energy-int Industry	0.244	0.452	0.095	0.540	-0.052
	(0.28)	[0.93]	(0.40)	[1.11]	[-0.14]
Intercept	0.616	0.077	-0.031	0.440	0.748
	(0.38)	[0.06]	(-0.06)	[0.41]	[0.78]
B-P Statistics	3.30	8.17	0.81	13.70	12.77
Adjusted-R^2	0.144	0.135	0.160	0.157	0.034

** statistically significant at 1% level (single-side test)
* statistically siginificant at 5% level (single-side test)
Values in ( ) are t-values; [ ] are t-values based on White standard errors

Oil/Energy: Share of Fossil Energy Use for Liquid Fuels
CO_2 EF: CO_2 Emission Factor
Energy-int Industry: Share of GDP for Energy-intensive Industries
B-P Statistics: Breusch-Pagan statistics

Table 9 Determinants of Energy Consumption per Area in Japan, 1975-1999

ln Energy / Area (difference)	(1) OLS 1975-80	(2) OLS 1980-85	(3) OLS 1985-90	(4) OLS 1990-95	(5) OLS 1995-99	(6) Pooled OLS 1975-99	(7) Fixed effects 1975-99
ln Energy/Area	-0.016	0.084	-0.104	-0.141*	0.021	-0.046	-0.751*
	[-0.15]	[0.78]	[-1.23]	[-2.03]	(0.21)	(-1.16)	(-8.42)
ln SO_2 EF	0.149	0.271	-0.050	-0.052	-0.056	0.022	0.175*
	[1.02]	[1.43]	[-0.81]	[-0.47]	(-0.76)	(0.39)	(2.16)
ln per capita GDP	0.251	0.582	-0.226	0.094	-0.508*	-0.059	0.327
	[0.67]	[1.24]	[-0.98]	[0.31]	(-2.02)	(-0.40)	(0.84)
Energy-int Industry	-0.579	0.556	1.111	0.584	0.837	0.064	1.590*
	[-0.43]	[0.65]	[0.95]	[0.84]	(1.06)	(1.39)	(1.73)
Urban	0.021	0.059	0.114	-0.086	-0.032	0.027	-
	[0.21]	[0.60]	[0.95]	[-0.87]	(-0.26)	(0.49)	
Time dummy at 1980	-	-	-	-	-	-0.067	-0.042
						(-0.51)	(-0.38)
Time dummy at 1985	-	-	-	-	-	-0.138	0.083
						(-1.53)	(0.53)
Time dummy at 1990	-	-	-	-	-	0.052	0.052
						(0.67)	(0.67)
Time dummy at 1995	-	-	-	-	-	0.186**	0.186**
						(2.73)	(2.73)
Intercept	-2.094	-4.840	1.674	-0.516	3.950*	0.393	0.393
	[-0.75]	[-1.34]	[0.95]	[-0.22]	(2.01)	(0.34)	(0.34)
B-P Statistics	15.85	5.88	23.96	13.83	3.49	0.88	-
Adjusted-R^2	0.097	0.142	0.109	0.219	0.144	0.096	0.144

Notes: ** statistically significant at 1% level (single-side test).
* statistically siginificant at 5% level (single-side test).
Values in ( ) are t-values; [ ] are t-values based on White standard errors.
SO_2 EF: SO_2 Emission Factor, Urban: Urban regional dummy,
Energy-int Industry: Share of GDP for Energy-intensive Industries,
B-P Statistics: Breusch-Pagan statistics.

Table 10 Determinants of SO_2 Emission Factor in China, 1985-1999

ln SO_2 EF (difference)	(1) 1985-91	(2) 1991-95	(3) 1995-99	(4) Pooled OLS 1985-99	(5) Fixed effects 1985-99
ln Energy/Area	0.106	0.033	-0.034	0.024	-0.416
	(1.30)	(0.62)	(-0.59)	(0.63)	(-1.53)
ln SO_2 EF	-0.375*	0.022	0.063	-0.058	-1.038**
	(-2.04)	(0.17)	(0.53)	(-0.70)	(-7.27)
ln per capita GDP	-0.394	-0.381	0.017	-0.159	0.411*
	(-1.43)	(-1.69)	(0.06)	(-1.14)	(1.85)
SOE ratio	0.063	1.056*	-1.306*	-0.114	0.320
	(0.06)	(1.75)	(-2.32)	(-0.32)	(0.58)
East dummy	0.127	0.392*	-0.217	0.063	-
	(0.38)	(1.83)	(-0.84)	(0.42)	
North dummy	0.038	0.114	0.101	0.033	-
	(0.21)	(0.94)	(0.63)	(0.36)	
Time dummy at 1991	-	-	-	0.293**	0.170
				(3.04)	(0.94)
Time dummy at 1995	-	-	-	0.031	0.320*
				(0.27)	(2.26)
Intercept	-3.522	-2.015	1.181	-0.941	1.870
	(-1.60)	(-1.32)	(0.90)	(-1.03)	(0.50)
B-P Statistics	0.69	0.27	0.40	0.42	-
Adjusted-R^2	0.233	0.242	0.281	0.100	0.012

** statistically significant at 1% level (single-side test)
* statistically siginificant at 5% level (single-side test)
Values in ( ) are t-values; [ ] are t-values based on White standard errors.
SO_2 EF: SO_2 Emission Factor
SOE Ratio: State-owned Enterprise Ratio
B-P Statistics: Breusch-Pagan statistics

Table 11 Determinants of CO_2 Emission Factor in China, 1991-1999

ln CO_2 EF (difference)	(1) 1991-95	(2) 1995-99	(3) Pooled OLS 1991-99	(4) Fixed effects 1991-99
ln Energy/Area	0.006	-0.006	-0.015*	-0.025
	(1.04)	[-1.14]	[-2.02]	[-0.72]
ln CO_2 EF	-0.294**	-0.294**	-0.489**	-0.944**
	(-8.51)	[-4.27]	[-6.46]	[-19.74]
ln per capita GDP	-0.014	-0.008	-0.018	-0.003
	(-0.69)	[-0.54]	[-0.75]	[-0.10]
SOE ratio	0.024	-0.024	0.119*	0.012
	(0.33)	[-0.90]	[2.16]	[0.16]
East dummy	-0.007	0.023	0.064*	-
	(-0.26)	[0.85]	[2.39]	
North dummy	0.015	0.004	-0.021	-
	(1.23)	[1.04]	[1.20]	
Time dummy at 1991	-	-	-0.003	0.021
			[-0.15]	[0.92]
Time dummy at 1995	-	-	0.008	0.013
			[0.52]	[0.70]
Intercept	-2.061**	-1.857**	-3.103**	-5.830**
	(-7.82)	[-7.26]	[-6.37]	[-11.12]
B-P Statistics	1.67	12.23	7.36	-
Adjusted-R^2	0.872	0.777	0.667	0.636

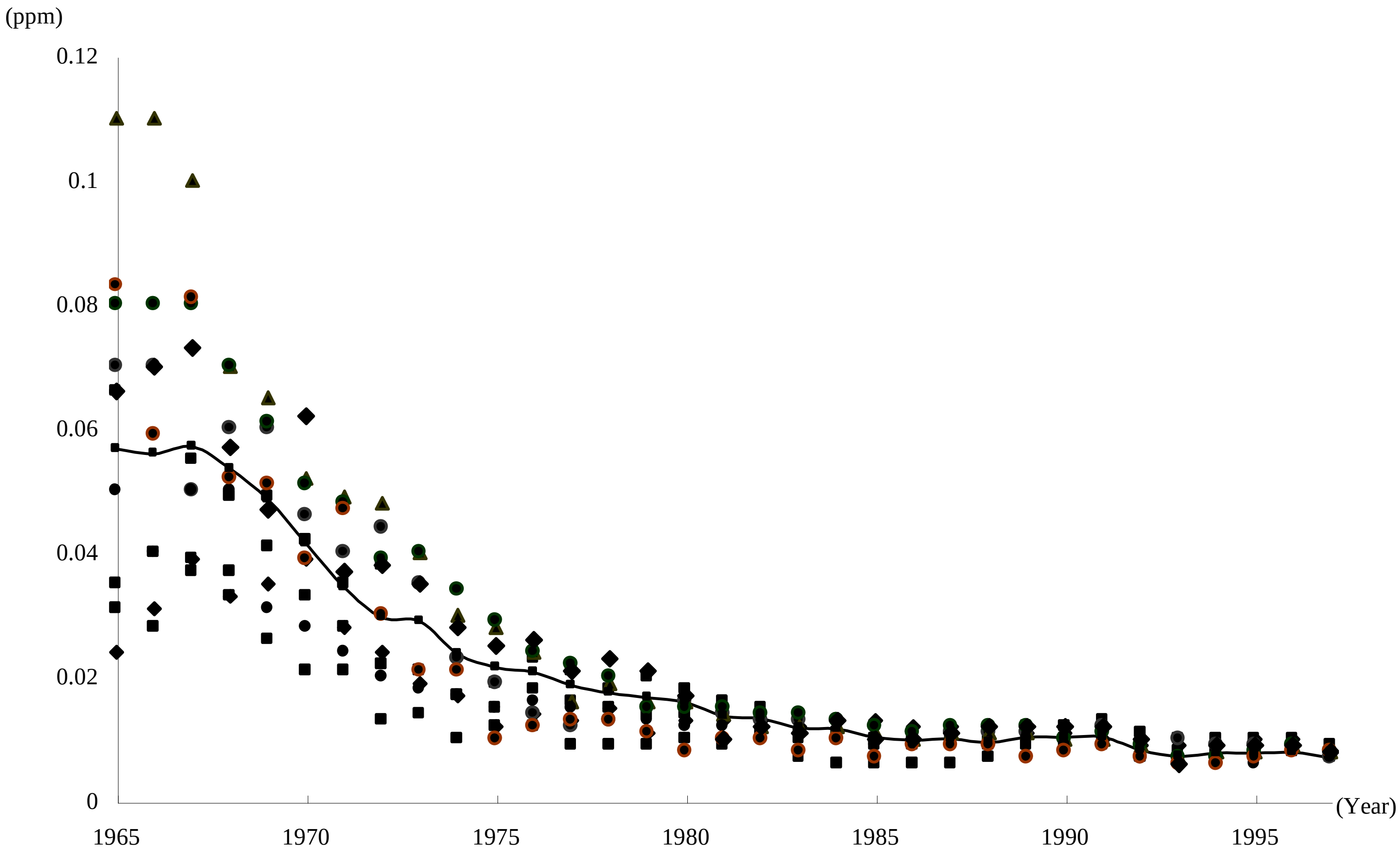
** statistically significant at 1% level (single-side test)
* statistically siginificant at 5% level (single-side test)
Values in ( ) are t-values; [ ] are t-values based on White standard errors.
CO_2 EF: CO_2 Emission Factor
SOE Ratio: State-owned Enterprise Ratio
B-P Statistics: Breusch-Pagan statistics

Table 12 Determinants of Energy Consumption per Area in China, 1985-1999

ln Energy / Area (difference)	(1) 1985-91	(2) 1991-95	(3) 1995-99	(4) Pooled OLS 1985-99	(5) Fixed effects 1985-99
ln Energy/Area	-0.084**	-0.053	0.016	-0.040*	-0.073*
	(-3.23)	(-1.41)	(0.31)	[-2.19]	(-3.28)
ln SO_2 EF	0.113*	-0.058	-0.089	-0.032	0.015
	(1.92)	(-0.65)	(-0.81)	[-0.43]	(0.13)
ln per capita GDP	0.064	0.139	-0.074	-0.004	-0.016
	(0.73)	(0.89)	(-0.31)	[-0.07]	(-0.09)
SOE ratio	-0.072	-0.201	0.489	-0.034	-0.268
	(-0.23)	(-0.48)	(0.94)	[-0.19]	(-2.18)
East dummy	0.098	0.045	0.001	0.056	-
	(0.91)	(0.30)	(0.01)	[0.79]	
North dummy	-0.042	-0.122	-0.174	-0.072	-
	(-0.72)	(-1.44)	(-1.18)	[-1.27]	
Time dummy at 1991	-	-	-	0.143*	-0.322*
				(2.33)	(-2.18)
Time dummy at 1995	-	-	-	0.111	-0.158
				(1.31)	(-1.37)
Intercept	2.073**	1.230	-0.638	0.6646	10.498**
	(2.94)	(1.16)	(-0.53)	[1.23]	(3.46)
B-P Statistics	0.25	0.90	1.74	23.53	-
Adjusted-R^2	0.364	0.041	0.131	0.185	0.030

** statistically significant at 1% level (single-side test)
* statistically siginificant at 5% level (single-side test)
Values in ( ) are t-values; [ ] are t-values based on White standard errors.
SO_2 EF: SO_2 Emission Factor
SOE Ratio: State-owned Enterprise Ratio
B-P Statistics: Breusch-Pagan statistics

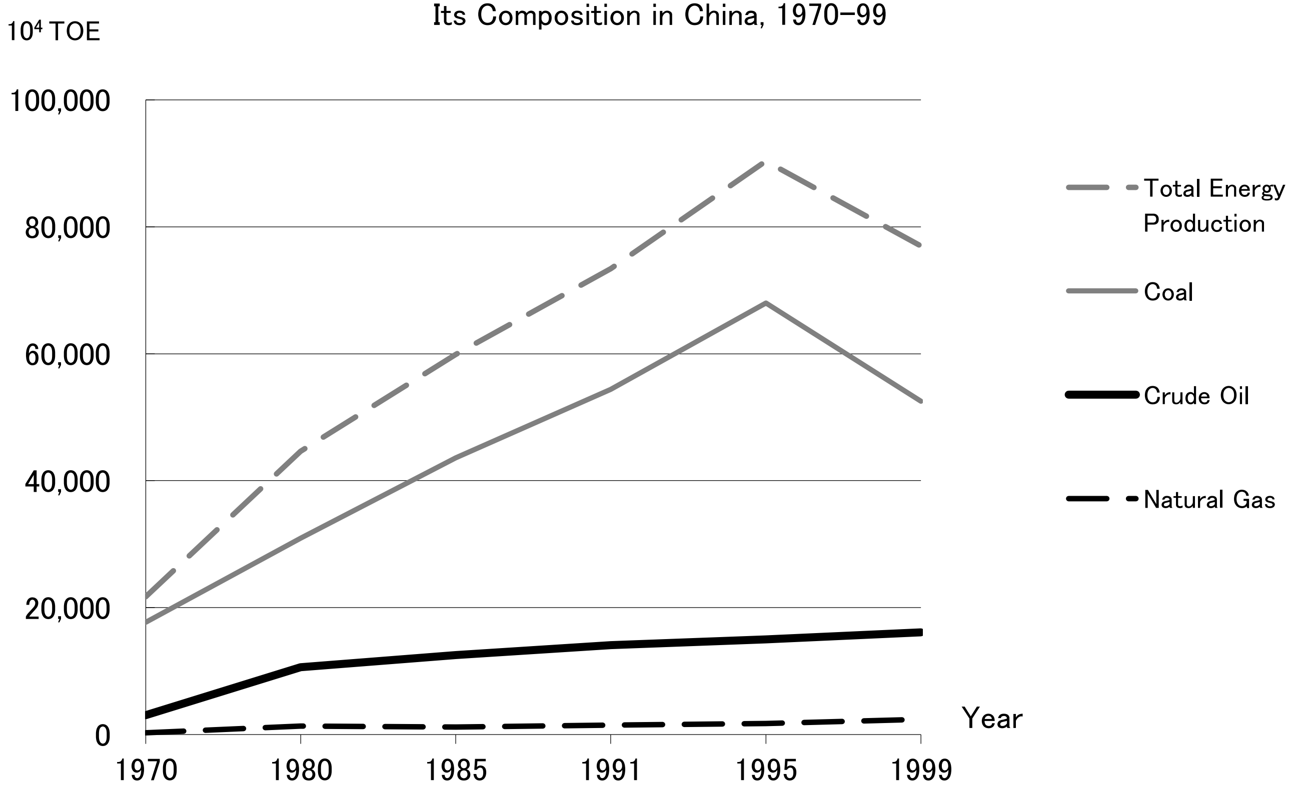
Figure 1 Air Pollution of SO_2 in Japan, 1965-1997



Note: Ambient concentration data from 17 observation points

Data sources: Agency of Environment, Japan, *Air-pollution in Japan,* various years.

Figure 2 Total Energy Production and Its Composition in China, 1970–99



Data Source: National Bureau of Statistics, China, China Statistical Yearbook, various years