〔研究ノート〕

An Application of Input–Output Analysis for China's Environmental Problems: Possibilities of Reduction of CO_2 Emissions

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1. Introduction

The countries of East Asia now form a major growth center in the world economy, but economic growth plays two different roles; one has positive aspects and the other has negative. One of the positive effects of economic growth is improvement of living standard and the negative side includes environmental problems, such as green house effects or air pollution with CO_2 or SO_x emissions. China is a good example to see the negative impacts of rapid economic growth. The later part of this note will show an example of an Input-Output model applying to this kind of issue.

2. An Input-Output Model Application on Environmental Problems in China

2-1. Estimation of CO_2 Emissions

The main purpose of this paper is to estimate the present China's emission of carbon dioxide (CO_2) and also to evaluate the possibility of its reduction using 1987 Input-Output tables of China and Japan.

[China's CO_2 Emissions in 1987]

To begin with, we show how CO_2 emissions can be estimated from ordinary publicly announced data. We here assume that carbon dioxide (CO_2) is generated only through the combustion of fossil fuels such as coal, oil and natural gas; that is to say, we neglect other origins like cement or pulp industries, gas flaring, deforestation, for the time being.

The easiest approaches to estimate the total amount of CO_2 emissions in China is as follows. First of all, data can be obtained for China's energy consumption (unit: mega (10^6) tons of coal equivalent) from the China Energy Statistics Yearbook (see Table 2-1).

At the next step, these numbers can be converted into thermal capacity (i.e., calorie basis) (Table 2-2 and Figure 2-1), if they are multiplied by the "standard coal calorie" (7.0 peta (10^{15}) calorie/mega

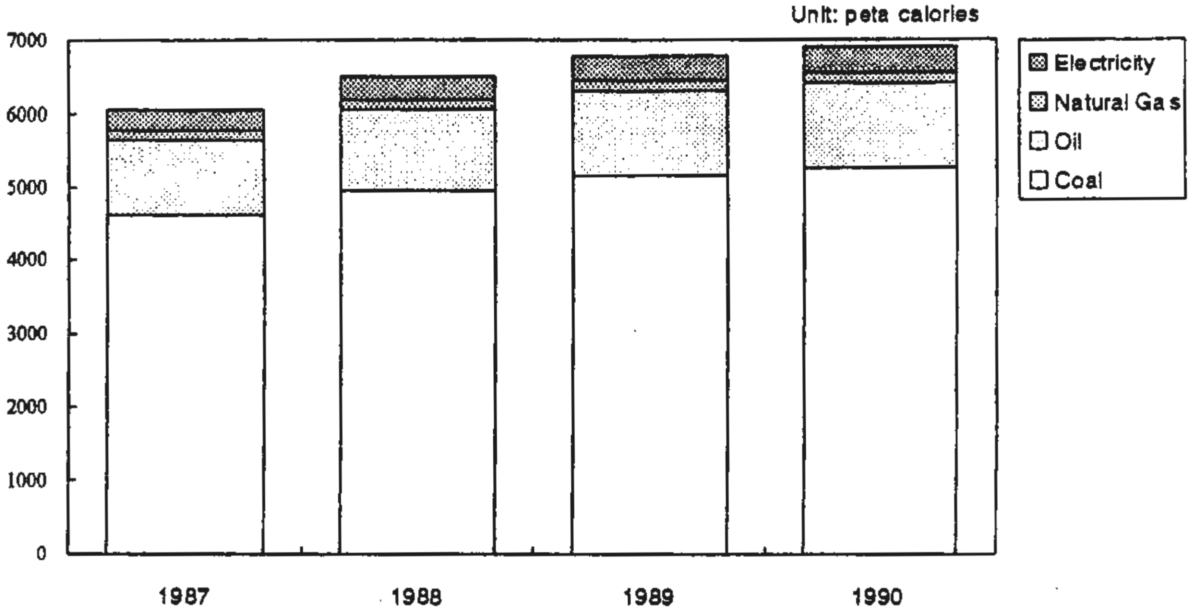
Table 2 − 1 China's Energy Consumption (megatons (10^6) of coal equivalent)

	Total	Coal	Oil	Natural Gas	Hydro-Electric Power
1987	866.32	660.23	147.45	18.45	40.20
1988	929.97	708.36	158.56	19.16	43.89
1989	969.34	736.41	165.56	19.97	47.40
1990	987.03	752.02	164.14	20.23	50.63

Table 2 − 2 China's Energy Consumption (peta (10^{15}) calories)

	Total	Coal	Oil	Natural Gas	Hydro-Electric Power
1987	6,064.28	4,621.58	1,032.14	129.17	281.38
1988	6,509.80	4,958.51	1,009.92	134.10	307.26
1989	6,785.38	5,154.85	1,158.94	139.78	331.81
1990	6,909.21	5,264.13	1,149.00	141.64	354.44

Figure 2 — 1 : China's Energy Consumption



(10^6) tons of coal) (see MITI, *Energy Statistics*).

As CO_2 emissions per calorie of various fossil fuels are known as shown in Table 2-3. If the figures in Table 2-2 are multiplied by these in Table 2-3, the total emissions of CO_2 in China can be obtained as is shown in Table 2-4 and Figure 2-2. However, this method tends to overestimate CO_2 emissions since it assumes that all fossil fuels are combusted and that there is no way to convert them into other

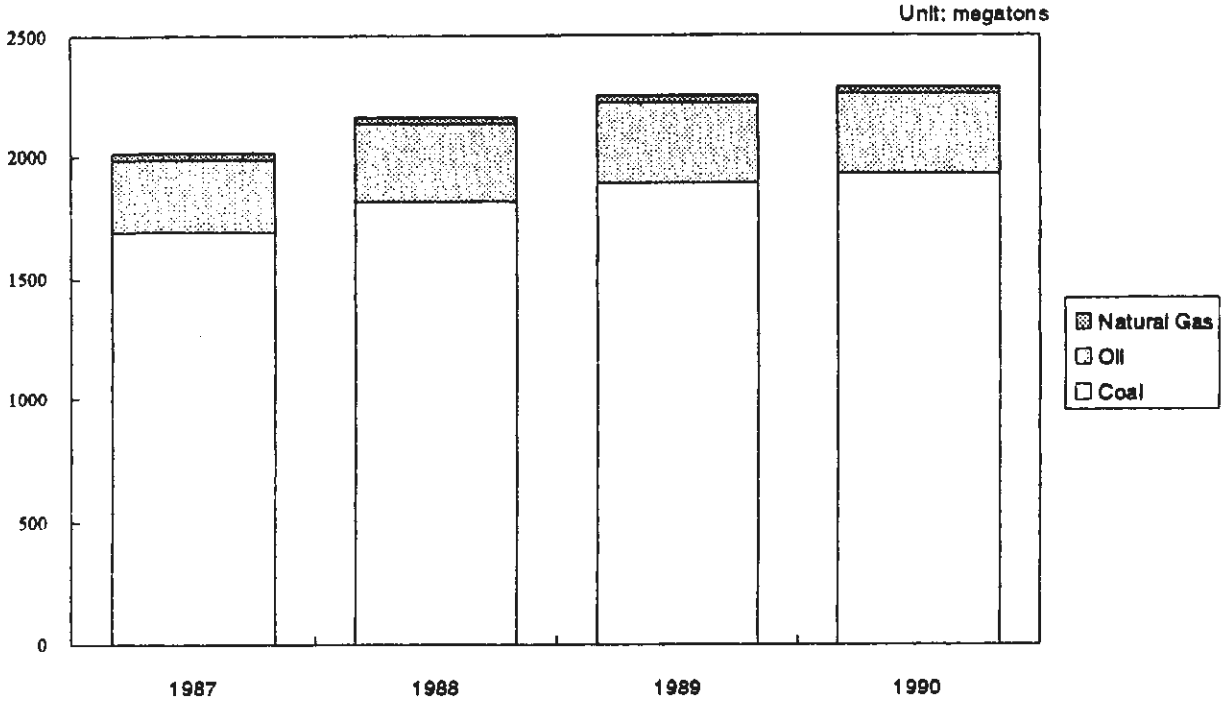
Table 2 — 3 CO_2 Emission Coefficients from Fossil Fuels

Coal	0.366 g/kilo calorie
Oil	0.287 g/kilo calorie
Natural Gas	0.209 g/kilo calorie

Table 2 — 4 China's CO_2 Emissions (megatons)

	Total	Coal	Oil	Natural Gas	Hydro-Electric Power
1987	2,014.72	1,691.50	296.22	27.00	0.0
1988	2,161.39	1,814.81	318.55	28.03	0.0
1989	2,248.51	1,886.68	332.62	29.21	0.0
1990	2,286.04	1,926.67	329.76	29.60	0.0

Figure 2 − 2 : China's CO_2 Emissions



products like synthetic fibers or plastic products.

[Japan's CO_2 Emissions in 1987]

The following tables are Japan's energy consumption and estimated CO_2 emissions after 1987, which are calculated in the same manner as used in Chinese case (see Figure 2-3 and 2-4). The share of coal is much smaller than in China and the share of oil is bigger instead. You can see that Japan's CO_2 emissions are 850 megatons in 1987, which are less than half of those in the case of China. Considering Chinese GNP was \$304 billion and Japanese GNP was \$2,423 billion in 1987, China's CO_2 emissions per unit GNP is approximately twenty times as large as that of Japan.

Hayami and Kiji (1994) estimates emissions of various air polluting materials using 1985 Japan and China environmental input-output tables. According to their study, China's CO_2 emissions are 2,346 megatons, which is 10-20% larger than our estimates. This is because

Figure 2 − 3 : Japan's Energy Consumption

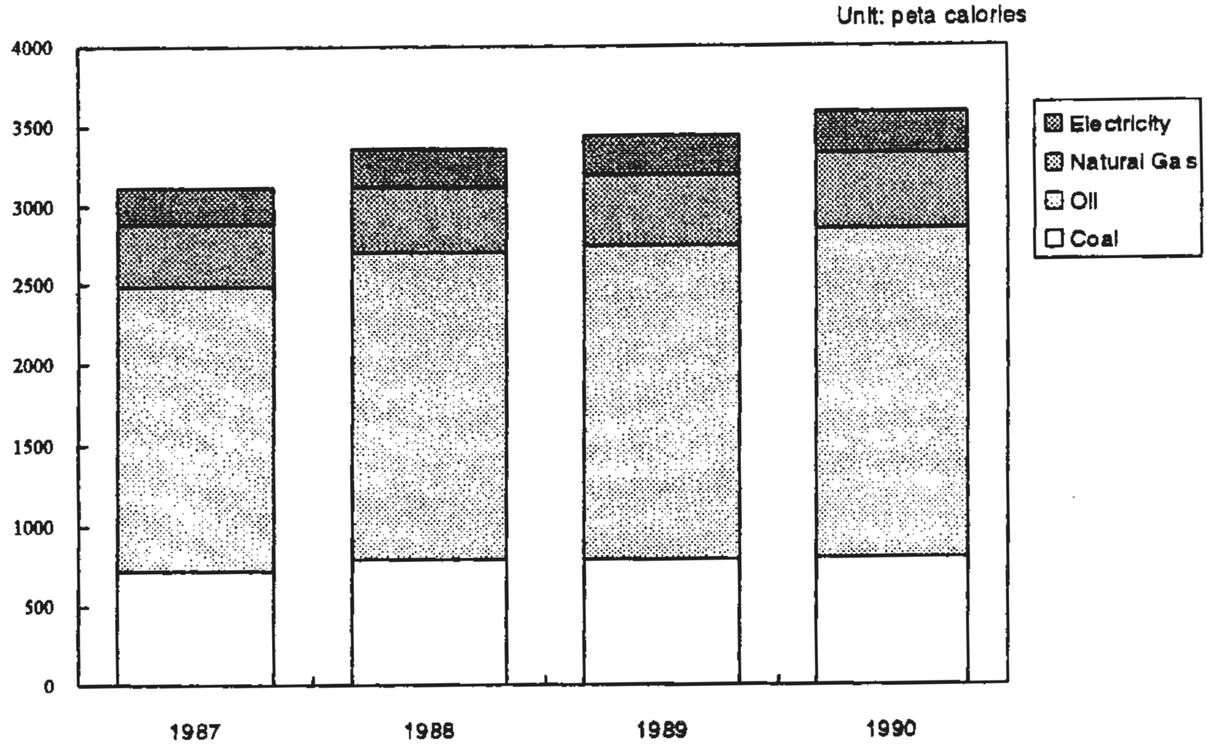


Figure 2 − 4 : Japan's CO_2 Emissions

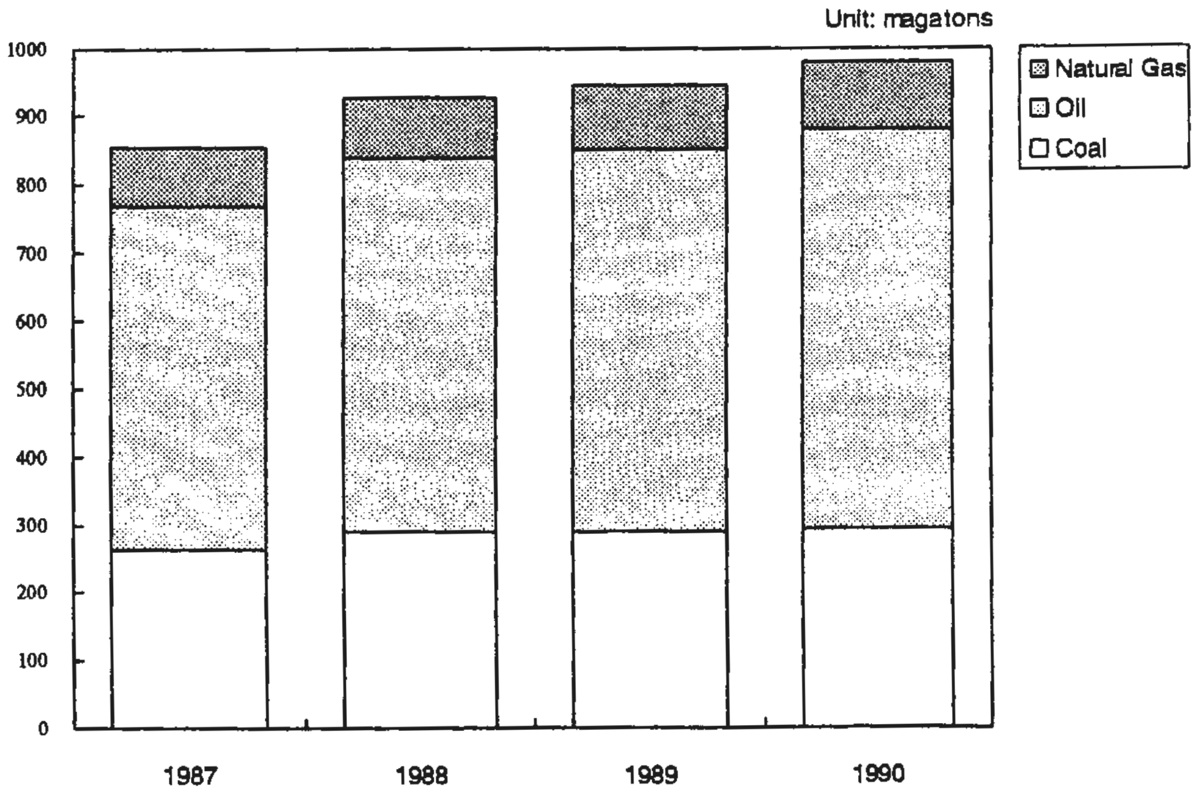


Table 2 − 5 Japan's Energy Consumption (peta calories)

	Total	Coal	Oil	Natural Gas	Hydro-Electric Power
1987	3,116.75	718.34	1,765.82	400.47	232.12
1988	3,360.63	792.68	1,912.75	417.97	237.23
1989	3,439.31	792.89	1,954.54	449.33	242.55
1990	3,584.77	803.39	2,044.63	478.97	257.80

Table 2 − 6 Japan's CO_2 Emission (megatons)

	Total	Coal	Oil	Natural Gas	Hydro-Electric Power
1987	853.40	262.91	506.79	83.70	0.00
1988	926.44	290.12	548.96	87.36	0.00
1989	951.06	290.20	560.95	99.91	0.00
1990	980.95	294.04	586.81	100.10	0.00

Hayami and kiji(1994) considers CO_2 emissions released from a production process in the Cement and Pulp industries, which are neglected in this note. Their study estimates that 1985 Japan's CO_2 emissions were around 1,000 megatons, which are also a little higher than our estimate.

2-2. CO_2 Emissions by industry

[China's CO_2 Emissions by industry in 1987]

This section shows how to calculate CO_2 emissions by industry and how to estimate the effects that the introduction of an energy tax would have on CO_2 emissions. IO model assumes that a unit production of a specific commodity requires a certain fixed quantity of energy (i.e. coal, oil and natural gas); in other words, IO model here assumes fixed input coefficients based on the 1987 China I-O table of which we make use here. Input coefficients of the I-O table, however, unfortunately represent those of nominal inputs: how many Yuan of energy are consumed for a unit production of a specific commodity,

Table 2 – 7 Thermal equivalent of fossil energy

	(1) Nominal Consumption	(2) Thermal Equivalent (IO Table, 10 thousand Yuan)	The ratio(2)/(1) (Bill. Calories)
Coal	2, 618, 247	4, 621, 584	1. 7651
Oil	2, 033, 432	1, 032, 140	0. 5076
Natural Gas	169, 436	129, 169	0. 7623

so we need to recalculate these input coefficients into those expressing real inputs: how many calories of energy are used for a unit of production in order to apply the same method as we used in the preceding section.

The following table shows the nominal value (from the 1987 I-O table) and thermal equivalent (from Energy Statistics) of energy consumption. By using the ratio of these figures, the nominal input coefficients can be converted those of into thermal basis.

Also, air pollution emissions are generally expressed as follows:

$$(2\text{-}1)\quad Emissions = \frac{Emissions}{Energy} * \frac{Energy}{Producition} * Production = EC * AE * X$$

To apply this equation in an I-O framework, the first term of the right hand side (EC: Emission Coefficients) is written as follows: (See, Table 2-3)

$$(2\text{-}2)\quad EC = \begin{bmatrix} 0.366 & 0.000 & 0.000 \\ 0.000 & 0.287 & 0.000 \\ 0.000 & 0.000 & 0.209 \end{bmatrix}$$

EC must be a 3x3 matrix so that three types of CO_2 emission from different fossil fuels can be calculated separately. The second term (AE: input coefficients of energy) is a product of the last column of Table 2-7 and I-O (nominal) input coefficients (So called "A" matrix).

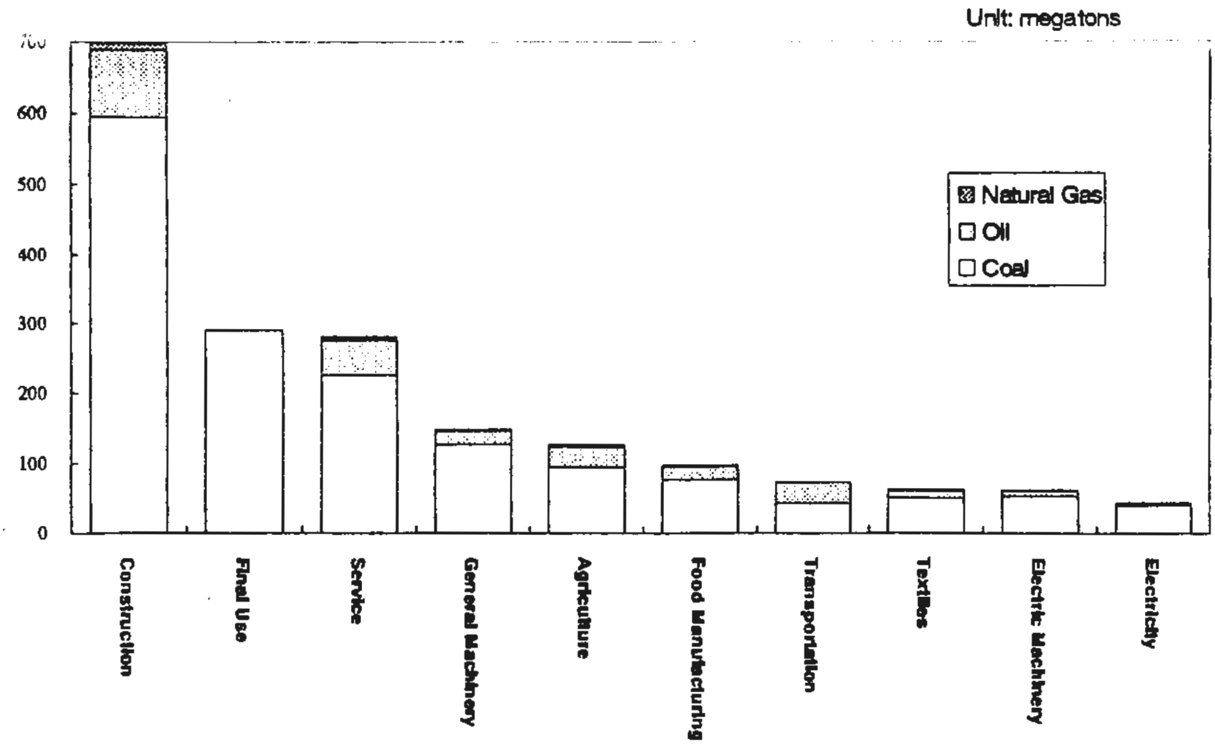
$$(2\text{-}3)\quad AE = \left[\begin{array}{cc:ccc:cc} 0 & 0 & 1.7651 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.5676 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.7623 & 0 & 0 \end{array}\right] {}^{*}A$$

The last term (X: outputs) is a diagonal matrix with total production.

$$(2\text{-}4)\quad X_1 = \begin{bmatrix} x_1 & & 0 \\ & x_2 & \\ & & \ddots \\ 0 & & x_n \end{bmatrix} \quad \text{or} \quad (2\text{-}4)' \quad X_2 = (I-A)^{-1} \begin{bmatrix} f_1 & & 0 \\ & f_2 & \\ & & \ddots \\ 0 & & f_n \end{bmatrix}$$

Though CO_2 emissions from the production process can be computed as EC*AE*X, the results using (2-4) show direct emissions of CO_2 from the corresponding sector, and those using (2-4)' show how much CO_2 is emitted in the whole, direct and indirect, production process of the corresponding sector's final demands; in other words, the latter results are evaluated as CO_2 intensity of the industry. In the follow-

Figure 2 – 5 : China's CO_2 Emissions (by sector) in 1987



ing section in this note, the results will be based on the latter formula (EC*AE*X_2). Since this calculation assumes all the fossil energy is burned and it does not consider oil used as material to produce synthetic fibers, and so on, the results should be taken as an upper limit.

Also CO_2 emissions from final consumption can be calculated in the same manner. If they are added to those from the production process, the total amount of CO_2 emissions of the whole (Chinese) economy can be obtained.

Figure 2-5 shows the top ten of largest CO_2 emitting sectors. The *Construction* sector accounts for a third of total emissions, followed by *Final Use, Service, General Machinery* and *Agriculture.*

[Introduction of a Energy Tax and CO_2 Emissions]

This section considers how much CO_2 emissions can be reduced through a price increase resulting from the introduction of an energy tax.

We estimated the demand functions for energy using annual of 1978-1992. The specification is of a traditional "income and price type" with two year lags (Almon lags) for the price effect. The price in the equations does not mean the absolute level of a specific energy but the relative price of the corresponding energy price in terms of the GDP deflator, and the coefficient of income and price terms express the income elasticity and the price elasticity, respectively.

Demand for Coal

$$\log(\text{Coal Demand}) = \underset{(72.1)}{5.163} + \underset{(78.3)}{0.665}{*}\log(\text{GNP}) - \underset{(4.47)}{0.197}{*}\log(\text{price})$$

$$- \underset{(4.47)}{0.131}{*}(\text{price}(-1)) - \underset{(4.47)}{0.055}{*}\log(\text{price}(-2))$$

R bar sq=0.999 DW=2.29

Demand for Oil

$$\log(\text{Oil Demand}) = \underset{(16.9)}{4.565} + \underset{(18.6)}{0.561}*\log(\text{GNP}) - \underset{(2.33)}{0.275}*\log(\text{price})$$

$$- \underset{(2.33)}{0.183}*\log(\text{price}(-1)) - \underset{(2.33)}{0.091}*\log(\text{price}(-2))$$

R bar sq=0.990 DW=2.64

Demand for Natural Gas

$$\log(\text{Gas Demand}) = \underset{(21.7)}{4.310} + \underset{(16.1)}{0.358}*\log(\text{GNP}) - \underset{(0.61)}{0.041}*\log(\text{price})$$

$$- \underset{(0.61)}{0.027}*\log(\text{price}(-1)) - \underset{(0.61)}{0.014}*\log(\text{price}(-2))$$

R bar sq=0.983 DW=1.84

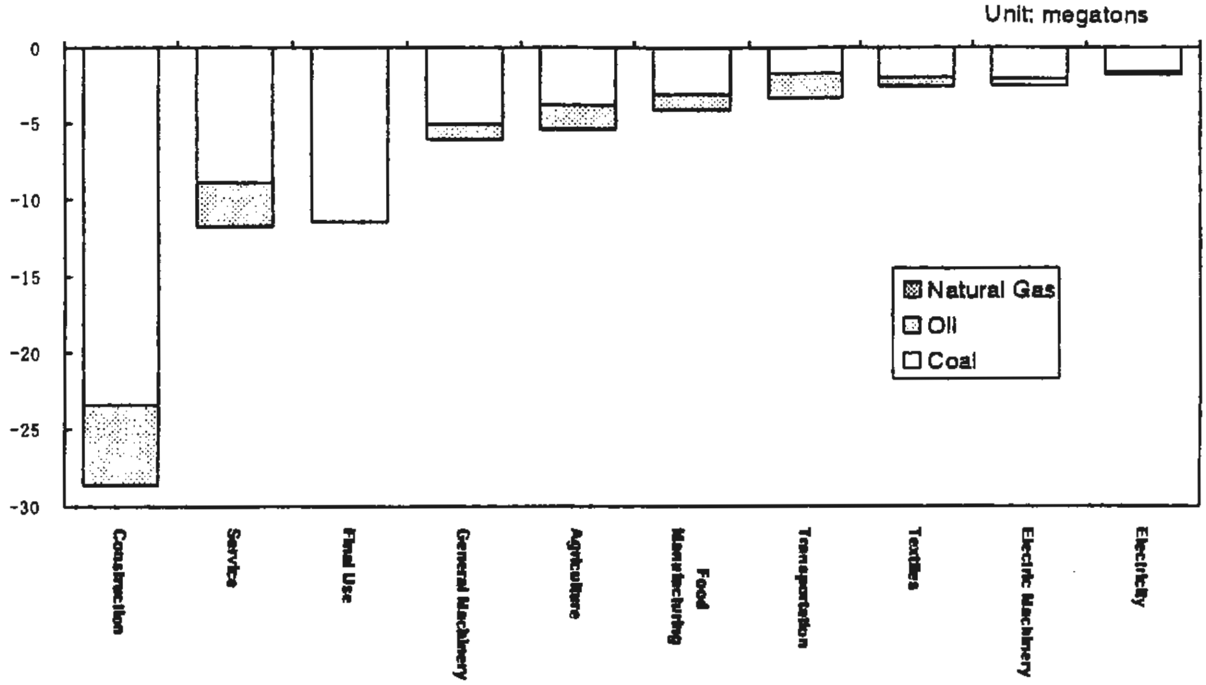
Table 2 − 8 Summary Table of Demand Functions for Fossil Energy in China

Energy	Income Elasticity (t value)	Price Elasticity (t value)
Coal	0.665 (78.31)	-0.383 (4.47)
Oil	0.561 (18.58)	-0.550 (2.33)
Natural Gas	0.358 (16.10)	-0.082 (0.61)

Although this type of demand function might be contradictory with the framework of input output analysis (i.e. constant input coefficients), we assume that input coefficients change corresponding price changes by picking up only the price terms of these demand functions. Concretely speaking, in case of 10% (specific) energy tax to a certain type of energy is introduced, we assume that the energy input coefficients for all sectors will decrease by the corresponding (estimated) price elasticity* 10%.

Figure 2-6 shows the reduction of CO_2 emissions in the case an energy tax is imposed to all of three types of energy by 10%. Total CO_2 emissions will be reduced by 87 megatons, which is a reduction

Figure 2 – 6 : Effect of 10% Energy Tax (Reduction of CO_2 Emissions) in China

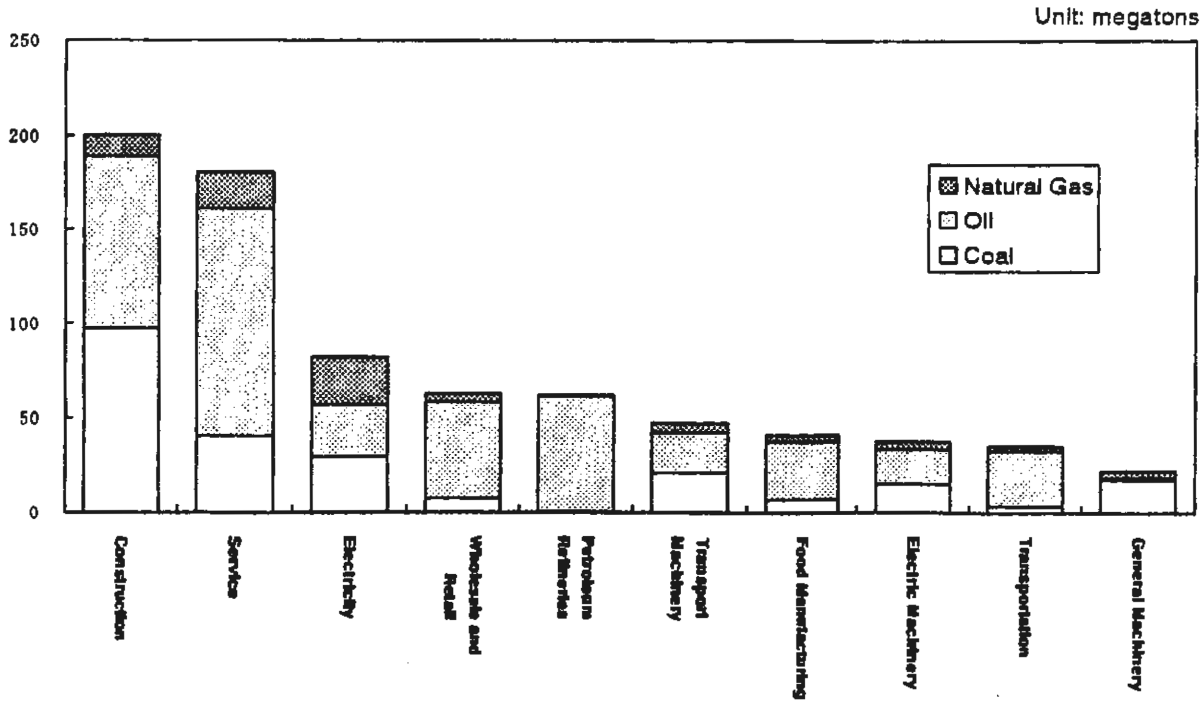


of approximately 4% of the total 2,100 mega tons.

[Japan's CO_2 Emissions in 1987]

Figure 2-7 shows CO_2 emissions of the Japanese economy in 1987.

Figure 2 – 7 : Japan's CO_2 Emissions (by sector) in 1987



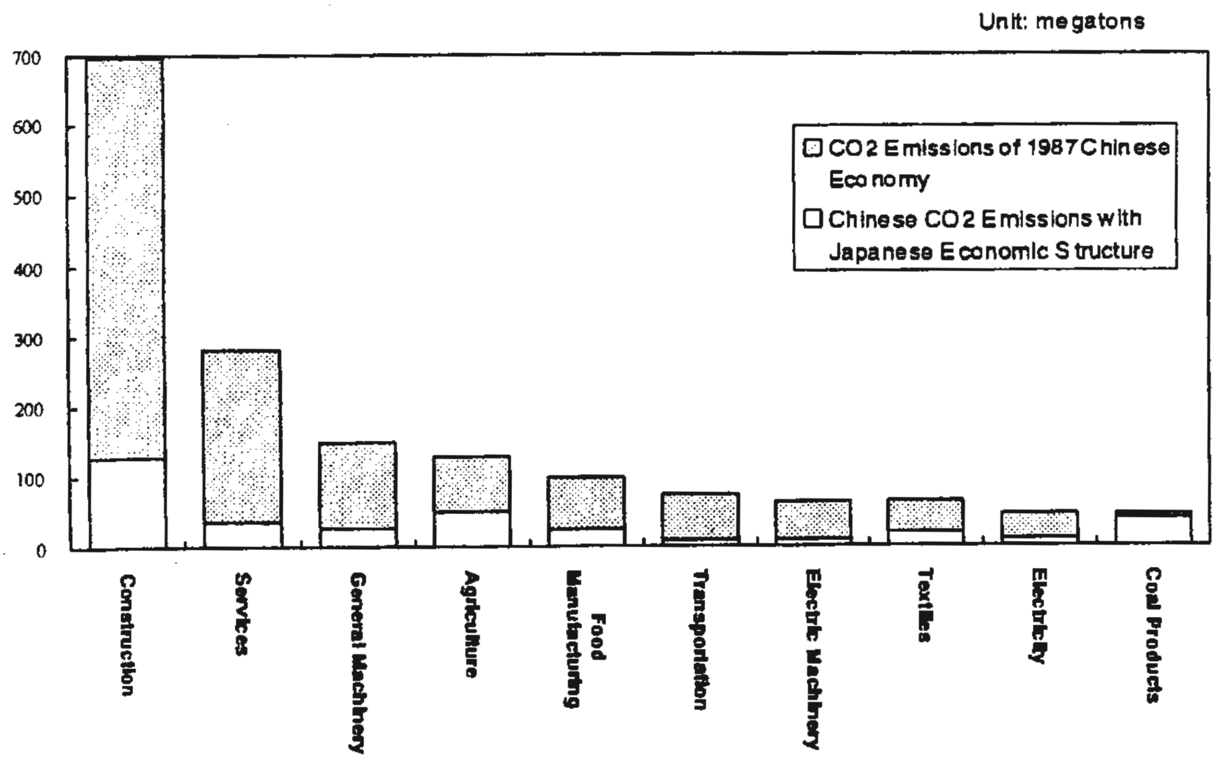
As we saw in the former section, the total Japanese emission is 850 mega tons, which are less than half of Chinese case. *Construction* sector also is the sector with the largest CO_2 emissions, explaining a quarter of the total emissions. *Services* sector, *Electricity* and *Wholesale and Retail* follow Construction.

[China's CO_2 Emission with Japanese Economic Structure]

It is sometimes said that CO_2 emissions would be reduced by technological assistance from developed countries. We here try to estimate how much of CO_2 would be reduced if Chinese Input-Output structure is almost same as that of Japan even though Chinese demand structure is unchanged. The results can be evaluated as the possible most extreme case of "technological assistance from Japan".

Figure 2-8 shows the actual CO_2 emissions and the quantity reduced by using the "new technology". Total emissions through new technology

Figure 2 – 8 : China's CO_2 Emission with Japan's Economic Structure



would be 670 mega tons, which are less than those of Japan. This is probably because weights of energy intensive sectors in China are smaller than those in Japan. The emission reduction effect is large in such sectors as Constructions, Services and Agriculture.

3. Concluding Remarks

The Input-Output approach is useful to evaluate environmental load of an economy in terms of industrial structure. This note showed a method of measuring CO_2 emission by industry and applied it to Chinese and Japanese economy in 1987. Obtained results can be summarized as follows:

(1) China's CO_2 emissions in 1987 are approximately 2,000 mega tons, more than the three quarters of which is explained by Coal consumption. Japanese counterparts in the same year are approximately 850 mega tons, sixty percent of which is attributed to Oil consumption.

(2) Activities of *Construction* sector explains a third of the China's total CO_2 emissions in China followed by *Final consumption* and *Service* sector, 15 percent respectively. Also in Japan, *Construction* sector accounts for a quarter of the Japan's total CO_2 emissions followed by *Service, Electricity* and *Wholesale and Retail.*

(3) If a 10% of carbon tax is introduced in China's economy for the following three fossil energies: Coal, Oil and Natural Gas, 4% of CO_2 emissions would be reduced because of input substitution.

(4) If the whole of China's input-output structure is replaced by Japan's counterpart, which can be considered as the most extreme case of technical transfer from Japan to China, the total CO_2 emission form China's economic activities would be 670 megatons, which

is less than those of Japan.

Acknowledgment

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