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Long-term Sulfur Emissions and Environmental Kuznets Curves: Comparison and Implications

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ABSTRACT

The environmental Kuznets curve hypothesis assumes an inverted U-shaped relationship between environmental damage and income, and such curves have been used to study how economic growth affects the environment. In this study, we analyzed data for gross domestic product (GDP) per capita and for sulfur emissions in the industrialized countries of the United Kingdom, United States of America, and Japan, as well as data for the developing country of China, to determine the relationship between emissions and income in these countries. Attempts by these countries' governments to incorporate environmental policy considerations into the income-environment relationship were also examined. The potential role of the environmental Kuznets curve as a policy tool was investigated. We determined that, at least in the case of sulfur emissions, policies and institutions significantly reduced environmental degradation in the industrialized countries studied. Furthermore, the environmental Kuznets curve can reliably predict the future relationship between environmental impact and GDP for developing countries.

Key words: Air pollutant, Economic growth, Developed country, Developing country, Environmental political implication

1. INTRODUCTION

Environmental problems have been closely related to human economic activities. Therefore, economic development is often observed to be associated with increased environmental pollution. To decrease environmental pollution and reconcile the opposition between the environment and economic development, means of non-polluting development should be sought. The World Commission on Environment and Development of the United Nations announced their report titled "Our Common Future" (World Commission on Environment and Development, 1987) in 1987, which advocates a central concept of sustainable development. In this report, the relationship between development and environment was clarified as a co-existing instead of a trade-off environment, and the importance of considering environmental protection during economic development was emphasized. Thereafter, this concept has become an important standard value of economic development, and the indispensability of sustainable development has been recognized widely in consideration of the coexistence of economic growth and environmental safeguard.

The hypothesis of the environmental Kuznets curve (World Bank, 1992) has been emphasized and intensively studied to investigate possibilities for sustainable development. This hypothesis depicts an inverted U-shaped curve between per capita income and quality of environment on the basis of an empirical law: the environmental load increases at the initial stages of economic development, but the load subsequently decreases after a critical point, at which environmental concerns are given greater weight, is passed. Under this hypothesis, the extent of sustainable economic development can be evaluated by analyzing the influence of economic growth on the environment. Therefore, if this hypothesis is realistic, then it can be used to predict long-term environmental changes, and it also may be an index for creating environmental policies that balance economic and environmental concerns.

2. BACKGROUND OF SULFUR EMISSIONS AND THE ENVIRONMENTAL KUZNETS CURVE

The concept of the environmental Kuznets curve has been widely recognized since the "World Development Report" was released by the World Bank in

1992 (World Bank, 1992). It has been a major subject of study in environmental economics in recent years. These studies were based on a proof-of-concept study of various pollution indexes and confirmed the existence of environmental pollution. It mainly focused on research about air quality (SO_2, NO_x, SPM and CO_2).

Sulfur emissions show the most typical environmental Kuznets curve among the air pollutants studied, and this finding was first confirmed by Selden and Song (1994) and Grossman and Krueger (1995) on the basis of data from several countries. The critical point (or turning point) was demonstrated to be from US$5,000 to US$10,000. However, Vincent (1997) reported that the estimation of the environmental Kuznets curve from analysis of SO_2 data in Malaysia might be impossible, since economic growth may differ in various countries. Stern and Common (2001) identified an inverted U-shaped relationship between pollutants and income when they used sulfur emissions to study the environmental Kuznets curve. However, compared with the turning point of US$9,000 in OECD countries, the turning point of non-OECD countries is extremely high and actually shows a unilateral increase. Markandya *et al.* (2006) analyzed relationship between economic growth and SO_2 emissions in some selected European countries. The relationship of an inverted "U" was identified in this study. Although many studies concerning air pollutants have indicated that the patterns of sulfur emissions support the hypothesis of the environmental Kuznets curve, there has been no agreement as to the turning point at which the environmental load begins to decrease.

The environmental Kuznets curve was originally defined as a law learned by experience that shows only tendencies regarding changes in environmental quality resulting from the process of economic growth. These changes are influenced by various elements such as changes in industrial structure and energy consuming structure caused by factors such as economic growth, the innovation of industrial technologies and the evolution of environmental protection measures. De Bruyn (1997) performed an analysis that showed that change in industrial structure is the main factor affecting trends in SO_2 emissions. Such changes in the industrial structure to reduce environmental load have not always been seen, and it has been emissions control acts, such as the Convention on Long-Range Trans-boundary Air Pollution (CLRTAP) (1979), the Helsinki Protocol (1985) and the Oslo Protocol (1994), that have led to the reduction of SO_2 emissions. Furthermore, Panayotou (1997) performed a proof analysis regarding the environmental Kuznets curve as well as increasing population density, the economic growth rate, and an environmental policy index. This study demonstrated that improvement of environmental quality is dependent on environmental policy and environmental control systems.

In this report, we analyzed data for gross domestic product (GDP) per capita and for sulfur emissions (sulfur dioxide emissions as SO_2-S) in the industrialized countries of the United Kingdom (UK), United States of America (USA), and Japan, as well as data for the developing country of China, to determine the relationship between emissions and income in these countries. Attempts by these countries' governments to incorporate environmental policy considerations into the income-environment relationship are also examined. Finally, the potential role of the environmental Kuznets curve as a policy tool was investigated.

3. THE DATA

Although many studies about the environmental Kuznets curve have been reported since the 1990s, data analysis had been limited owing to the alternating use of panel or cross-sectional data to obtain yearly trend data. However, it is important that the environmental Kuznets curve be plotted in time series instead of in a cross-section because relationships between tracks of economic growth and environmental improvement have to be clarified from studies of long-term chronological analysis.

The aim of our research was to determine the relevance of economic growth with respect to environmental safeguard by observing the cause-and-effect relationship between long-term environmental regulation and economic growth. We observe this relationship by analyzing sulfur emissions, which represent environmental pollutants. Although the same results might not always be observed from analysis of other environmental pollutants, we assume that the present study is applicable as a general principle.

Long-term data for population and GDP of four countries (UK, USA, Japan, and China) were obtained from Maddison (Maddison, 2006). The numerical values were evaluated by purchasing power parity (PPP) converted from real 1990 US dollars. The data for long-term sulfur emissions in each country were obtained from David Stern's estimation (Stern, 2005a, b).

The GDP of the countries chosen in this analysis showed a long-term increase from 1850 to 2000. Fig. 1 shows the GDP per capita in each country in terms of the reference value for the year 1850. The UK, which was industrialized in 1820, increased its GDP by a factor of almost 10, whereas the USA and Japan increased their GDPs by a factor of 15 and 30, respec-

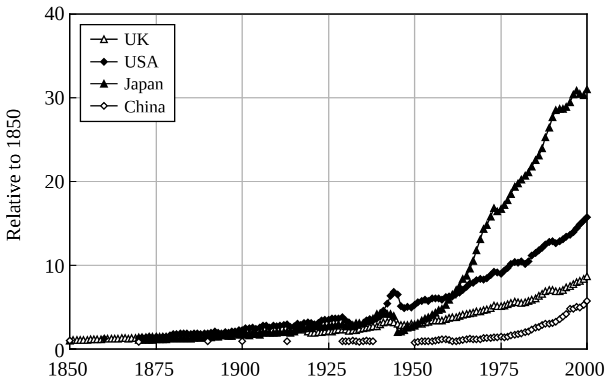

Fig. 1. Change in GDP per capita in different countries during the years 1850-2000.

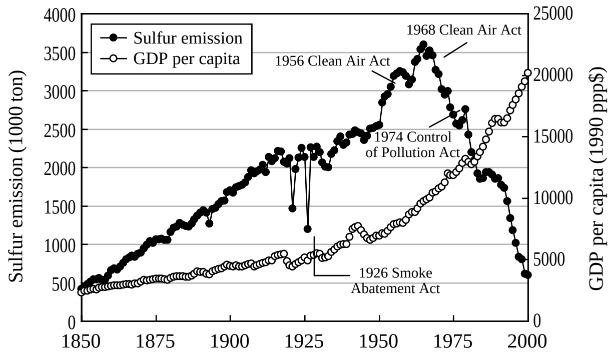

Fig. 2. UK: sulfur emissions and real GDP per capita for 1850-2000.

tively. China's GDP per capita only increased for a factor of 5. However, the rate of increase in China in the latter half of the 20th century is comparable with that of the USA.

Similar increases were not observed for sulfur emissions. Although sulfur emissions continually increased in developed countries over the long term, sulfur emissions in the USA peaked and then decreased many times during the same period (1850-2000). All three of the developed countries had peak emissions during the period of 1970-1980, such as the emissions of 1965 in the UK and those of 1973 and 1970 in the USA and Japan. Sulfur emissions per capita in the UK were lower in 2000 than in 1850.

4. PATTERNS OF SULFUR EMISSIONS AND ENVIRONMENTAL LEGISLATION

The occurrence of air pollution preventive measures is in accordance with the timing of industrialization in each country. In the UK, where the Industrial Revolution started, the history of air pollution measures dates back to the 18th century. The environmental Kuznets curve was observed in the countries studied, but the relationships between the sulfur emissions per capita and GDP per capita differed markedly among the countries. Furthermore, the value of the sulfur emissions per capita and the GDP per capita differed in their peak values among the countries, as well, perhaps as a result of differing social and economic factors between the countries. The changes in the environmental Kuznets curve of each country are explained in terms of environmental policy and regulation below.

4. 1 The United Kingdom and Air Regulations

The UK tried to regulate sulfur emissions as early as 1821. Although various regulations have been imposed to reduce sulfur emissions, the most effective one was the smoke abatement act of 1926. As shown in Fig. 2, sulfur emissions deceased markedly in 1926. However, this reduction was short term, and sulfur emissions continued to increase in general until they peaked in 1965. The enforcement of the Clean Air Act triggered by the London Smog Affair in 1952 led to an actual reduction in sulfur emissions. During the 1960s and 1970s, the Clean Air Act of 1968, the environmental action program of 1972, and the Control of Pollution Act of 1974 were issued, and sulfur emissions continued to decrease. In contrast, the GDP per capita increased consistently during this same time period. When GDP per capita rose from US$2,330 in 1850 to US$4,492 in 1900, sulfur emissions per capita increased from 15 to 41 kg. Then, GDP per capita almost doubled to US$9,000 from 1900 to 1960, and sulfur emissions per capita also showed a rapid rise, reaching a peak of 60 kg in 1965. In 2000, sulfur emissions per capita decreased to 10 kg despite the fact that GDP per capita had more than doubled to US$20,000 since 1960. At present, even less sulfur is discharged into the atmosphere than that emitted in 1850. British environmental regulations have greatly contributed to the reduction in sulfur emissions.

As shown in Fig. 2, sulfur emissions in the UK increased from 400,000 tons in 1850 to 3,600,000 tons in the peak year of 1965. After that, a rapid reduction in emissions was observed, and emissions continued to decrease until they reached 600,000 tons in 2000.

4. 2 The United States and Air Regulations

The USA established its environmental policy system in the 1960s. The establishment of the Clean Air Act in 1970 led to the reduction of air pollution. After

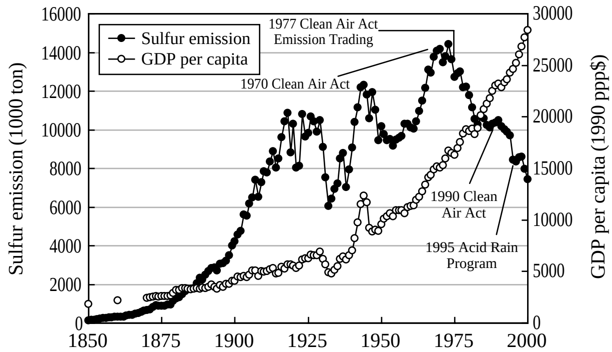

Fig. 3. USA: sulfur emissions and real GDP per capita for 1850-2000.

this law was revised in 1977 and 1990, in addition to reinforcement of pollutant emission control, significant expansion of pollution sources and substances, the introduction of the regulation for the car fuel, the emission trading system was introduced as the acid rain measures. Sulfur dioxide is the causative of acid rain. To solve the acid rain problem that surfaced in the 1970s, the emission trading system was officially enforced from 1995, and further reductions in sulfur emissions were achieved. As shown in Fig. 3, in spite of a 260% increase in GDP and a 137% increase in population from 1970 to 2000, the sulfur emissions were reduced by 48% in that period.

In the USA, the amount of emissions increased from 120,000 in 1850 to 10,873,000 tons in 1918, and then it decreased to 6,059,000 tons in 1932 by the influence of financial panic in Fig. 3. The amount of emissions went up and down several times because of the influence of World War II, it increased again dramatically in the 1960s and reached a peak of 14,421,000 tons in 1973; this peak value is more than 100 times greater than the value observed in 1850. The emissions decreased gradually after the 1970s, and a nearly 40% reduction occurred from the 1980s to 2000.

4. 3 Japan and Impact of Environmental Legislation on Sulfur Dioxide

In the case of Japan, oil was applied as the main source of energy to revive the industry in the period of high economic growth. Heavy oil with high sulfur content of 3% extracted from the crude oil of Middle Eastern area was used. The first air pollution prevention law in Japan was smoke regulation method which was established in 1962 because the outbreak of smog in industrial areas such as Tokyo was regarded as a social issue in the same year. As a typical case of severe air pollution and serious human health influences, Yokkaichi asthma accident caused by the sulfur oxide air pollution in Yokkaichi industrial complex is famous in the world. The sufferer of asthma took legal action, as one of the "four environment legal actions in Japan" in 1967. Atmospheric pollution was caused mainly by sulfur dioxide in various areas. Therefore, the government of Japan began to regulate sulfur dioxide in 1970.

The Air Pollution Control Law was enacted in 1968 to set the atmospheric environmental standard. As a result, a method called K-value controls was adopted to regulate emissions. This method differed from the traditional concentration controls method in that it depended on the total pollution load controls. So that sulfur dioxide regulations began with outlet concentration controls were repeatedly revised and reinforced as they shifted towards K-value controls. Emission control was even stricter for new establishments or expansions of institutions that discharged smoke. However, the K-value regulation method aimed to limit the emissions of individual sources, and it was insufficient to control the total increase in emissions caused by multiple sources. To meet the strengthened emission reduction target stationary sources had made several kind of measures as starting with higher stack for K-value regulation, fuel switching to low sulfur oil or gas, and installation of desulphurization equipment for large-scale sources as power station, and heavy and petrochemical industries. Therefore, the Air Pollution Control Law was revised in 1974 to control the total amount of sulfur dioxide discharged. Thus, in addition to the normal regulations, regulation for the total discharge of harmful industrial waste was introduced in appointed areas with more serious air pollution, including industrial districts such as Yokkaichi and large cities such as Tokyo and Kawasaki. By regulating the total discharge of harmful industrial waste, the governments of metropolitan areas and districts established a total pollution load controls plan for discharge sources within the districts, and various guidelines and regulations were implemented. The government-led measure resulted from the realization that air pollution was a serious social problem. The power of the public opinion to resolve the "Kogai (Public Nuisance)" problems became a strong driving force for the government to promote the anti-pollution measures. The Diet in 1970 was called "pollution Diet" and the Environmental Agency was established in 1971. Environmental regulations were established and revised at the national level. In addition, after the oil crisis of the 1970s, many anti-pollution measures were widely adopted in private enterprise, such as low-sulfurization of fuel, switching from coal to petroleum or Liquid Natural Gas (LNG), and the installment of electric precipitator equipment, especially in large-scale factories and power stations and in petrochemi-

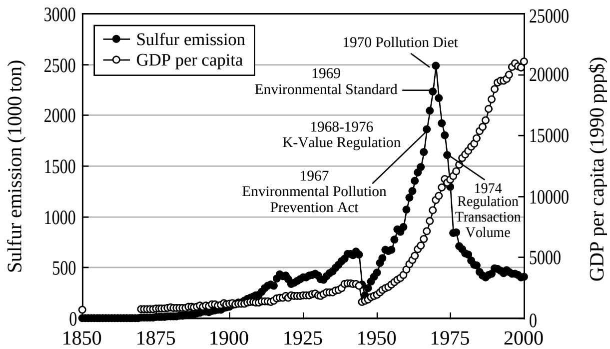

Fig. 4. Japan: sulfur emissions and real GDP per capita for 1850-2000.

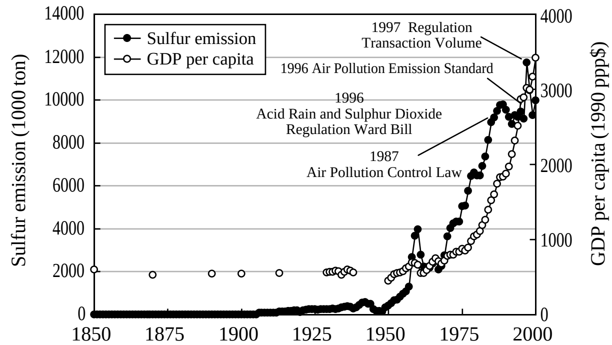

Fig. 5. China: sulfur emissions and real GDP per capita for 1850-2000.

cal plants. In addition, the government offered low-interest financing of anti-pollution systems to promote and support the companies' pursuit of anti-pollution measures. Such financial aid was especially important for small- and medium-sized companies with smaller amounts of financial resources. Overall, sulfur emissions in Japan were greatly reduced by these efforts. As shown in Fig. 4, the sulfur emissions decreased drastically, sulfur emissions per capita from 24 kg in the peak year of 1970 decreased to 5 kg in 1980. More than 70% of the total reduction was accomplished in these 10 years.

Japanese sulfur emissions in 1900 were equivalent to those observed in USA in 1850. A rapid increase was observed during the economic revitalization period after World War II as shown in Fig. 4. Over the next 25 years, the emissions increased by more than a factor of 10, from 224,000 tons in 1946 to 2,487,000 tons in 1970. In Japan the increasing speed for factor 10 was surprising high, twice of USA.

4.4 China and Impact of Environmental Legislation on Sulfur Dioxide

Fig. 5 shows the sulfur emissions and GDP per capita for China, a developing country that began its industrialization after the 1950s. The sulfur emissions per capita and GDP per capita of the China showed no reverse U-shaped curve, in sharp contrast to the developed countries. The GDP per capita was low, from US\$1,000 to US\$3,000 dollars, while the sulfur emissions per capita showed a monotonous increase. This difference in data may be caused by the shorter history of full-scale industrialization in China as compared with that of the developed countries. The USA and UK have an industrialization history of more than 200 years, and even Japan has an industrialization history of more than 100 years since the Meiji Restoration. In contrast, the low levels of emissions observed for China continued from 1850 to the start of industrialization, and a rapid increase in emissions occurred only within the most recent 50 years. Sulfur emissions remained at an extremely low level for a long period following 1850 then increased beginning in the 1970s, with a brief increase in the 1950s as well.

A new constitution including an environmental protection rule was adopted in 1978 and environmental protection law (test implementation) started in 1979. After that, an Air Pollution Control Law was established in 1987 and was revised in 1995 and 2000 (Song, 2008). In this revision, a method to control the total volume of emissions was introduced instead of the conventional concentration regulation method. The total pollution load controls regulation was introduced to three types of area where exceed the atmospheric environment standard, the acid rain control ward and the sulfur dioxide control ward. By taken in the successful policy in the developed countries such as control policies of total emission volume, this policy is expected to be applicable and effective to developing countries as China in an earlier stage of economic development. The data before foundation of People's Republic of China, both GDP and emissions have low reliable, however it might be not so serious problem because the absolute value is lather small. After 1949 the year of foundation of People's Republic of China, GDP and emission of sulfur both increased rapidly and accurately with short exception period as shown in Fig. 5.

4.5 Relationships between Economic Growth and Sulfur Emissions

Fig. 6 shows relationships between sulfur emissions per capita and GDP per capita from 1850 to 2000. Figures of three developed countries UK USA, and Japan showed the reverse U-shaped curves that so-called environmental Kuznets curve, however in China a case of developing country both GDP and emissions has increased in the period even though increasing speed of emissions coming flat. Peak points of environmental load in the environmental Kuznets curves about sulfur emission level per capita are occurred around US$10,000 per capita of GDP clearly in UK, Japan and in case of USA with several sub peaks, however in China peak point hasn't come yet.

In the first stage, sulfur emissions increased when the GDP per capita increased, but sulfur emissions decreased continually after both factors passed their peaks. As shown by the x-axis, the economic level represented as GDP per capita was relatively similar (about US$10,000) for each country at the turning point, but the amount of sulfur emissions per capita differed, as shown by the y-axis.

As the changes in sulfur emission in developed countries, representing a trend of reduction uniformly. Sulfur emissions in the UK increased from 15 kg per capita in 1850 to 66 kg per capita in the peak year of 1965. After that, a rapid reduction in emissions was observed, and emissions continued to decrease until they reached 10 kg per capita in 2000. In the USA, the amount of emissions increased from 5 kg per capita in 1850 to 104 kg per capita in 1918, and then it decreased to 48 kg per capita in 1932. Although the amount of emissions went up and down several times because of the influence of World War II, it increased dramatically in the 1960s and reached a peak of 69 kg per capita in 1973; this peak value is more than 10 times greater than the value observed in 1850. The emissions decreased gradually after the 1970s, and a nearly 40% reduction occurred from the 1980s to 2000. Low levels of emission were observed in Japan from the 1850s to 1900s because Japan's industrialization history is short as compared with those of the UK and USA. Japanese sulfur emissions in 1900 were equivalent to those observed in America in 1850. A rapid increase was observed during the economic revitalization period after World War II. Over the next 25 years, the emissions increased by more than a factor of 8, from 3 kg per capita in 1946 to 24 kg per capita in 1970. That increase is surprising considering that even the USA took nearly 50 years to increase by a factor of 10.

In terms of peak level, USA is the highest 103 kg per capita, UK case is 66 kg per capita, and Japan case shows much lower 24 kg per capita. China case has not reached peak, however in the recent stage it shows maximum 10 kg per capita in the year of 1997. The GDP per capita level was about US$10,000 in the three countries when sulfur emissions started to decrease. A clear turning point was observed for the UK and Japan, but second and third turning points were observed as well for the USA. Since the turning points ranged from US$5,000 to US$15,000, the value of around US$10,000 was considered to be the average turning point value.

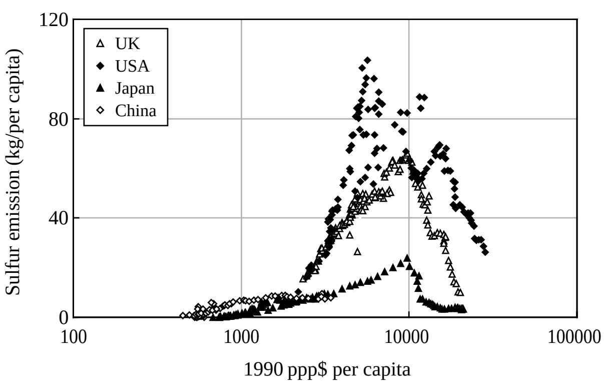

Fig. 6. Sulfur emissions and income of the four countries studied for 1850-2000.

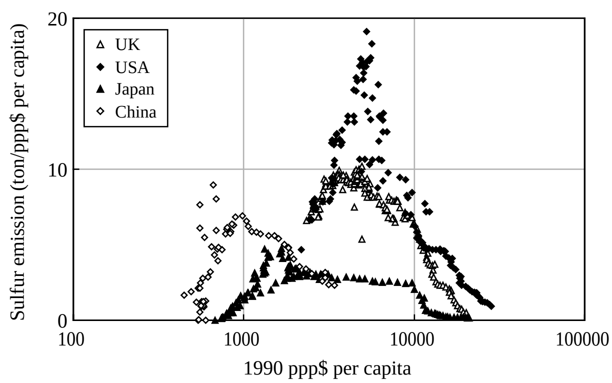

Fig. 7. Sulfur intensities and income of the four countries studied for 1850-2000.

Table 1. Year of turning point with GDP, population, and sulfur emissions in the UK, USA, and Japan.

Country	Year	Population	GDP	Sulfur emission	GDP per capita	Sulfur emission	SO_x/GDP
		1000 person	million 1990 ppp$	1000 ton	1990 ppp$	kg/person	ton/1990 ppp$
UK	1965	54350	529996	3598	9752	66	7
USA	1973	211909	3536622	14421	16689	68	4
Japan	1970	104344	1013602	2487	9714	24	2

Table 2. Period of industrialization with GDP and industrial output in different countries.

Country	GDP			Industrial output		
	Period	Multiples	Yearly growth (%)	Period	Multiples	Yearly growth (%)
UK	1870-1913	2.2	1.9	1876-1913	1.9	1.7
USA	1870-1913	5.3	3.9	1874-1913	7.4	5.4
Japan	1950-1973	7.7	9.3	1947-1975	11.3	9.1
China	1978-2004	10.3	9.4	1978-2004	16.8	11.2

Table 1 shows the year of emission peak with GDP, population, and sulfur emissions in the UK, USA and Japan corresponding with Fig. 6. The sulfur emissions/GDP ratios of the UK, USA and Japan were 7, 4 and 2 tons per GDP, respectively. In terms of China as seen in Fig. 6, there is no emission peak in the period.

Fig. 7 shows the relationships between sulfur emissions per GDP and GDP per capita from 1850 to 2000. Sulfur emissions per GDP show the economic efficiency in terms of emissions. A smaller ratio indicates better economic efficiency. As shown in Fig. 7, the value of the sulfur emissions/GDP ratio decreased in each country as the economic level increased. When the sulfur emissions per GDP was considered, the turning points of both the UK and the USA were more clearly determined than they were when sulfur emissions per capita were considered. When the GDP per capita reached US$5,000, the turning point of emissions reduction in the UK was 10 tons per GDP, and the turning point for the USA was 19 tons per GDP. For Japan, we observed a gentler curve with lower values than those observed for the UK and USA. When the GDP per capita reached US$1,600, the turning point of emissions reduction in the Japan was 5 tons per GDP. Therefore, the economic growth in Japan was more efficient by taking Late Comer's Advantage. On the other hand, for China, we observed a gentler curve with lower values than those observed for the UK and USA, but higher than that observed for the Japan. When the GDP per capita reached US$600, the turning point of emissions reduction in the china was 9 tons per GDP. In case of China, however at the level of US$600 GDP per capita, half of Japan case and one-eighth of UK and USA case, tendency of peak emission downlink is performed. The shape of the trend after the peak is similar to Japan even if the reduction speed is higher. In particular, When the GDP per capita reached US$1,000, the rapid decline is observed in emission per GDP. On the other, in the UK, USA and Japan, it has seen a rapid reduction after the GDP per capita reached US$10,000. In terms of sulfur emissions per GDP, economic growth in China was more efficient by taking Late Comer's Advantage. It implies that is Possible to achieve high economic growth and low emissions in developing countries by taking Late Comer's Advantage. In Fig. 7, comparing the most recent emission level, in the year of 2000, the developed countries shows lower unit emission level per GDP than developing countries, for instance, 0.15 ton/ppp$ of Japan, 0.49 ton/ppp$ of UK, and 0.92 ton/ppp$ of the USA and versus 2.3 ton/ppp$ of China.

Table 2 shows Period of industrialization with GDP and industrial output growth speed in different countries. In the process of industrialization and economic growth, the scale and growth rate of economic is growing faster by the advantage of late comer. It can infer that the increase of pollutant caused such as sulfur emissions. Recent industrialization pace in China is extremely higher than that of UK, USA and Japan had experienced. Thus, China is thought to increase the pollutant emissions.

5. CONCLUSIONS

This research compared the environmental Kuznets curve of long-term sulfur emissions of a developing country (China) with those of three developed countries. The existence of the environmental Kuznets curve for sulfur emissions is examined, and Peak point of environmental load in the environmental Kuznets curve about sulfur emissions level per capita is observed around US$10,000 per capita of GDP clearly in UK, Japan and USA with several sub peaks, however in China peak point hasn't come yet. In one hand in terms of sulfur emissions per GDP the environmental Kuznets curve is demonstrated in China as well as developed countries. The peak of sulfur emission per GDP is already seen in earlier stage at the GDP level of lower than US$1,000 per capita, comparing with emission peak at around US$5,000 per capita level in developed countries as UK and USA, at US$2,000 per capita level in Japan. Even though the existence of the environmental Kuznets curve is examined, environmental problems cannot be resolved without environmental policy in any countries. As a policy tool in the country analysis, as shown Figs. 2-4, developed countries enabled the simultaneous achievement of environmental impact reduction and economic growth mainly due to policy change about the specific pollutants (sulfur emissions (SO_2-S)).

The experience of developed countries indicates that reductions of sulfur emissions have been realized by several environmental policies and the strong enforcement of actions of emission sources by policy implementations. In the case of China, air pollution control policies have been established. However, because of continuous increasing of GDP, emission reduction effect per capita has not clearly been seen yet.

However, China case indicates the possibility of any other developing countries, and the comparison analysis of environmental Kuznets curve within different developing levels countries can be applied to promote the environmental improvement in several stages of economy or policies in developing or also in developed countries. By this comparison of environmental Kuznets curve about sulfur emissions, we can conclude that it is possible to reduce the environmental load in earlier stage of economic development in developing countries with appropriate environmental policy implementations. Near future we would try more and promote applications of environmental Kuznets curve for practical policy making processes.

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