Discussion Paper # 95-D0F-22

Why SOx Emissions are high in China?

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ABSTRACT

This paper examined the factors that attributed to the high emissions of SOx in China with respect to the size of its economy. Although SOx emissions in China is 70 times larger than that in Japan, the above difference is reduced to about 17 times when the evaluation problem relating to the exchange rate is taken into consideration. Our factor analysis based on the open input-output model estimated the reduction in SOx emissions in China by substituting in the various Japanese coefficients in the simulation. Firstly, for the effects of final demand pattern, our results showed that contrary to the hypothesis that the share of capital formation with high energy intensity is low in matured economy, SOx emissions increase when China is assumed to have the same goods and services composition as Japan. Emissions increase are recorded in industries such as electricity, iron & steel and transport equipment. Secondly, although China has a lower dependency on imports than Japan, the import coefficients for sectors with high energy consumption and high SOx emissions such as electric power, cement, iron & steel, machinery and transport equipment are larger in China. We also found no evidence to support the hypothesis that SOx emissions are higher in China as Japan exports more manufacturing products. Thirdly, with regards to the effects of the production sectors, our analysis revealed that the reduction in SOx emissions are large when the Japanese input per unit from the energy sectors are applied and when sulphur content in energy is reduced in China. However, as China is abundant in coal,it is unlikely that China will switch its energy inputs to petroleum, Hence increasing energy efficiency and increasing the removal of SOx in China are the major policy alternatives available.

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by

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I. Introduction

According to *the Statistical Yearbook of China*, SOx emissions in China amounted to 14.12 million tons (in molecular mass of SOx) in 1987, and 16.85 million tons in 1992. China ranked second in the world, with the US topped at 21 million tons. Further, SOx emissions in China had been increasing at an annual rate of 3% for the period from 1985 to 1992 (see Figure 1).

However, as the values in *the Statistical Yearbook* exclude small size production units such as the township-village enterprises, the above values are likely to be underestimated. Based on our Japan-China input-output tables for environmental analysis, China's SOx emissions in 1987 reached 20 million tons, which was as large as the emissions from the US. Hence, with the rapid rate of economic growth, China would probably become the world largest emitter of SOx in the future. As Japan's emissions of SOx in 1985 was estimated to be 1.15 million tons, SOx emissions in China was thus 18 times larger than that in Japan. On the other hand, GDP of Japan in 1985 was 1.4 trillion dollars, whereas the size of the Chinese economy was 0.3 trillion dollars in 1987, which was less than one-fourth the size of the Japanese economy. Therefore, the aim of this paper is to examine why SOx emissions are high in China with respect to the size of its economy based on the Japan-China input-output tables[1].

With regard to the above issue, various kinds of reasoning could be gathered from individuals ranging from economists to technicians working at the factory floor. During our five visits to China, we observed the low productivity of energy and we hardly came across any desulphurization equipment. However, instead of relying on information obtained from small sample, we hope to find out the dominating factors governing the issue through the use of input-output table, even though there are many problems regarding the statistical information and the year of compilation[2].

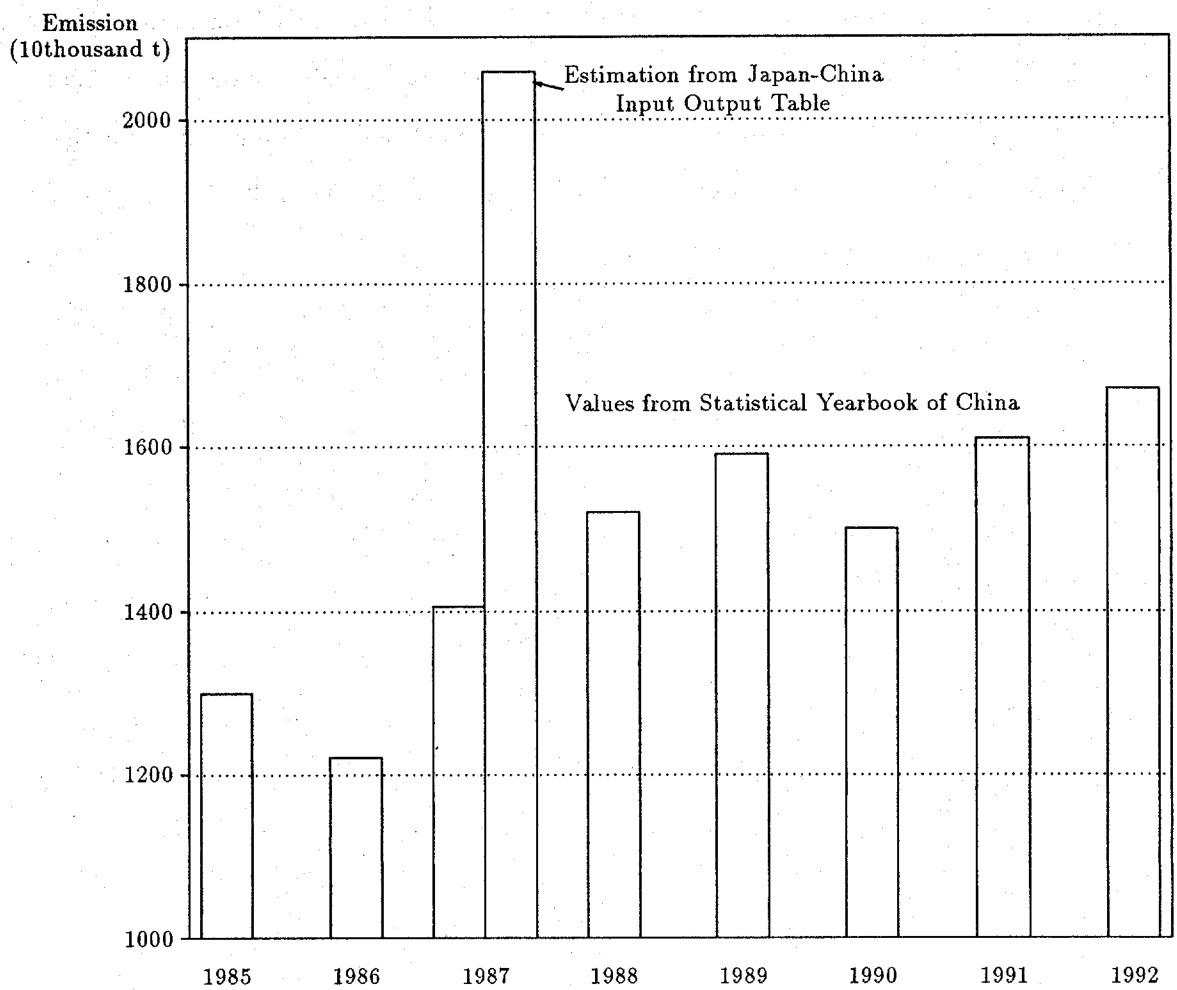

Figure 1: SOx Emission in China

II. Issues

The first issue concerns the size of the Chinese economy. It is widely suspected that exchange rate in China is under-valued. By assigning a value of 1 to 1985, we estimated the purchasing power parity index for the 1987 producers prices (see Table 1).

Firstly, in nominal values, every 100 million dollars of final demand results in 75 tons of SOx emissions in Japan, as compared to 5,721 tons of SOx emissions in China. If the above values are divided by the purchasing power parity index, emissions from China reduces to 1,294 tons/100 million dollars, thus reducing the difference in size of emissions to 17 times. Hence, there are in fact problems in the valuation of exchange rates.

Nevertheless, we need to find out the factors behind the 17 times different in emission size. Here, the first possible reason is the differences in the component of goods and services in final demand. It is possible that as China is a developing country, it may have a large share of fixed capital formation which is relatively high in induced energy. From Table 2, it can be seen that China has a large share of fixed capital formation in final demand. As compared to the 23.4% in Japan, the corresponding share in China is 28.8%, with probably a large share of fixed capital formation that requires much iron and cement. Further, in terms of the components in the private consumption of goods and services, demands for goods are higher in developing countries. On the contrary, as the services sector which has low induced energy is getting more important in the Japanese economy, energy intensities would be different for Japan and China even with

Table 1: SOx Emission Per Unit of Final Demand in Japan and China

	Japan 1985	China 1987
SOx/Nominal Value of Final Demand	75t/100 mil.us$	5,721t/100 mil.us$ (74 times)
SOx/Real Value of Final Demand	75t/100 mil.us$	1,294t/100 mil.us$ (17 times)

Table 2: Differences in the Final Demand between Japan and China

	Japan	China
Share of Fixed Capital Formation in Final Demand (Nominal)	23.4%	28.8%
Share of Primary and Secondary Products in Private Consumption Expenditure (Nominal)	35.5%	80.5%

the same level of consumption. Table 2 shows that within private consumption expenditure, the purchase of goods from the primary and the secondary sectors constitutes 35.5% in Japan, whereas the corresponding share is 80.5% for China. In other words, given the same level of consumption expenditure, demands for primary and manufacturing products are higher in China, with smaller purchases from the services sector. However, we have some reservations on the effects of the differences in the goods and services in consumption expenditure. For instance, as the private consumption share of gasoline and light oil is high in Japan, this may also produce some opposite effects.

The second issue concerns the fact that while Japan exports processed goods, China is abundant in natural resources. This implies that SOx emissions from the extraction of natural resources are left out in the case of Japan.

The third issue lies in the criticism that China has lower energy efficiency that Japan in the manufacturing of the same good. We illustrate the energy efficiency conditions of the major industries in Figure 2.

Figure 2 reveals clearly that high energy consuming industries certainly have low energy efficiencies. However, it should be noted that energy efficiency of the services industries is on the contrary higher in Japan. Nevertheless this result is not surprising as energy intensities in Japan are high in, for examples vending machines and refrigeration of food, etc. Hence, we need to examine in greater details whether the overall differences in energy efficiency is in fact the dominant factor.

The fourth issue rests on the type of energy used. As the main source of energy in

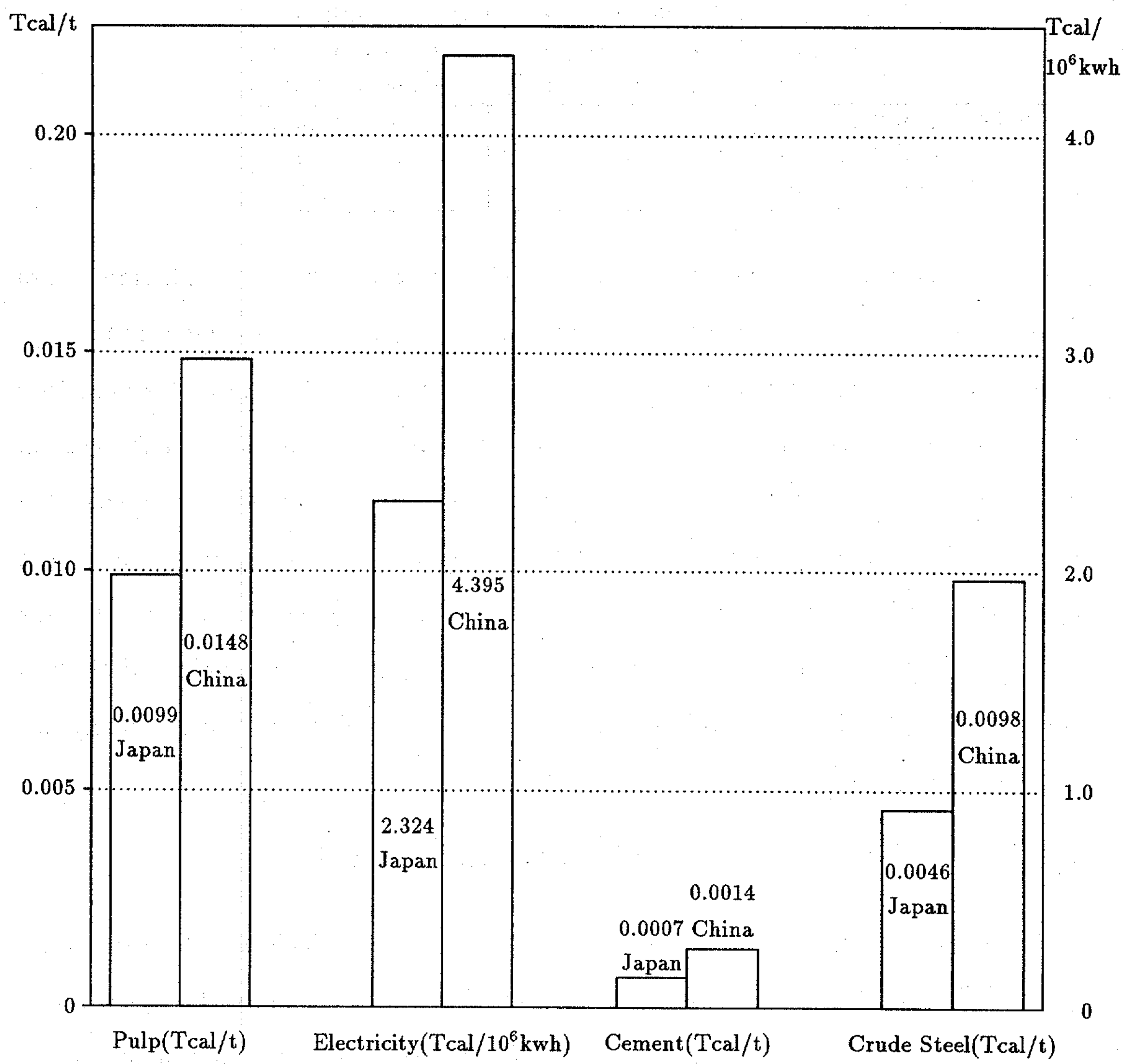

Figure 2: Energy Efficiency in Major Industries

Table 3: Main Energy Consumption and Desulphuring Ratio

	Japan(1985)	China(1987)
Domestic Energy Demand		
Coal	109.72 million t	1010.76 million t
Crude Oil	210.41 million kl	134.14 million t
Electricity	536,402 10^6 kwh	498,560 10^6 kwh
SOx contents in Energy	3.50 million t	23.4 million t
SOx Emission	1.15 million t	20.31 million t
Desulphuring Ratio	67.0%	13.2%

China is coal, this high dependency on coal naturally resulted in the high emission of SOx. Further, as the SOx generated in the combustion of coal is not removed through desulphurization equipment, this is one of the factors that lead to high SOx emissions in China. Evidence on the above is revealed in Table 3. The demand for coal in Japan is 100 million tons, which is equal to 10% of China's total demand on coal. On the other hand, Japan 's demand for crude oil is about 200 million tons, 2 times the corresponding demand in China. Further, in Japan, the ratio of SOx emissions to SOx content is low at 1/3 due to the presence of desulphurization equipment and the low content of sulphur in petroleum products. In contrast, desulphurization is usually not carried out in China.

III. Factor Analysis Based on Input-output Model

Although many factors could have attributed to the high emission level of SOx in China, in the following we try to distinguish the dominant factor by using the open input-output model. We measure the reduction in SOx emissions in China by substituting in the various Japanese coefficients such as the input coefficients or import coefficients in the calculation. We define 8 possible factors as follows,

A_1 composition of expenditure items in final demand

A_2 composition of goods and services in the expenditure items of final demand

A_3 import coefficients

A_4 input per unit from non-energy sectors

A_5 input per unit from energy sectors (total energy and its composition)

A_6 sulphur content per ton/calorie

A_7 energy efficiency

A_8 SOx removal rate

SOx emissions per unit of real final demand, S, in the two countries based on the conventional open model in input-output analysis is written as follows,

$$S^N = f(A^N{}_1, \ldots A^N{}_8)$$

where N is the subscript denoting China (C) and Japan (J). The following equation shows the reduction effects on SOx when the Chinese values of the above 8 factors are substituted by the Japanese figures,

$$\begin{aligned} f(A^J{}_1, \ldots A^J{}_8) &= f(A^C{}_1, \ldots A^C{}_8) \\ &+\sum_{i=1}^{8}[f(A^C{}_1, \ldots A^J{}_i, \ldots A^C{}_8) - f(A^C{}_1, \ldots A^C{}_8)] \\ &\textit{Effects of changing each factor} \\ &+\textit{Aggregation of cross} - \textit{effect} \end{aligned}$$

The reduction effects on SOx emissions are summarized in Figure 3. The cross-effects caused by various factors are aggregated together. This is because due to problems in the basic data, it is difficult to further decompose the aggregation of cross-effects. Hence, as in the ${}_8C_2$ case where 2 factors imposed on one another, errors of secondary order are produced, whereas similarly errors are in third order in the ${}_8C_3$ case where 3 factors imposed on one another, this avoids the decomposition of factors in the aggregation of cross effects. Even then, it could be seen from Figure 3 that

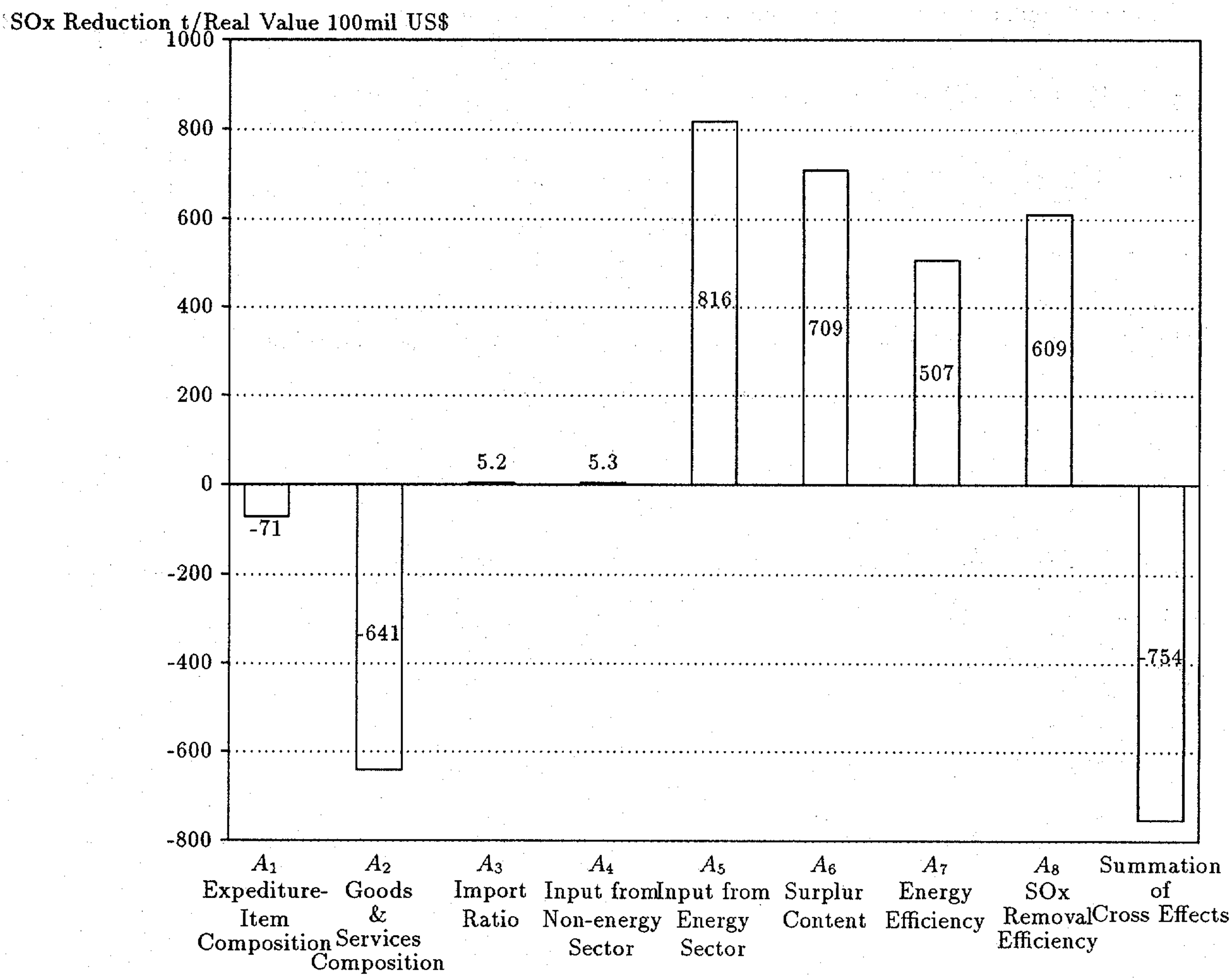

Figure 3: Reduction Effects on SOx in China if Factors are Equivalent to that in Japan

the aggregation of cross-effect has a large negative value. The reason behind could be explained as follows. For instance, as China's dependency on coal is 10 times greater than that of Japan, hence the introduction of desulphurization facilities at the Japanese level will have a large effect (609 ton/100 mil$) in the reduction of SOx emissions. At the same time, changing the energy structure to one that has the same dependency on petroleum also reduced SOx emissions by as large as 816 ton/100 mil$ in China. However, it must be noted that with SOx removal rate and petroleum dependency at the same level of Japan, the reduction in SOx emissions in China is not the aggregate of the above reduction, namely 1,425 ton/100 mil$. This is because as the level of desulphurization is performed with low dependency on coal, the aggregation of cross-effect will have negative value, decreasing the magnitude of reduction. In the following sections, we examine the respective effects in greater details.

(1) Effects of the Final Demand Pattern

Firstly, we examine the effect when China is assumed to have the same final demand pattern as that in Japan. In general, the share of capital formation with high energy intensity is low in a matured economy. In addition, with the increase demand for services, in which energy intensity is low, this also help to reduce SOx emissions per unit of GDE.

However, our results show to the contrary that SOx emissions per unit actually increase when China is assumed to have Japanese final demand pattern. SOx emissions increase by 71.1 ton/bil$ in real term for the composition of expenditure-item (A_1) and 641 ton/bil$ in real term for the composition of goods and services (A_2). Table 4 provides a comparison of expenditure-item composition in Japan and China.

Table 4 shows that in terms of real values, contrary to the expectation on a matured economy, the share of fixed capital formation is high in Japan. This is the reason leading to the increase effect for A_1. The above reveals the fact that Japan maintained a high

Table 4: A Comparison of Final Demand Expenditure Components in Japan and China

Final Demand Expenditure	Japan 1985	China 1987	
		Nominal	Real*
Other Consumption	12.7 %	10.1 %	8.2 %
Household Consumption	50.5 %	45.0 %	47.4 %
Fixed Capital Formation	23.4 %	28.8 %	21.3 %
Inventory, Others	0.5 %	4.3 %	4.8 %
Exports	12.9 %	11.9 %	18.3 %
Total Final Demand(100 million us$)	15,420	3,551	16,123

*Constant pricing evaluation based on p.p.p. Index set at 1 for Japan in 1985

Table 5: Reduction Effects on SOx in China if the Composition of Goods and Services are Changed to be in equivalent with that in Japan(SOx Reduction t/Real Value/100 million us$)

Agriculture and Forestry	18.7
Paper and Pulp	−16.6
Electricity and Heat Supply	−387.0
Ceramic, Stone and Clay	−75.7
Iron and Steel	−103.5
Transport Equipment	−63.5
Railway	−23.0
Commerce	−25.0
Emission from Households	240.8
Total	−641.0

level of fixed capital formation even in the 1980s. However, it must be noted that with the construction boom in China recently, we may have different results as compared to that above.

The next question concerns why SOx emissions increase instead when the China is assumed to have the same goods and services composition as that in Japan. Table 5 shows the industries which have large changes in SOx emissions. Data from Table 5 shows that while SOx emissions from households, and agriculture & forestry decline, emissions increase from industries such as electricity, iron & steel and transport equipment amount to 641 ton/100 mil$.

(2) Effects of the Import Coefficients—

As mentioned in the previous section, since China is a country abundant in natural resources whereas Japan exports processed or manufacturing products, it is suspected that a large part of the SOx emissions may have omitted in the estimation for Japan. However, Figure 3 shows that in fact opposite effects prevail. Our results show that when the Japanese import coefficients are applied to China, SOx emissions reduce only in agriculture, coal manufacturing, and petroleum and LNG mining. SOx emissions increase in the rest of the sectors which is contrary to prediction. Table 6 compares the import coefficients in Japan and China respectively.

Data from Table 6 show that the simple average for the import coefficients in China is 6%, as compared to 11% for Japan, thus showing that Japan has a higher dependency on imports. The above difference is due to the different in the structure of imports in the 2 countries. With respect to the emissions of SOx, mining industries such as coal mining and LNG mining have higher imports ratios in Japan. On the other hand, the import coefficients for sectors such as electric power, cement, iron & steel, machinery and transport equipment are higher in China. This shows that China has a higher import share of products with high energy consuming and high SOx emissions. However, as the overall decrease in SOx emissions is negligibly small at 5 ton/100 mil$, there is no evidence to support the hypothesis that SOx emissions are higher in China as compared to Japan due to the fact that Japan exports more manufacturing products.

(3) Effects of the Production Sectors

In Figure 3, we showed the reduction effect on SOx emissions when the factors in column A_4 to A_8 are substituted by the Japanese figures. We expect the high emissions of SOx in China to be attributed by the production sectors. Table 7 shows the reduction in SOx emissions in the major sectors, allowing us to examine the above factor in greater details.

Table 6: Comparison of Import Coefficients in Japan and China

Sector	China	Japan	China/Japan
1.Agriculture and Forestry	0.0281267	0.1809285	0.1554577
2.Fishery	0.0017325	0.1943999	0.0089119
3.Coal Mining	0.0110581	0.8227295	0.0134408
4.Petroleum and Natural Gas	0.0000000	0.9868031	0.0000000
5.Metal Ore Mining	0.1427444	0.9376517	0.1522361
6.Non-ferrous Metal Mining	0.0481796	0.1302884	0.3697918
7.Food Products	0.0453675	0.0603786	0.7513849
8.Textiles	0.0446495	0.0854805	0.5223358
9.Sewing and Leather	0.1555493	0.0776886	2.0022160
10.Wood and Furniture	0.0809860	0.0694894	1.1654439
11.Paper and Pulp	0.0832580	0.0469089	1.7748871
12.Printing and Education	0.1408406	0.0540817	2.6042179
13.Electricity and Heat Supply	0.0078083	0.0000590	132.39574
14.Petroleum Refineries	0.0452255	0.1451317	0.3116165
15.Coke Manufacturing	0.0158137	0.0008753	18.065712
16.Gas and Coal Products	0.0000000	0.0014984	0.0000000
17.Chemical Products	0.1535843	0.0727099	2.1122889
18.Medical Products	0.0643228	0.0734551	0.8756747
19.Rubber and Plastic Products	0.0145018	0.0200270	0.7241122
20.Cement	0.0129278	0.0060856	2.1243129
21.Ceramic, Stone and Clay	0.0131047	0.0248512	0.5273285
22.Iron and Steel	0.1678311	0.0191930	8.7444114
23.Non-ferrous Metal	0.0914450	0.2726408	0.3354046
24.Metal Products	0.0248782	0.0092196	2.6984108
25.Machinery	0.2186002	0.0277587	7.8750049
26.Transport Equipment	0.2183139	0.0266741	8.1844906
27.Electrical Machinery	0.1012063	0.0254138	3.9823305
28.Electronics and Communication Equipment	0.2561480	0.0325530	7.8686426
29.Testing Machines · Measuring Instruments	0.3469343	0.1115122	3.1111780
30.Machinery Equipment Repairing	0.0000000	0.0000401	0.0000000
31.Other Manufacturing	0.2987270	0.0242420	12.3227000
32.Construction	0.0000000	0.0010973	0.0000000
33.Railway	0.0001859	0.0067849	0.0273994
34.Road Freight Transport	0.0000000	0.0000000	0.0000000
35.Road Passengers Transport	0.0010937	0.0139875	0.0781912
36.Air Transportation	0.0353762	0.2045325	0.1729615
37.Other Transport Industry	0.0000000	0.1648699	0.0000000
38.Communication	0.0000000	0.0046898	0.0000000
39.Commerce	0.0218007	0.0115217	1.8921329
40.Restaurants/Eating Places	0.0000000	0.0182007	0.0000000
41.Public Enterprises and Non-profit Private Services	0.0007249	0.0101166	0.0716506
42.Education, Health and Scientific Research	0.0064150	0.0078027	0.8221610
43.Finance and Insurance	0.0001260	0.0170250	0.0074015
44.Administrative Organizations	0.0000000	0.0027210	0.0000000
45.Other Services	0.0000000	0.1085226	0.0000000
Simple Average	0.0644353	0.1136143	0.5671408

Table 7: Reduction Effects on SOx in China if the Japanese Production Process is used (Total Demand t/100 million us$)

Factors	A_4	A_5	A_6	A_7	A_8
Major Related Sectors	Inputs from Non-energy Sectors	Inputs from Energy Sectors	Sulphur Content	Energy Efficiency	SOx Removal Efficiency
Agriculture and Forestry	4.4	17.6	18.2	11.3	17.7
Coal Mining	2.0	33.7	35.4	30.0	12.1
Paper and Pulp	−37.7	−0.1	13.2	12.4	19.0
Electricity & Heat Supply	8.8	233.4	231.0	167.2	301.6
Chemical Products	11.8	17.1	18.6	−3.2	25.2
Ceramic, Stone and Clay	19.7	53.5	55.2	88.6	53.9
Iron and Steel	2.8	−9.1	10.6	28.5	43.9
Industrial and Household Total	5.3	816.0	708.6	507.2	609.4

First, it is noted the effect contributed by A_5 is the greatest, as reduction effect of 816 ton/100 mil$ in real term results when the Japanese input per unit from the energy sectors are applied in China. The second largest effect results from A_6, SOx emissions reduction of 709 ton/100 mil$ in real term is observed when the content of sulphur in energy is the same as that in Japan. This is followed by 609 ton/100 mil$ due to sulphur removal rate A_8 and 507 ton/100 mil$ due to energy efficiency A_7. On the other hand, the results show that the reduction effect on SOx emissions is small when China is assumed to have the same input per unit from the non-energy sectors as that of Japan. With regard to factors A_5 and A_6 which the reduction effects are large, it is difficult to imagine China, which has been depending heavily on domestically produced coal, to have a structure similar to that of Japan. In other words, it is unlikely that China will depend more on energy input from petroleum instead of coal or to import energy with low sulphur content. Consequently, the remaining measures lie in factor A_7 and A_8, that is, by increasing energy efficiency in China and through the introduction of desulphurization equipment.

Next, we the emissions reduction effects in each sectors. It is worth noting that when the various factors are converted to take the Japanese figures, it is found that the reduction effects in the respective sectors differ widely. Increases in SOx emissions are observed in some of the sectors. For instance, for the paper & pulp industry, factors A_4 and A_5 result in increase emission effects. In particular, when input per unit from the non-energy sector is made equal to that in Japan, the increase in SOx emissions from the paper & pulp industry amount to 37.7 ton per 100 mil$ of final demand. This reveals the fact that paper and pulp products are heavily used in production processes. Further, for the effect of A_5 with respect to the iron and steel industry, SOx emissions increase China is assumed to have the common input from the energy sectors as that in Japan. This is because scrap iron is commonly used in open-hearth furnace to manufacture steel in China.

As for the strategies of reducing SOx emissions from China, firstly, the effect will be significant if the sulphur removal rate of Japan is applied in the electric power industry of China. SOx reduction could amount to 302 ton per 100 mil$. Secondly, raising the energy efficiency in electric power will have an effect of about 167 ton/100 mil$. The third strategy is to raise the energy efficiency in the ceramic, clay & stone industry. The fourth strategy will to increase desulphurization activity in the iron and steel industry.

IV. Conclusions

In the above sections, we have examined the reasons why SOx emissions in China is larger than that in Japan. Based on the size of the Japanese economy, SOx emissions in China is more than 70 times greater than that Japan. However, the above difference is reduced to about 17 times when the exchange rate problems is taken care of.

Our factor analysis based on the open input-output model estimated the reduction in SOx emissions in China by substituting in the various Japanese coefficients in the simulation. Firstly, for the effects of final demand pattern, our results showed that contrary to the hypothesis that the share of capital formation with high energy intensity is low in matured economy, SOx emissions increase when China is assumed to have the same goods and services composition as Japan. Emissions increase are recorded in industries such as electricity, iron & steel and transport equipment. Secondly, although China has a lower dependency on imports than Japan, the import coefficients for sectors with high energy consumption and high SOx emissions such as electric power, cement, iron & steel, machinery and transport equipment are larger in China. We also found no evidence to support the hypothesis that SOx emissions are higher in China as Japan exports more manufacturing products. Thirdly, with regards to the effects of the production sectors, our analysis revealed that the reduction in SOx emissions are large when the Japanese input per unit from the energy sectors are applied and when sulphur content in energy is reduced in China. However, as China is abundant in coal,it is unlikely that China will switch its energy inputs to petroleum. As China will continue to depend on coal, we suggest that the major policy measures should emphasize the improvement in energy efficiency and the provision of desulphurization technology to China.

However, in this paper, we have not been able to analyze in greater details the changes in final demand due to the limits in the estimation of purchasing power parity. In particular, we have not analyze the effect on the reduction of SOx emissions if the services sector is to become more important in the Chinese economy. These topics are left for further research.

Appendix:Method of Factor Analysis

The method used in analyzing factors contributing to the differences in air pollution coefficients in Japan and China is explained as follows, (1) estimating the emission per unit of final demand based on the open model in input-output analysis; and (2) estimating the changes in the emission per unit of final demand by altering the 8 factors relating to emission level.

(1)

Let ${S^A}_j$ be the induced SOx emissions from the jth sector of country A, and ${S^A}_{cons,k}$ be the emissions from the final consumption $cons$ of expenditure-item k. Then it follows that

$$
\begin{aligned}
{S^A}_j &= {R^A}_j \frac{{U^A}_j}{{X^A}_j} \sum_{i=1}^{mat} \left(\frac{{u^A}_{ij}}{{U^A}_j} \frac{{e^A}_{ij}}{{u^A}_{ij}} \right) {x^A}_j \\
{S^A}_{cons,k} &= {R^A}_{cons,k} \sum_{i=1}^{mat} \left(\frac{{u^A}_{cons,ik}}{{U^A}_{cons,k}} \frac{{e^A}_{cons,ik}}{{u^A}_{cons,ik}} \right) \frac{{U^A}_{cons,k}}{{F^A}_{cons,k}} {f^A}_{cons,k}
\end{aligned}
$$

where

${R^A}_j$ 1−SOx removal rate in jth sector of country A, subscript $cons$, k denotes 1−SOx removal rate for the final consumption of the k expenditure-item. $cons$ is the variable used in the calculation of emission from final consumption, where $j = 1, ..., n(=45)$, $k = 1, ..., n\ cons\ (= 2$, $k = 1$: other consumption, $k = 2$: household consumption).

${U^A}_j$ total energy consumption (in calorie equivalent value, Tcal) in the jth sector of country A

${u^A}_{ij}$ total energy consumption of the ith type of energy (in calorie equivalent value, Tcal) in the jth sector of country A, $i = 1, \ldots, mat$: mat: the number of energy type, here $mat = 19$

$e^A{}_{ij}$ quantity of air pollutants SOx (in molecular mass of SO2, ton) in the ith type of energy in the jth sector of country A, $i = 1, \ldots, mat$.

$X^A{}_j$ real output of the jth sector in country A, 1985 as the base year and Japan as the base country, in 10 thousand dollars.

$F^A{}_{cons,k}$ real final consumption of the kth expenditure-item of country A, 1985 as the base year and Japan as the base country, in 10 thousand dollars.

$f^A{}_{cons,k}$ the final consumption ratio of the kth expenditure-item in the final demand of country A. $k = 1,\ 2$

x^A the column vector (output) of country A in line with the real output $x^A{}_j$ in the jth sector when 1 unit is demanded in the final demand composition of country A, is obtained as follows,

$$x^A = (I - (I - \tilde{M}^A)A^A)^{-1} f^A$$

For vector f^A of per unit of final demand in country A, the goods and expenditure-item compositions can be decomposed as follows,

$$f^A = \begin{pmatrix} (1-m^A{}_1)fx^A{}_{11} & \cdots & (1-m^A{}_1)fx^A{}_{1,(nf-1)} & fx^A{}_{1,nf} \\ \vdots & & \vdots & \vdots \\ (1-m^A{}_n)fx^A{}_{n1} & \cdots & (1-m^A{}_n)fx^A{}_{n,(nf-1)} & fx^A{}_{n,nf} \end{pmatrix} \begin{pmatrix} fr^A{}_1 \\ \vdots \\ fr^A{}_{nf} \end{pmatrix}$$

$$\sum_{i=1}^{n} fx^A{}_{ij} = 1, \quad (j = 1, \ldots, nf)$$

$$\sum_{i=1}^{nf} fr^A{}_j = 1$$

where

$fx^A{}_{ij}$ the ratio of the ith good in the jth expenditure-item of the final demand of country A. The nfth expenditure-item is exports. Expenditure-items j comprise

1: other consumption,

2: household consumption,

3: fixed capital consumption,

4: net increase in inventory (including statistical discrepancies), and

5: exports.

$fr^A{}_j$ the ratio of the jth expenditure-item to final total demand of country A; $fr^A{}_j = fr^A{}_{cons,j}$, *where* $j = 1, 2$.

Hence, SOx emissions from the output of the jth sector and the final consumption of the kth expenditure-item in country A can be calculated as shown above. The aggregate emissions

$$S^A = \sum_{i=1}^{n} S_j{}^A + \sum_{k=1}^{ncons} S^A{}_{cons,k}$$

is the induced emission from per unit of final demand and the emission from final consumption.

(2)

SOx emissions, S^N, per unit of final demand in country N is decomposed into the following 8 factors,

$A^N{}_1$ SOx removal rate in country N; $R^N{}_j(j = 1, \ldots, n)$, $R^N{}_{cons,k}(k = 1, \ldots, cons)$

$A^N{}_2$ energy efficiency in country N;

$$\frac{U^N{}_j}{X^N{}_j} \ (j = 1, \ \ldots, \ n) \quad \frac{U^N{}_{cons,k}}{F^N{}_{cons,k}} \ (k = 1, \ \ldots, \ ncons)$$

$A^N{}_3$ energy composition in country N. Here involves changing at the same time the ratio of energy consumption in calorie in the jth sector and the kth final consumption expenditure-item; and the input composition with respect to energy in the input coefficients $a^N{}_{ij}$ of the input-output tables as follows,

$$\frac{u^N{}_{kj}}{U^N{}_j} \qquad (k = 1, \ \ldots, \ mat, \ j = 1, \ \ldots, \ n),$$

$$a^N{}_{ij} \qquad (i = i_{eng1},\ \ldots,\ i_{engm},\ j = 1,\ \ldots,\ n),$$

$$\frac{u^N{}_{cons,kl}}{U^N{}_{cons,kl}} \qquad (k = 1,\ \ldots,\ mat,\ l = 1,\ \ldots,\ ncons)$$

$A^N{}_4$ emission coefficient (ratio of SOx content) by energy type in country N;

$$\frac{e^N{}_{kj}}{u^N{}_{kj}} \qquad (k = 1,\ \ldots,\ mat,\ j = 1,\ \ldots,\ n),$$

$$\frac{e^N{}_{cons,kl}}{u^N{}_{cons,kl}} \qquad (k = 1,\ \ldots,\ mat,\ l = 1,\ \ldots,\ ncons)$$

$A^N{}_5$ input coefficients other than those include in the energy composition of country N; $a^N{}_{ij}$ $(i = i_{other1},\ \ldots,\ i_{other(n-engm)},\ j = 1,\ \ldots,\ n)$

$A^N{}_6$ import coefficients of country N; $\tilde{M}^N_{ii}$ $(i = 1,\ \ldots,\ n)$

$A^N{}_7$ composition of goods in the each final demand item of country N; $fx^N{}_{ij}$ $(i = 1,\ \ldots,\ n,\ j = 1,\ \ldots,\ nf)$

$A^N{}_8$ composition of expenditure-item in the final demand of country N; $fr^N{}_j$ $(j = 1,\ \ldots,\ nf)$, $f^N{}_{cons,k}$ $(k = 1,\ \ldots,\ ncons)$

With the above factors, SOx emissions per unit in the final demand of country N, S^N, is in general written as $S^N = \Psi(A^N{}_1,\ \ldots,\ A^N{}_8)$. Based on Yoshioka and Arai (1980), and superscripts C and J denoting China and Japan, respectively, the following can be written,

$$\begin{aligned} S^J \;=\;& S^C + \sum_{i=1}^{8}\{\Psi(A^C{}_1,\ \ldots,\ A^J{}_i,\ \ldots,\ A^C{}_8) - \Psi(A^C{}_1,\ \ldots,\ A^C{}_8)\} \\ &+ \sum_{i1=1}^{7}\ \sum_{i2=i1+1}^{8} \{\Psi(A^C{}_1,\ \ldots,\ A^J{}_{i1}, .., A^J{}_{i2}\ \ldots,\ A^C{}_8) - \Psi(A^C{}_1,\ \ldots,\ A^C{}_8) \\ &- \Psi(A^C{}_1,\ \ldots,\ A^J{}_{i1},\ \ldots,\ A^C{}_8) - \Psi(A^C{}_1,\ \ldots,\ A^J{}_{i2},\ \ldots,\ A^C{}_8) \\ &+ \Psi(A^C{}_1,\ \ldots,\ A^C{}_8)\} + \cdots \\ &+ \sum_{i1=1}^{1}\ \sum_{i2=i1+1}^{2} \cdots \sum_{in=8}^{8}\{\Psi(A^J{}_1,\ \ldots,\ A^J{}_8) - \cdots + (-1)^{n+1}\Psi(A^C{}_1,\ \ldots,\ A^C{}_8)\} \end{aligned}$$

Notes

(1) This study is based on the Japan- China Input-Output Tables for the Analysis of energy and Air Pollutants, compiled under a joint research comprising the Ministry of International Trade and Industry in Japan, State Statistical Bureau (China), Environmental Protection Bureau (China) and Keio Economic Observatory of Keio University, .

(2) The basic tables are 1985 for Japan and 1987 for China. This is because conversion to the same year will require further assumptions and processing of data. For the purchasing power parity index use for the comparison in real term, the 1987 index for China is calculated by assuming a value of 1 for Japan in 1985. The purchasing power parity index used in our study is taken from reference [5]. However, as calculated values for services industries, manufacturing products such as medical products and measuring equipment , and agriculture are very small, our calculation here make use of the industrial average excluding the above sectors. This is a temporary measure as for the services industries, evaluation on quality is difficult as purchasing power parity is obtained from wage or services charges. Further quality differences are also large for medical products, measuring equipment and agricultural products.

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