Why do CO_2 Emissions Differ in China, Japan and Korea?

Hyun-Sik Chung

Oxford Institute for Energy Studies

EV25

1998

Why do CO_2 Emissions Differ in China, Japan and Korea?

Hyun-Sik Chung

Oxford Institute for Energy Studies
EV 25

1998

The contents of this paper are the
author's sole responsibility.
They do not necessarily represent the views of the
Oxford Institute for Energy Studies
or any of its Members.

ISBN 1 901795 03 9

CONTENTS

1. INTRODUCTION

Climate change arising from the emission of greenhouse gases is one of the most pressing global environmental problems. Scientific evidence suggests that a continued increase in the atmospheric concentration of carbon dioxide (CO_2) and other greenhouse gases resultant from human activities will lead to global climatic change with a potentially catastrophic impact. In response to growing international concern, the UN Framework Convention on Climate Change (UNFCCC) was adopted on 9 May 1992 in New York and opened for signature during the UN Conference on Environment and Development (UNCED) held in June 1992 in Rio de Janeiro. The Convention is specifically directed at stabilising greenhouse gas concentrations in the atmosphere at a level intended to reduce any further endangering of climate systems. The Convention entered into force on 21 March 1994, with provisions that impose common but differentiated responsibilities upon signatory countries in reducing the harmful gases. It requires OECD member countries to reduce their emission levels to the 1990 level by 2000, while less strict provisions apply to developing countries.

At the Berlin Conference of March 1995, the representatives of signatory nations concurred that the proposed level of reductions by advanced countries to the 1990 level by year 2000 would not be sufficient to help solve the worsening greenhouse effect. Therefore, they adopted the Berlin Mandate to be applied to years 2000 to 2020 by which the target level of further reductions was stipulated. The Second Assessment Report of the Inter-governmental Panel on Climate Change (IPCC), published in June 1996, reconfirmed the potential risk of damage from climate change due to the continued concentration of greenhouse gases in the atmosphere. It strongly suggested that further action beyond the so-called 'no regrets' measures is needed. Under the circumstances, the Kyoto Convention in early December 1997 brought about further concrete steps to reduce emissions. According to the Kyoto protocol, the advanced countries will reduce their greenhouse gas emissions by 8–10 per cent below their 1990 levels by the period 2008–2012. Further details are expected to be formalised in the next convention to be held in Buenos Aires in early November 1998.

The most important single element of greenhouse gas emissions is CO_2 arising from energy use, particularly from the burning of fossil fuels. Country reports submitted in 1995 in accordance with the provisions of the UN Convention showed that 41 per cent of CO_2 emissions from the use of fossil fuel came from fifteen advanced countries led by the USA, Japan, Germany, and the UK. In view of the importance of CO_2 emissions from fossil fuel burning, a greater improvement in fuel efficiency and structural change in production are needed in those industrialised countries as well as in developing countries in order to stabilise the level of CO_2 emissions.

As a new member of the OECD, South Korea is also required to reduce its share of CO_2 emissions to the 1990 level by 2000. In order to achieve reduced emissions, Korea will have to improve fuel use efficiency, which may necessitate changing its industrial structure and consumption patterns. Climate change due to greenhouse gases is a global environmental problem and cannot of course be tackled by a single nation in isolation. It requires international coordination and cooperation including joint regional efforts among neighbouring countries. With this in mind, this study estimates and compares South Korea's CO_2 emissions with those of her two close neighbours, China and Japan. This comparison is important because these two countries are both significant contributors to global CO_2 emissions, and are in close economic relations with each other.

We begin by calculating the current level of CO_2 emissions in South Korea, Japan and China, and then compare these levels among the three countries, broken down by industrial sector and by the composite factors that create differences in the emission profiles. These differences may be analysed under two broad categories – economic size and economic structure. The latter can be further attributed to different fuel efficiency, production techniques, consumption patterns, and so forth. In this analysis, we primarily focus on CO_2 emissions from the burning of fossil fuels,[1] and the sources of emissions are analysed in depth by decomposing industries into polluting sectors. This study uses the well-known input-output model modified for environmental study. It attempts to decompose the sources of CO_2 emissions by the methods popularised by Chenery, Syrquin and others and recently by Proops et al (1993) and Common et al (1993). Their analyses have been applied mostly to the CO_2 emissions of Western countries, while here we concentrate on East Asia. A series of research projects on environmental problems in Japan and China was conducted by the Keio Economic Observatory team, including the work of Hayami, Kiji, and Wong (1995). They applied environmental input-output models to Japanese and Chinese air pollution, but unlike the current analysis they did not employ decomposition techniques as part of the analysis.

---

[1] A relatively minor but still important source of CO_2 emissions is limestone processing in the cement industry, but these emissions are from the direct burning of fossil fuels.

In Section 2, the basic environmental input-output model is introduced. Section 3 explains data collection and data processing. Section 4 shows the results of our estimation and comparison among the three countries, including emission intensities by sectors and by component factors. A summary and some concluding remarks are contained in Section 5.

2. AN ENVIRONMENTAL INPUT-OUTPUT MODEL

Energy use is the major source of CO_2 emissions, through fossil fuel burning in the industrial and final consumption sectors. In our environmental input-output model, CO_2 emissions from fossil fuels are thus divided into these two sectors. Industrial emissions are generated by burning fossil fuels in production processes while those from consumption sectors come from the use of fuel in households, primarily for heating, cooking, and transportation. Industrial emissions arise from the burning of fossil fuels for intermediate use[2] in the production process, and are induced by final demand. In the household sector, emissions are due to the final use of fuel, as it is not being used as input to other production processes. In the model presented below, industrial emissions are divided further into direct and indirect emissions. The former refers to the initial induction from final demand and the latter to the subsequent inter-industry transactions.

Emissions arising from final demand are mainly caused by domestic sector use of fossil fuels in the household sector for domestic heating and personal transportation, and to a lesser degree by governmental use of fuel. Total CO_2 emissions are defined in equation (1) as the sum of emissions from the intermediate and final demand sectors.[3]

$$C = C_{ind} + C_{con} \tag{1}$$

where C is total CO_2 emissions, C_{ind} is CO_2 emissions from fossil fuels burning in industry, and C_{con} is emissions from consumption sectors. Industry emissions are calculated from equation (2).

$$C_{ind} = e'K\,(I-A)^{-1}y \tag{2}$$

---

[2] Fuel use in industrial sectors can arise either by direct burning or by use as raw materials. As far as CO_2 emissions are concerned, the former is important and considered as 'the' fuel use. Fuel use is to produce goods and services to be delivered to the final demand. The fuel so-used in industrial sectors is called intermediate input. Thus, the industries are often called intermediate demand sectors, and the households to which goods and services are delivered for final use are often called final demand sectors.

[3] CO_2 is also generated from various non-fossil fuel sources, such as biological metabolism (for example, human breath), burning firewood (including natural forest fires), occasional volcanic eruptions, and natural and artificial chemical dissolution (for example, decaying process involving organic substances, and manufacturing production involving the chemical processing of materials containing carbon molecular, notably from limestone ($CaCO_3$) processing in the cement industry.) We assume that all these sources of CO_2 emissions from non-fossil fuel are of secondary importance and will not analyse them explicitly in our analysis, even though their magnitude may be non-negligible.

where e' is a (1x15) row vector of CO_2 emission coefficients for the various types of fossil fuels, the element e_f (f=1, . . . ,15) being the amount of CO_2 emitted per unit of type *f* fossil fuel burnt; K is a (15x45) matrix of industrial energy input coefficients, the element k_{fj} (f=1, . . . ,15; j=1, . . . ,45) being the amount of type f fossil fuel (measured in tonnes of oil equivalent units) burned for unit production in the *j*th industry; $(I-A)^{-1}$ is the inverse of the Leontief matrix (I-A); and u is a (45x1) vector which shows the composition of final demand, with its elements u_{jj} denoting the share of sector j in the sum total of final demand, y.

Similarly, emissions in the consumption sectors are given by equation (3):

$$C_{con} = e'H'Zuy \tag{3}$$

where H' is a (15x45) matrix of energy use coefficients in final demand and is composed of private and government consumption. The elements of matrix H', h'_{fj} (f=1, . . . ,15; j=1, . . . ,45) are energy use coefficients of final demand, and show the amount of *f* type fossil fuel (in tonnes of oil equivalent) per unit of consumption in the *j*th consumption sector. Z is a (45x45) diagonal matrix, whose diagonal element, z_{ij}(i=j=1, . . . ,45) is private consumption and government spending in the *j*th sector as share of its sectoral final demand, uy.

The fossil fuels used by private and government sectors in the final demand are directly related to CO_2 emissions within the country, whereas those corresponding to export, capital formation and change in inventories are not. Therefore, it is necessary to exclude exports, capital formation and change in inventories in calculating a measure for CO_2 emissions from final demand sectors. In other words, vector Zuy in equation (3) is the final demand comprised of private and government spending only.[4] Substituting equations (2) and (3) into equation (1), we then obtain the following expression for total CO_2 emissions:

$$C = e'K(I-A)^{-1}\, y + e'H'Zuy \tag{4}$$

We describe e'K in equation (4) as the direct emission intensity (DEI) in intermediate demand, i.e. CO_2 emissions induced by unit production of goods and services delivered to final

[4] Matrix Z is not present in expression (2) because the final demand inclusive of exports and investments is relevant in determining emissions of CO_2 in the intermediate demand sectors.

demand. Similarly $e'K(A+A^2 + A^3 + ...)$ is the indirect emission intensity (IEI) of intermediate demand, i.e. the emissions by various industries through subsequent inter-industry transactions.[5] Thus, the expression $e'K(I-A)^{-1}$ is the total emission intensity (TEI) in intermediate demand, i.e. the sum of DEI and IEI. Likewise, the final expression in equation (4) can be called DEI in the final demand. There is no IEI in the final demand, because there are no indirect pollution effects in consumption.

The basic equation (4) thus calculates the total CO_2 emissions from both intermediate and final demand. Similarly, the difference in emissions between countries can also be divided into two parts. This paper analyses the source of differences in industrial emissions because they comprise more than 80 per cent of all emissions in the countries concerned. This means that only the first term on the right hand side of equation (4) is decomposed into various composite factors to compare the difference in CO_2 emissions. A detailed analysis of emissions from consumption sectors is left for further research.

The difference in industrial emissions between countries is decomposed into various factors as follows. For a given year, let dC stand for the difference in industrial CO_2 emissions between any two countries. Similarly, let d(e'K) stand for the difference in the DEI between two countries, $d(I-A)^1$ for the difference in input technology (i.e. direct and indirect input requirements), du for the difference in the composition of final demand, and dy for the difference in size of the economy measured in GDP. Applying the technique of 'decomposition by differencing',[6] we arrive at equation (5).

$$dC = d(e'K)\,(I-A)^{-1}y + e'Kd(I-A)^{1}\,uy + e'K(I-A)^{-1}u\,y + e'K(I-A)^{-1}dy \qquad (5)$$

This expression holds approximately with all the variables measured as the mean of two observations except the differences. Thus, $(I-A)^{-1}$ in equation (5) is a simple arithmetic mean of two Leontief matrices, $\{(I-A)^{-1}\}_1$ and $\{(I-A)^{-1}\}_2$, u is the simple mean of of u_1 and u_2, and similarly y is the simple mean of y_1 and y_2 and so on, where the subscripts 1 and 2 represent

[5] By tracing back along the decomposed elements of 'indirect' industrial pollution intensity for a large, disaggregated input-output model, it will be possible to analyse the so-called life cycle assessment (LCA) of pollution for a product or a group of products.

[6] For an explanation of this method of decomposition, see Proops *et alia* (1993) Chapter 3.

different countries. The application of equation (5) will then attribute the differences in emissions between two countries (dC) to the following four sources:

(i) differences in fuel efficiency (d (e'K) $(I-A)^{-1}$uy)

(ii) differences in input technology (e'Kd$(I-A)^{-1}$uy)

(iii) differences in the composition of the final demand (e'K$(I-A)^{-1}$u y)

(iv) differences in the size of the economy (e'K$(I-A)^{-1}$dy)

3. THE ESTIMATION OF TOTAL CO_2 EMISSIONS

Most of the data used in our calculations are based on input-output tables.[7] South Korean data come from the Bank of South Korea, the Office of Statistics, Ministry of Finance and Economics (formerly the Economic Planning Board), and the Korea Energy Economic Institute. Japanese and Chinese data come mainly from the Research Institute of International Trade and Industry, the Ministry of International Trade and Industries (MITI) and the Research Institute of Industry, Keio University (1995).[8] The Korean data have been modified to make them compatible with the Japanese and Chinese counterparts in the following ways:

(1) The basic 413x423 South Korean input-output table (1990) was aggregated into 45 sectors.

(2) The 'Materials allied-to-energy table' was compiled from the 'table of domestic products and imports by sector and commodity' and the 'transactions table at producers' and imports' prices'.[9] It shows energy-related raw materials for production and fuels for combustion.

(3) Based on the 'materials allied-to-energy table' and 'report on energy census' (1990), an 'energy (fuels) use table' was constructed for 'fuels used up in combustion' in the intermediate and final demand. It was compiled by subtracting from 'materials allied-to-energy' those materials exclusively used, not as fuels but as 'intermediate inputs' in the production processes. Here, 'energy use' is classified according to its users and fuel types.

(4) Finally, the unit of energy use was standardised into calorific terms by converting 'energy (fuel) use' from various physical units into a common unit of tons of oil

---

[7] The author wishes to thank Dr. Hae Chun Lee at Keio University, Japan for providing him with the necessary data.

[8] Chinese data were taken partly from 'Japanese and Chinese input-output tables in 45 sectors with its energy-use and emission coefficients matrices for 1985' published by Keio Economic Observatory, Keio University, Japan in 1995. (See Keio Economic Observatory, Keio University, '1985 inter-industry transaction table for analysing energy use and air pollution') Another statistical source is 'International Input-Output Table for South Korea-Japan (1990)' published by Institute of Developing Economies, Tokyo, Japan in 1996.

[9] Here 'materials allied-to-energy' are energy-related materials selected from the transactions table at producers' and import prices. They are deflated into physical units by prices obtained from the 'table of domestic products and imports' which is given both in quantity and value terms. However, they are not the same as energy-related materials actually consumed (that is, fuels used up in combustion), because some of them are inputs into other industries, as is the case with bituminous coal which was processed into coal tar, coal gas, cokes, etc. and crude oil refined into various liquid fuels and petrochemical components.

equivalent (toe). From the calorie table, 'calorie coefficients' were calculated for various fuel types and industrial sectors. From calorie coefficients (i.e. the amount of fuel burnt in tonnes of oil equivalent per unit of output) and 'CO_2 emission factors'[10] (i.e. CO_2 emissions per tonne of oil equivalent) for various fuel types, CO_2 emission intensity can be calculated to show CO_2 emission per unit of output in each sector.

The results of our calculations are shown in Table 1. They demonstrate that South Korea's total CO_2 emissions in 1990 were 320 million tons (measured in terms of the molecular mass of CO_2),[11] and those of Japan in 1990 and China in 1987 were 1,002[12] and 2258 million tons of CO_2 respectively. Thus South Korea's total CO_2 emissions were about 36 per cent of Japan's and 14 per cent of China's. Our figures for Japan and China are lower than those derived by Hayami, Kiji and Wang (1995), who produce a figure of 2376 million tons for China in 1987 and 987 million tons for Japan in 1985. Different estimation will give different results, particularly for China, partly due to the different prices applied to fossil fuels used. In the case of our figures, we suspect that the omission of CO_2 emissions from limestone processing in the cement industry is the major source of difference.

Table 1: Total CO_2 Emissions in China (1987), Japan (1990) and Korea (1990). Million Tonnes of CO_2.

Country	*Intermediate Demand*	*Per cent*	*Final Demand*	*Per cent*	*Total*
China	1895	83.9	363	16.1	2258
Japan	875	87.4	127	12.6	1002
Korea	269	84.0	52	16.0	320

[10] 'CO_2 emission factors' by fuel type are obtained from conversion tables based on engineering data.

[11] Given the amount of CO_2 emitted from burning fossil fuels in units of tons in molecular mass of carbon (tons-carbon), conversion into units of tons of molecular mass of CO_2 is achieved by multiplying with a conversion factor, (44/12). This factor comes from the molecular mass of carbon dioxide, 12+16x2, and that of carbon, i.e. 12. We use tons of CO_2 as our unit of measurement to avoid unnecessary confusion.

[12] According to an OECD report, Japan's total CO_2 emissions were 1,146 million tons-CO_2 in 1993. Our other estimate for Japan's CO_2 emissions in 1985 was 893 million tons-CO_2. Thus, our estimate for 1990 is in between the two figures. See EMEP/CORINAIR, *Atmospheric Emission Inventory Guidebook*, 1996, vol. 1: 43.

Appendix 2 shows the break-down of total emissions into sectoral components for China, Japan and South Korea according to the industrial classification listed in Appendix 1. The classification and nomenclatures shown in Appendix 1 apply to all the following tables and graphs.

Sectoral CO_2 emissions for the three countries are shown in Figures 1a to 1c. From Figure 1a it can be seen that railways (sector 32), machinery (25), agriculture and forestry (1), and food products (7), stand out as prominent polluters among Chinese industrial sectors. Among Japanese industrial sectors as shown in Figure 1b, construction (31), electric and heat supply (13), education, health and science (42), food products (7), commerce (39), and machinery (25) are the most polluting sectors, while in South Korea, as shown in Figure 1c, the major polluters are construction (31), commerce (39), public and non-profit service (41), education, health, and science (42), and food products (7). The rank order of polluting sectors varies in the three countries except in the case of construction in South Korea and Japan.

When Figures 1a to 1c are collated into one graph in terms of percentiles, we have Figure 1d. A similar graph for sectoral GDP in terms of percentiles is also shown in Figure 1e below for comparison. According to Figure 1d, railway transport (32) in China and construction (31) in Japan and South Korea are prominent polluters. However, construction is not as polluting as other sectors in terms of emissions per unit of output, because its emissions in percentiles are much smaller than its GDP in percentiles (see Figure 1e). The reason why construction shows up as the most polluting sector in the two countries is because of its relatively large magnitude as a component of final demand.

On the other hand, the reason why CO_2 emissions are highest in Chinese railway transport is partly because of its large magnitude in the final demand (see Figure 1e), and partly because of its high emission intensity. The magnitude of the Chinese railway transport sector is almost the same as agriculture and forestry, the biggest in China, and amounts to 243 billion Chinese yuan. Next to agriculture and forestry and railway transport, the other large sector in China is food production. The shares of the three sectors in GDP are 18.4 per cent, 18.4 per cent, and 10 per cent respectively, while their respective shares in total CO_2 emissions are 7.1 per cent, 31.3 per cent, and 5.9 per cent. This means that agriculture and forestry and food production are emitting considerably less per unit of output than railway transport. As another example, China's electricity and heat supply (13) delivered into final demand is relatively small (0.28 per cent), because it is used up mostly in intermediate demand. However, CO_2 emissions induced by this small portion of electricity and heat supply delivered to the final demand is much higher in percentage terms (3.19 per cent), revealing the high emission intensity shown in Figure 1d.

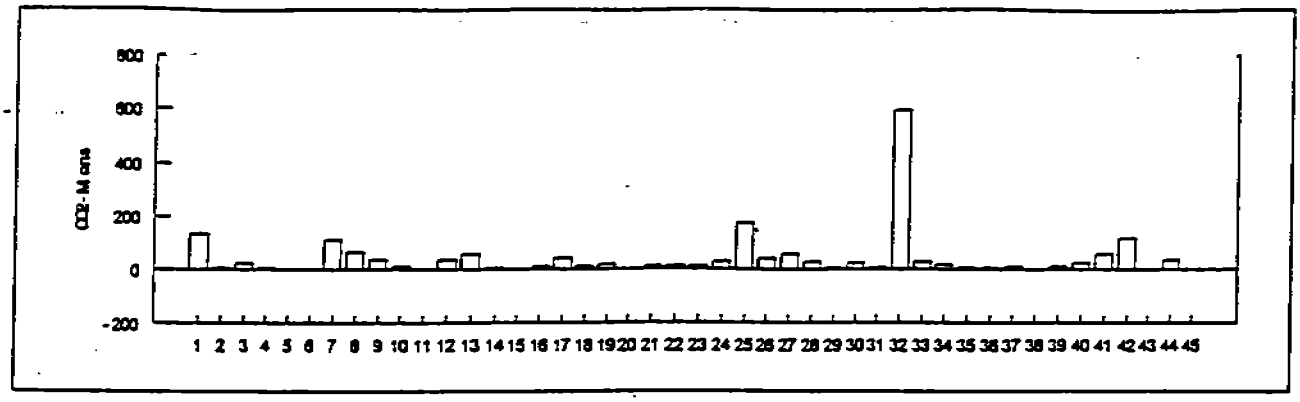

Figure 1a : China's CO_2 Emissions by Sector. 1987. Million Tonnes of CO_2.

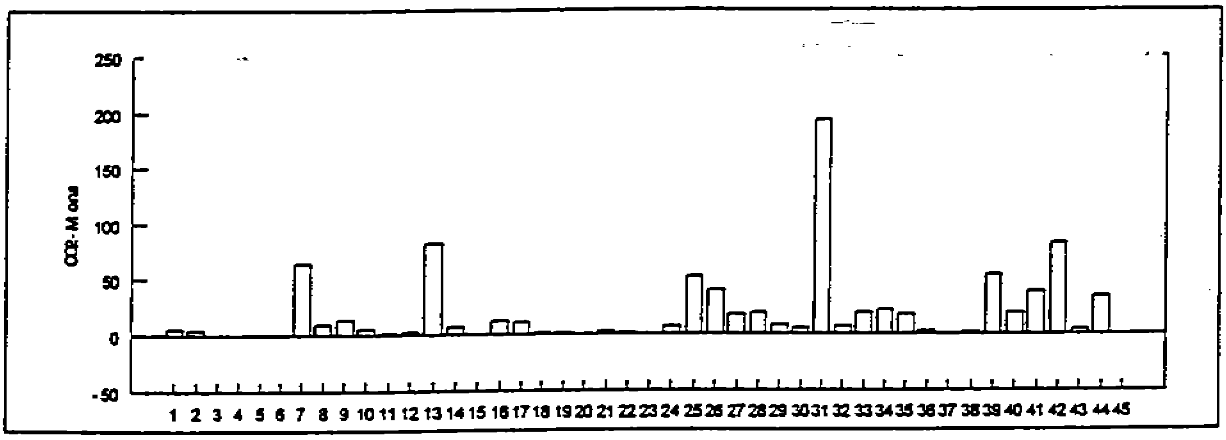

Figure 1b : Japan's CO_2 Emissions by Sector. 1990. Million Tonnes of CO_2.

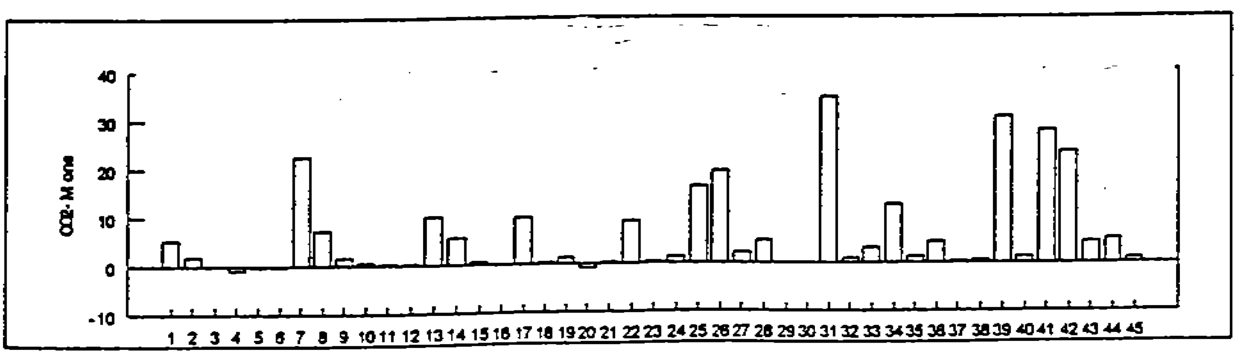

Figure 1c : South Korea's CO_2 Emissions by Sector. 1990. Million Tonnes of CO_2.

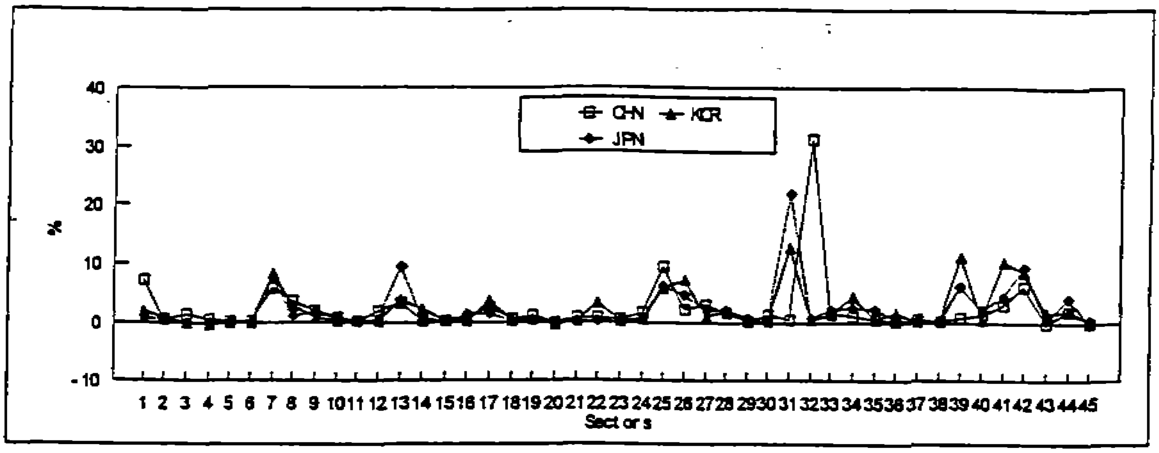

Figure 1d : Relative Sectoral CO_2 Emissions. Per cent.

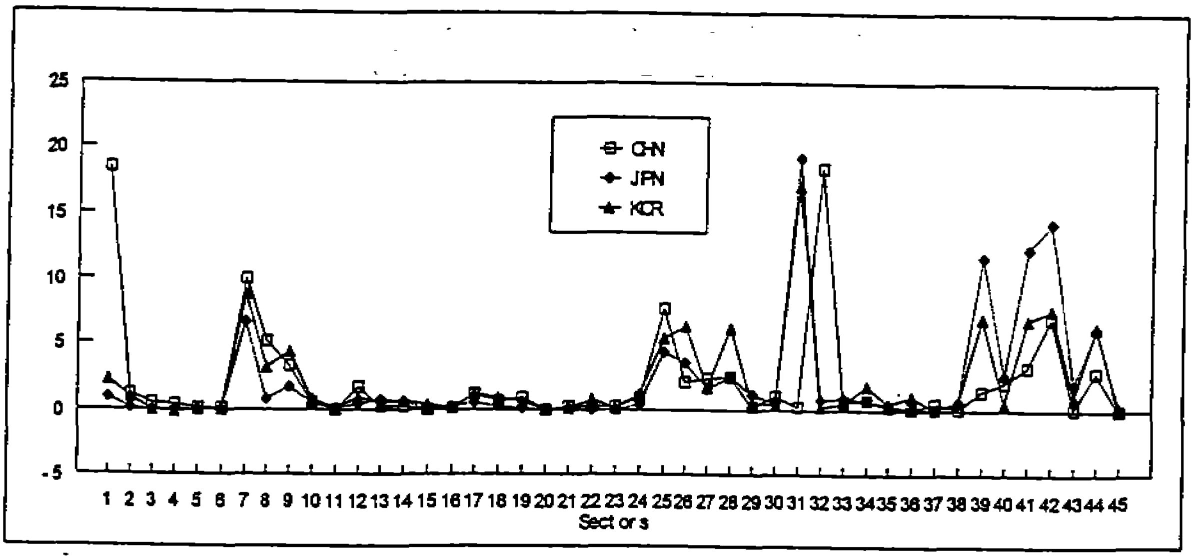

Figure 1e : Relative Sectoral Output. Per cent.

In general, the variance in sectoral emissions within a country will be due to various factors such as emission factors, energy efficiency, production technique, and the size of individual sectors. For example, any particular industry can be a big polluter because of its large size even if it has a relatively low emission factor or a high level of energy efficiency. To correct for this, in subsequent comparisons of CO_2 emissions among industries we rely on emission intensities, ie. the level of emissions per unit of sectoral GDP. Appendix 3 summarises sectoral CO_2 emission intensities by industry, where the first column under each country name shows direct emission intensities (DEI), the second column shows indirect emission intensities (IEI), and the third column shows the total emission intensities (TEI).[13] Figures 2a to 2c below show sectoral TEI for the three countries. TEI here is defined as the amount of additional CO_2 emitted, with all the inter-industry interactions considered, when final demand of any particular sector increases by one million Korean won.[14]

In China, as shown in Figure 2a, the most polluting sector in terms of TEI is electricity and heat supply (13) followed by cement (20) and iron and steel (22). The same is true for Japan and South Korea as shown in Figure 2b and Figure 2c. The Chinese railway industry (32), which was shown to be the most polluting in terms of the absolute amount, is relatively less polluting in terms of TEI. Its TEI of 1.2193 ranks only thirteenth among 45 sectors.[15]

We now look into the details of TEI as shown in Figure 2c and in Appendix 3, taking South Korea as an example. Similar to the other countries, electricity and heat supply (13) is the most polluting industry in South Korea in terms of TEI followed by cement (20), iron and steel (22), petroleum refineries (14), chemical products (17), petroleum and natural gas (4), road passenger transport (33) and road freight transport (34). Comparing direct with indirect intensities among three big polluting sectors, DEI is greater than IEI in the electric and heat supply and cement sectors, while the reverse is true in the iron and steel industry, which reflects the greater inter-industrial effects of the latter sector. Among those with DEI higher than IEI are major polluting sectors in terms of TEI, such as electricity and heat supply (13), cement (20), transport (air, road, rail and water) (32–36), ceramic, stone and clay (21), and coal product (15). Except these industries, the majority shows IEI higher than DEI. This means that, even though an industry may not pollute directly, it can do so indirectly by inducing others. This demonstrates the importance of inter-industry linkages in industrial CO_2 emissions.

---

[13] Total emission intensity (TEI) is defined as the sum of direct and indirect emissions of CO_2 in tons of molecular mass of CO_2 in producing a unit of sectoral GDP.

[14] About US$1,400 at the official exchange rate in 1990.

[15] Its TEI is ranked thirteenth after electricity and heat supply (8.118), town gas (3.740), cement (3.206), coal products (2.616), ceramic, stone and clay (2.537), iron and steel (2.189), coal mining (1.947), non-ferrous metal (1.678), road freight transport (1.526), chemical product (1.445), paper and pulp (1.265), and metal production (1.227).

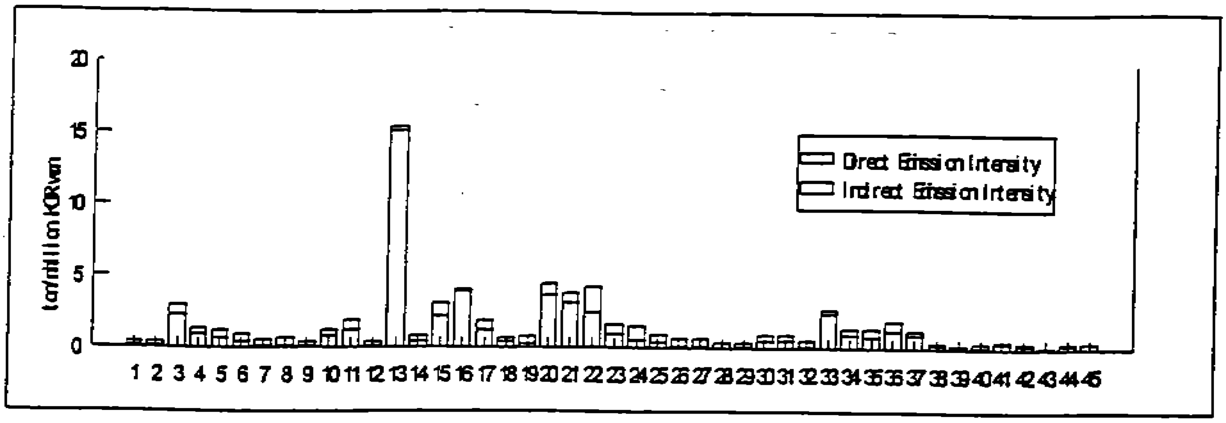

Figure 2a : China's Total Emission Intensities. 1987.

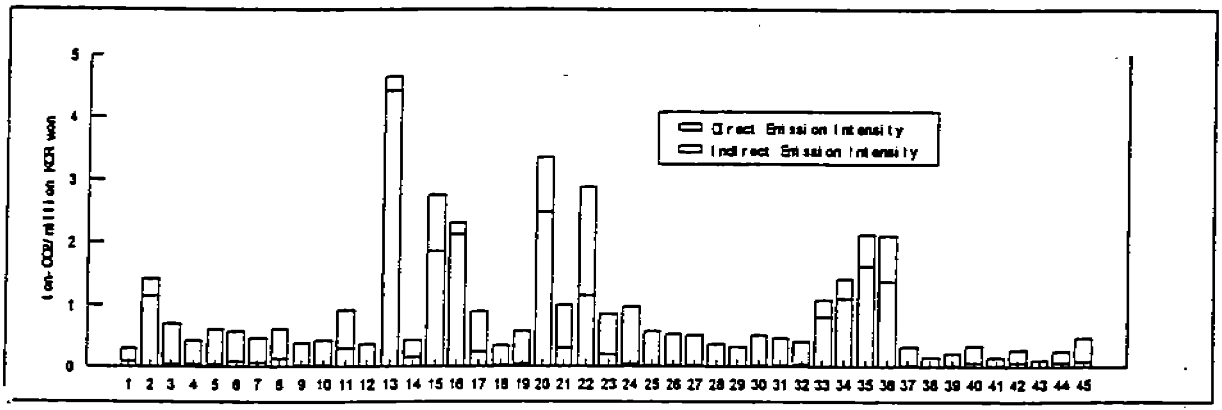

Figure 2b : Japan's Total Emission Intensities. 1990.

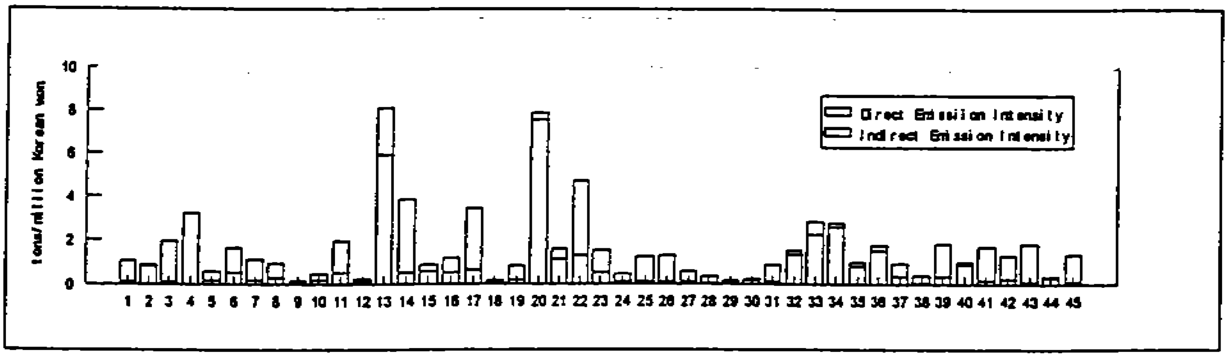

Figure 2c : South Korea's Total Emission Intensities. 1990.

It was shown above that the three major industrial emitters in terms of TEI in the East Asian countries are electric and heat supply (13), cement (20), and iron and steel (22). In all three countries, DEI is greater than IEI in the electricity and heat supply (13) and cement (20) sectors. This implies that both sectors use more fossil fuels per unit of output than others. In Japan and China, the nine biggest polluting sectors all have DEIs greater than IEIs with the sole exception of the Japanese iron and steel sector (22). Figure 2d shows DEIs for China and Japan as relative to those for South Korea. It shows that South Korea's DEI structure is similar to that of Japan, while it varies widely for China across sectors. It also shows that Japan's DEIs are generally lower than those of the other two countries, reflecting its high energy use efficiency. The reverse holds in the case of China.

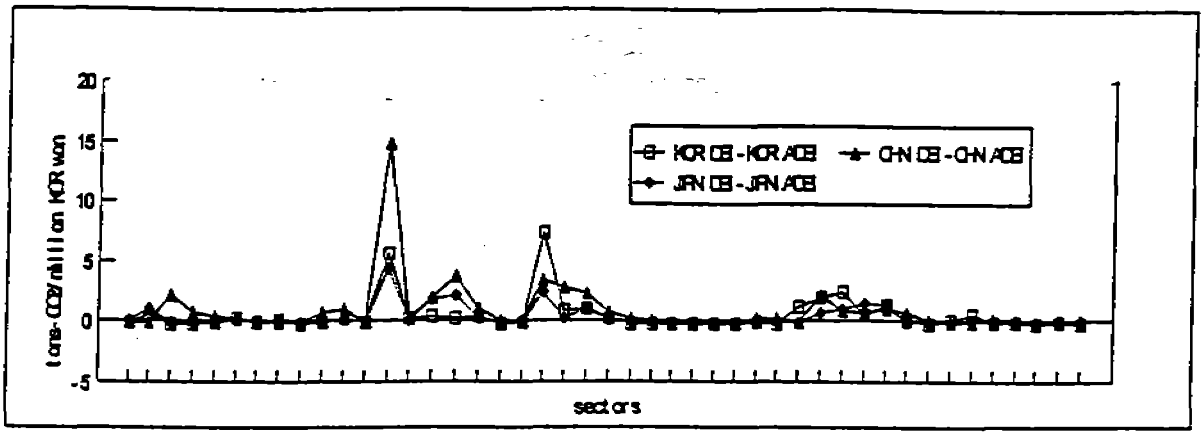

Figure 2d : Relative Direct Emission Intensities.

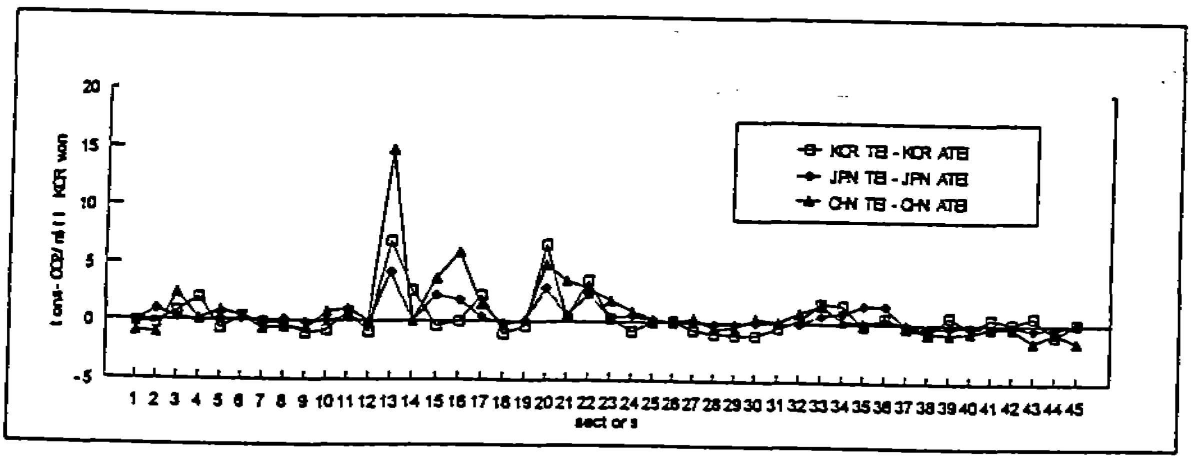

Figure 2e : Truncated Total Emission Intensities.

Figure 2e shows TEIs for the three countries put together. Here the truncated TEIs for each country are defined as deviations of sectoral TEIs from its aggregate total emission intensity (ATEI), where ATEI is simply the total CO_2 emissions of a country divided by its GDP. Hence ATEI is a measure of overall CO_2 emission intensity. When a sector's truncated TEI is greater (smaller) than zero, it means that it is polluting more (less) than the overall average of the country, in producing a given value of output. In particular, electricity and heat supply (13), cement (20) and iron and steel (23) are the most polluting sectors in terms of TEI in all three countries. Beyond these three sectors, the industrial ranking in terms of TEI (or DEI) varies widely among countries due to different emission factors and industrial structure, the latter in turn reflecting the differing composition of the final demand. One policy implication that can be drawn from ranking the sectors in terms of TEI is that a sector with high TEI can be targeted as a candidate for reducing emissions because the social cost in terms of lost output (in value terms) will be lower, if such reduction in emissions entails output loss. Similarly, ATEI can be used as an indicator to identify which country needs to cut emissions more or less within any 'joint-implementation' scheme.

The size of the industry, the emission factors, and energy efficiency together determine TEI, but determinants in explaining difference in total CO_2 emissions among countries will include additional factors such as input technique and size of the economy. These composite factors explaining differences in emissions are discussed in the next section.

4. A COMPARISON OF EMISSION DIFFERENCES AMONG COUNTRIES

Since most CO_2 emissions come from intermediate demand, our comparative analysis is based on those sectors. As was shown in Section 2, the source of differences in CO_2 emissions between two countries can be decomposed into its composite factors. Table 2 summarises the results of the decomposition based on equation (5) in Section 2. It attributes the source of differences in emissions between two countries to the size of the economy, composition of final demand, input techniques, and energy use techniques. As shown in Table 2, of the 1940 million tonnes of

Table 2 : Decomposition of Differences in CO_2 Emissions between Countries

Decomposition by	*Comparison*	*Difference (Million tonnes)*
Size of Economy	China–South Korea	2180
	Japan–South Korea	2710
	China–Japan	-756
Composition of Final Demand	China–South Korea	83
	Japan–South Korea	-0.8
	China–Japan	58
Input Techniques	China–South Korea	-219
	Japan–South Korea	-491
	China–Japan	30
Energy Use Techniques	China–South Korea	-449
	Japan–South Korea	-1740
	China–Japan	1730
Total	China–South Korea	1600
	Japan–South Korea	48
	China–Japan	1010

difference in industrial emissions between China and South Korea, 1600 or about 82 per cent can be explained by these four factors. If we divide the source of pollution into two broad categories – economic growth and change in economic structure – the size of economy factor will belong to the former and the other three to the latter. The table shows that China would have emitted 2180 million tonnes more than South Korea due to its bigger size, if it were not for the structural factors which reduced them by 580. Likewise, most of the difference in CO_2 emissions between Japan and South Korea can be attributed to the difference in the size of economy, or the difference in the level of production and consumption.[16]

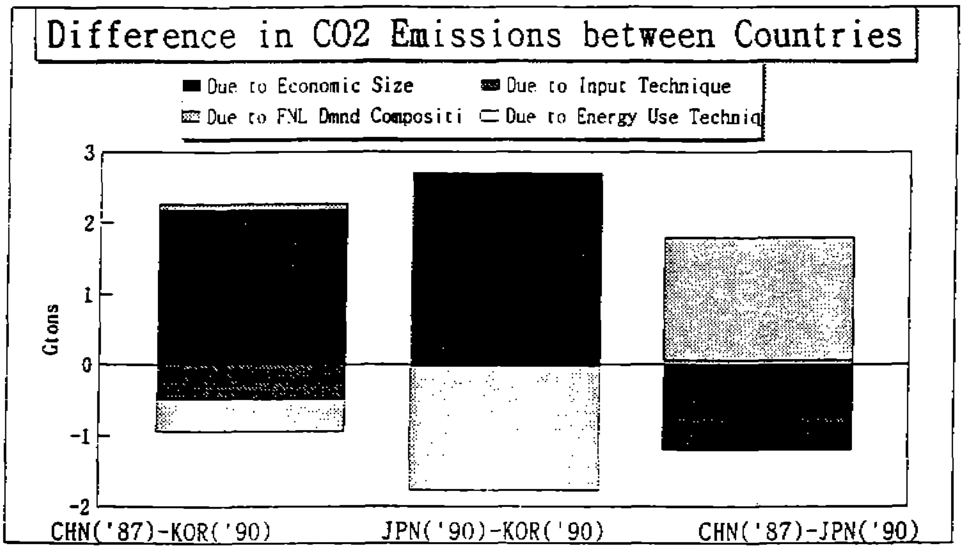

Figure 3 : Differences in CO_2 Emissions between Countries

In other words, that there is more pollution in Japan than South Korea in absolute terms is because there is more production and more consumption (or higher GDP) in the former. This does not mean that the level of emissions will be the same if two countries produce the same amount of output. Even at the same level of GDP, countries can differ in total CO_2 emissions due to the difference in economic structure involving the composition of final demand, input techniques, energy use techniques, and so on. As Figure 3 demonstrates, China emits more than Japan, in spite of its smaller economy, mostly because of the inefficient energy use techniques. Japan emits less total CO_2 than China, in spite of the bigger economy and energy-intensive input techniques, thanks to efficient energy use. Japan emits more than South Korea, but much less than might be expected, due to its more efficient energy use techniques. This is shown by a negative block in the middle part of Figure 3. This implies that South Korea can reduce emissions by this amount by attaining the Japanese level of energy use efficiency. Compared to South Korea, China emits more total CO_2 mostly due to the greater size of its economy, but it would have emitted much more, without input and energy use techniques favourable to lower

[16] This may be another counter-example to the Common's hypothesis that asserts that the cause of industrial pollution lies in structural change rather than in economic growth.

emissions. This is shown in Figure 3 as the two negative shaded blocks in the left-hand part of the figure.

Taken together, it can be inferred that South Korea is the most polluting among the three countries as far as energy use techniques are concerned, because while both South Korea and China are more polluting than Japan, South Korea is even more so than China. Figure 3 shows that if it were not for the difference in economic size, South Korea would be the most polluting, China in the middle and Japan the least. The structural factors contributing to the greater emissions in South Korea are attributed to input and the energy-intensive nature of its industries – a result of rapid industrialisation with an emphasis on heavy and chemical industries. Sudden structural change from labour-intensive to input-energy-intensive production processes and lack of incentives for firms to save energy due to low energy prices may have contributed to this result. Similar reasons can be ascribed to Chinese energy inefficiency. According to Lio (1996), China's thermal efficiency in power generation is more than 20 per cent less than in industrialised countries, while transmission and distribution losses are often more than twice as great. Lio notes that China's energy prices are, on average, one-third of supply costs and half those in industrialised countries.

We can also provide a comparison of emission intensities in the three countries by averaging sectoral TEIs into an aggregate total emission intensity (ATEI), where the ATEI is a weighted mean of sectoral TEIs using sectoral GDPs as weights. Table 3 includes some basic economic indicators and a summary of Appendix 3, showing TEIs in intermediate and final demand sectors and the ATEI. Here, TEI in the intermediate demand is sectoral TEIs averaged across intermediate demand sectors. It is a weighted average of sectoral emissions produced in delivering US$1,000 worth of goods and services to the final demand. Similarly, TEI in final demand is a weighted average of DEIs in direct combustion of fossil fuels in households and government sectors. ATEI is a sum of the TEIs in intermediate and final demand.

It can be seen from Table 3 that Japanese emissions are the least in terms of ATEI, South Korea is in the middle, and China produces the most. It suggests that as a country develops it may emit less in terms of its ATEI. Figure 4 shows the per capita emissions and ATEIs of three countries under two alternative exchange rates. It reveals a positive relation between per capita emissions and per capita GNP (as a proxy for the level of economic development), and a negative one with ATEI. ATEI plotted against per capita GNP is shown here as two negatively-sloped curves, where one is steeper than the other. This is due to the higher Chinese ATEI under the official rate (A) than under the PPP rate (B),[17] which means that ATEI will depend considerably on the rates of exchange rate chosen. This is particularly important in analyses involving China, whose foreign exchange market remains under tight governmental control.[18]

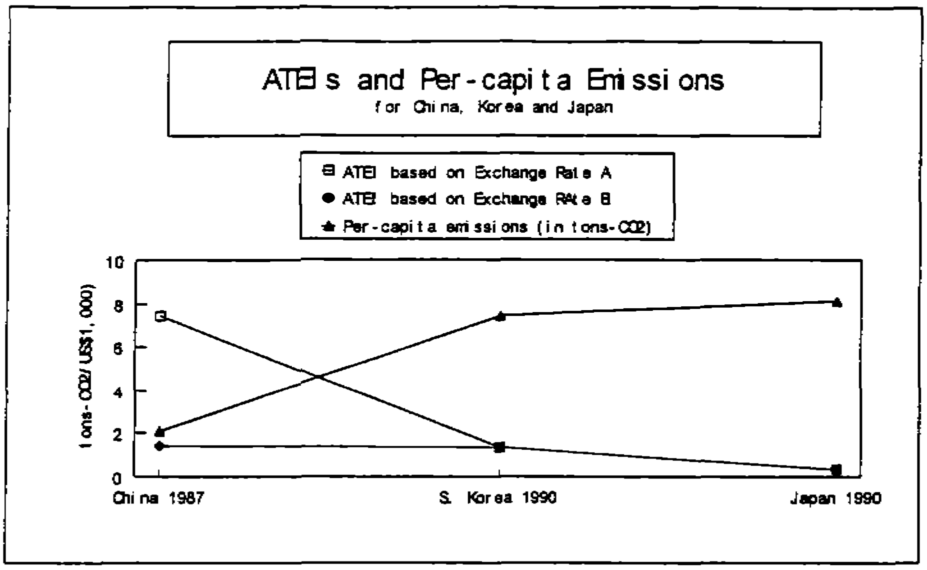

Figure 4 : Aggregate Emission Intensities and Per capita Emission Intensities

Selden and Song (1994) tested the hypothesis that there is an inverted U curve relation between per capita emissions of greenhouse gases and per capita GDP, similar to Kuznets' inverted U curve of income inequality. They implied that even though the per capita pollution of a developing country might increase at the earlier stage of its economic development, it would eventually decrease at its mature stage of development. Our evidence does not support the

[17] We adopt the exchange rate between Chinese yuan and Japanese yen as estimated by the Institute of Industrial Research, Keio University (1995). They used 1 Chinese yuan = 200 Japanese yen as an equilibrium market exchange rate to correct the undervalued Chinese official exchange rate, which was about 1 Chinese yuan = 40 Japanese yen in 1990. Zhang and Folmer (1995:18) assert that China's GDP in 1987 calculated on the basis of an equilibrium exchange rate (e.g. on the basis of purchasing power parity (PPP)) may reach between 7 and 8 times as much as those calculated directly on the basis of the official exchange rate. If so, the exchange rate that we used (i.e. 1 Chinese yuan = 200 Japanese yen) may still undervalue China's GDP. Considering the chronic current account imbalance between Japan and South Korea favouring the former, the official exchange rate between the Japanese yen and South Korean won (which was about 1 yen = 5 won in 1989/90) could also be adjusted to reflect some equilibrium exchange rate, but it was not. Thus we applied 1 Chinese yuan = 200 Japanese yen = 1,000 South Korean won as some kind of PPP exchange rate (B) among the three currencies to calculate Appendix 3. Official exchange rate (A) is approximately 1 Chinese yuan = 40 Japanese yen = 200 South Korean won, which is based on IFS (1992) for China 1987, Japan 1990 and South Korea 1990.

[18] It is not a simple matter to determine which equilibrium exchange rate is the proper one to apply in order to compare Chinese GNP with that of another country. The exchange rates suggested above are simply two representative alternatives.

inverted U curve hypothesis as it stands, but instead suggests a negative relationship between ATEI and per capita GDP.

We would suggest that ATEI is a more useful indicator in defining any meaningful relationship between degrees of pollution and the stages of economic development. The inverted U curve hypothesis suggests that in the long run per capita pollution in the world will decline as per capita income rises. It is however a matter of conjecture as to whether the less developed countries will ever reach that stage of economic development, and converge into the high income block in the course of their economic development, with the result that their per capita pollution will decline. Nevertheless, it might then be too late if global environmental deterioration has already reached a certain critical point.

Therefore, perhaps a more practical approach is to ensure that a country reduces its ATEI in the course of economic development. To compare pollution among countries in terms of pollution per capita or pollution per unit area will be important also when the purpose is to compare them from an equity point of view or to assess their assimilative capacities. For example, the absolute level of Chinese CO_2 emissions is quite large – amounting to about 10 per cent of the world total – yet its per capita emission is well below the world average because of its large population. Likewise, China's CO_2 emissions per square kilometre are among the world's lowest. While these emission indicators will stay low for a considerable time, China's TEI and ATEI measures will respond more elastically to the absolute and per capita level of income.

However, our concern in this analysis is not with environmental issues involving equity or absorptive capacity, but rather with the economic causes of emissions and their implications for greenhouse gas reduction. For this purpose, emission intensities (i.e. emission per unit of production or consumption for different sectors and countries) serve as a more useful measure. Using ATEI rather than per capita emissions, it is inferred that, rather than the inverted U curve, there is an inverse relation between ATEI and per capita income, and there is a positive relationship between per capita emission and per capita income. The major proviso to the conclusion is that the sample we have used is not large enough to produce definitive evidence.[19]

[19] One might argue that a time series analysis is necessary to test the inverted U curve for pollution. For a country like China and for most less developed countries, however, their levels of per capita income have been very low during the period for which necessary data are available. For this reason, it will be difficult for any meaningful relationship to be drawn between per capita pollution and per capita income, which the inverted U hypothesis of pollution purports to establish. According to Selden and Song (1994) who surveyed and empirically tested Kuznets' inverted U hypothesis for pollution, the turning points for the inverted U curve mostly exceed US$8,000. This

What is proposed here is, however, that there is a potentially useful inverse relation between ATEI and per capita income rather than the inverted U curve, especially for policy purposes. A country with a high ATEI can lower its total CO_2 emissions at lower cost than its neighbour with low ATEI, especially in its high TEI sectors. Given its large CO_2 emissions,

Table 3 : Per capita Emissions and Aggregate Total Emission Intensities (ATEI) for China (1987), South Korea (1990), and Japan (1990)

	China		*South Korea*		*Japan*	
Population (millions)	1089.61		42.87		123.54	
CO_2 emissions (million tonnes)	2258		320		1002	
Per capita CO_2 emissions (tonnes)	2.072		7.744		8.111	
	(A)	(B)	(A)	(B)	(A)	(B)
GNP (billion US$)	304	1596	242	242	2960	3027
GNP per capita (US$)	279	1465	5652	5652	23965	24502
TEI/ID (tonnes CO_2/US$1000)	6241	1.187	1.110	1.110	0.296	0.289
TEI/FD (tonnes CO_2/US$1000)	1.196	0.227	0.215	0.215	0.043	0.042
ATEI (tonnes CO_2/US$1000)	7437	1415	1.321	1.321	0.338	0.331

Notes: TEI/ID stands for the total emission intensity in intermediate demand. It is the average total (direct and indirect) CO_2 emissions in industrial sectors produced in delivering US$1,000 worth of goods and services to the final demand. Likewise, TEI/FD stands for total emission intensity in the final demand. It is the average direct CO_2 emissions in the households and government sectors. ATEI is the sum of TEI/ID and TEI/FD.

Column A = based on 1990 official exchange rates among three countries quoted in IFS (1992).

Column B = based on exchange rate between Chinese yuan and Japanese yen estimated in KUIID (1995) .

TEI/ID, TEI/FD, and ATEI in the table are recalculated from original figures measured in tons-CO_2/million Korean won using appropriate exchange rates. The original figures corresponding to the B columns are as follows: (in ton-CO_2/million Korean won)

	China	*S. Korea*	*Japan*
TEI/ID	1.4346	1.1587	0.4096
TEI/FD	0.2750	0.2218	0.0592
ATEI	1.7096	1.3805	0.4688

not only in absolute terms but also in terms of ATEI, China provides a challenging case for a regional joint effort towards the global greenhouse gas problem, A similar logic can be applied

---

means that potentially big polluting countries like China and India will be ever increasing their absolute and per capita levels of emissions for a long time, perhaps too long for the global greenhouse gases problem, until they can reach the threshold level of income.

to identify an industry to reduce emissions at lower cost. For this, TEI will serve as a good indicator by which to identify those sectors where improvements in energy use efficiency are most needed.

The inverted U curve hypothesis for pollution postulates that there is a positive relationship between per capita pollution and per capita output during the earlier stages of economic development and a negative relation in the later stages. This relationship also assumes that the income elasticity for environmental quality is positive beyond a certain level of economic development, and that production techniques and the composition of output and consumption also change favourably for the environment beyond the same threshold level of development.[20] We postulate instead that pollution is positively related to output in the typical shape of a total product curve (or in a concave functional form). This is a typical production technology applied to the pollution problem. Assuming the familiar total product curve between pollution and output, an inverted U curve relation is derived between ATEI (average pollution) and output (or per capita output), while a negative one between ATEI and output is implied under strictly concave production technology. Thus, either an inverted U curve or a negative relation can emerge between ATEI (which is nothing but average pollution in production) and the level of output (or per capita output) depending on the assumed production technology.[21] While only a study of three countries is presented here, the case is nevertheless strong given that these countries together contribute about 15 per cent of global greenhouse gas emissions.

It is argued above that ATEI is a more useful measure of pollution than per capita pollution from the environmental policy point of view, because ATEI can be used as an indicator to identify a target country or industry where pollution can be reduced at lower cost. Similarly from an efficiency point of view, it is also more meaningful to regulate pollution in terms of ATEI. For a country such as China, which contributes about 10 per cent of global CO_2 emissions, its per capita emission is still well below the world average, even though its ATEI is very high. In other words, while the level of Chinese pollution may be very high and become a major threat to the global climate change problem, yet its per capita pollution remains very low.

---

[20] See Seldon and Song (1994).

[21] Under strictly concave production technology, the inverse relation between ATEI and the level of output can be associated with a positive relation between per capita pollution and per capita output as shown in Figure 4, because the latter merely reflects the relation between total pollution and total output.

5. SUMMARY AND CONCLUSIONS

In this study we have estimated the total CO_2 emissions of three East Asian countries, which together represent more than 15 per cent of total global emissions (by some estimates amounting to 22 billion tons of CO_2 annually).[22] Being a large part of the problem, China, Japan and South Korea will almost certainly have to be a large part of any solution. South Korea, for example, as a new member of the OECD and as a signatory party to the UN Climate Change Convention, will be expected to play its part in actions towards greenhouse gas abatement.

Based on our analysis, we suggest three possible economic adjustments that South Korea can make. At the present time, economic growth seems to be something that the government can not sacrifice for the sake of the environment. But for the sake of sustainable development, it will be necessary for South Korea to readjust its economic structure, particularly its energy-intensive methods of production, because as shown in Section 3, it was evident that many areas need to be improved in terms of energy use efficiency – particularly in the industrial sectors. This suggests that the South Korean economy must restructure its industries in such a way as to economise on the use of fossil fuels, perhaps by catching up with the energy use techniques of an advanced country such as Japan. This will mean cleaner production technology and improvements in input technology. These measures may all require a restructuring of economic incentive systems. In particular, it will be necessary to readjust South Korea's energy price so that it reflects the pollution cost. The relatively low energy efficiency in South Korea strongly suggests that its energy price has not been set at the proper level. A carbon tax could be a possible solution to the problem. Our present analysis, however, will not enable us to justify such a policy prescription. Indeed, more analysis will be needed before we can draw further policy implications.

It is clear from our analysis that, even though China's per capita emissions are low, its total CO_2 emissions and ATEI are very high, if we compare them with those of Japan and South Korea. The negative relationship between ATEI and per capita GNP suggested in the previous section implies, however, that China's high ATEI during the initial stage of industrial

[22] This figure is given by Morita et al. 'An Energy-Technology Model for Forecasting CO_2 Emission in Japan,' National Institute for Environmental Studies, 1994: 3–4, which summarises CO_2 emission forecasts by 23 world-leading forecasting models. The emission figures forecast for 2030 range from a 50 per cent to a 300 per cent increase from the present level.

development may be temporary. As it enters into the semi-industrialised stage, China's ATEI will become lower and eventually subside as it develops further to the advanced stage.

The proposed negative relationship between ATEI and per capita GNP is a different argument from the so-called inverted U curve relation between per capita pollution and per capita income. We have argued that pollution per unit of production or consumption is a more useful measure from an environmental policy point of view. It was suggested that ATEI can be used as an indicator to identify a country to be targeted for emission reduction, in the sense that those with a high ATEI can lower total CO_2 emissions at lower cost than others with low ATEI, especially in their high TEI sectors. This is an area for the so-called 'joint implementation programme'. Similarly, TEI is a good emission indicator by which to identify those sectors where improvement in energy use efficiency is most needed. This argument requires empirical evidence to make it more concrete, and needs further investigation.

Appendix 1

Industry Classification and Nomenclature

1 Agriculture and Forestry
2 Fishery
3 Coal Mining
4 Petroleum and Natural Gas
5 Metal Ore Mining
6 Non Ferrous Metal Mining
7 Food Product
8 Textile
9 Sewing and Leather
10 Wood and Furniture
11 Paper and Pulp
12 Printing and Education
13 Electric and Heat Supply
14 Petroleum Refineries
15 Coal Product, Cokes and Coaltar
16 Town Gas
17 Chemical Products
18 Medical Products
19 Rubber and Plastic Products
20 Cement
21 Ceramic, Stone and Clay
22 Iron and Steel
23 Non-ferrous Metal
24 Metal Products
25 Machinery
26 Transport Machinery
27 Electrical Machinery
28 Electronics Communication Equipment
29 Testing, Measuring Machine
30 Other Machinery
31 Construction
32 Railway
33 Road Freight Transport
34 Road Passengers Transport
35 Air Transport
36 Water Transport
37 Other Transport Industry
38 Communication
39 Commerce
40 Restaurant, Eating Place
41 Public, Non-Profit Service
42 Education, Health, Science
43 Finance and Insurance
44 Administrative Organization
45 Others

Appendix 2

Total Emission Intensities, Sectoral GDP, and Sectoral CO2 Emissions: China(1987), Japan(1990) and Korea(1990)

	Chinese CO2 by sectors 1987			Japanese CO2 by sectors 1990			Korea's CO2 by sectors 1990		
	TEI	sec Y	sect CO2	TEI	sec Y	sect CO2	TEI	sec Y	sect CO2
1	0.5512	2.43E+008	1.34E+008	0.3027	2.02E+007	6.12E+006	1.0353	5.18E+006	5.36E+006
2	0.4810	1.62E+007	7.80E+006	1.4178	3.15E+006	4.46E+006	0.9043	2.09E+006	1.89E+006
3	3.8934	5.94E+006	2.31E+007	0.6946	-1.24E+005	-8.63E+004	1.9785	-1.67E+004	-3.30E+004
4	1.6843	4.51E+006	7.59E+006	0.4183	4.42E+005	1.85E+005	3.2588	-2.72E+005	-8.86E+005
5	2.4010	9.73E+005	2.34E+006	0.6156	-1.09E+005	-6.70E+004	0.5696	-1.18E+005	-6.71E+004
6	1.8550	1.16E+006	2.15E+006	0.5705	-2.91E+004	-1.66E+004	1.6485	-8.17E+004	-1.35E+005
7	0.8441	1.32E+008	1.12E+008	0.4558	1.41E+008	6.45E+007	1.0977	2.04E+007	2.24E+007
8	0.9822	6.76E+007	6.64E+007	0.6096	1.63E+007	9.96E+006	0.9472	7.49E+006	7.10E+006
9	0.7627	4.36E+007	3.33E+007	0.3779	3.62E+007	1.37E+007	0.1574	1.03E+007	1.62E+006
10	2.2396	6.14E+006	1.38E+007	0.4309	1.17E+007	5.04E+006	0.4456	1.74E+006	7.76E+005
11	2.5305	5.56E+005	1.41E+006	0.8970	1.29E+006	1.16E+006	1.9554	1.92E+005	3.75E+005
12	1.5140	2.20E+007	3.32E+007	0.3570	8.27E+006	2.95E+006	0.2445	1.97E+006	4.81E+005
13	16.2367	3.72E+006	6.04E+007	4.6652	1.77E+007	8.25E+007	8.1343	1.23E+006	1.00E+007
14	1.4964	2.97E+006	4.44E+006	0.4304	1.46E+007	6.27E+006	3.9217	1.48E+006	5.81E+006
15	5.2324	1.48E+005	7.74E+005	2.7545	1.03E+005	2.84E+005	0.8796	7.48E+005	6.58E+005
16	7.4804	1.60E+006	1.20E+007	2.3033	5.26E+006	1.21E+007	1.1926	1.28E+005	1.53E+005
17	2.8890	1.52E+007	4.38E+007	0.8936	1.18E+007	1.06E+007	3.4924	2.76E+006	9.63E+006
18	1.2897	8.57E+006	1.11E+007	0.3436	4.05E+006	1.39E+006	0.1763	2.14E+006	3.78E+005
19	1.6185	1.16E+007	1.88E+007	0.5770	3.31E+006	1.91E+006	0.8401	1.61E+006	1.35E+006
20	6.4116	-2.85E+005	-1.83E+006	3.3644	1.51E+004	5.08E+004	7.8979	-1.19E+005	-9.43E+005
21	5.0732	2.43E+006	1.23E+007	0.9896	2.29E+006	2.26E+006	1.6247	2.98E+005	4.84E+005
22	4.3785	2.95E+006	1.29E+007	2.8696	4.34E+005	1.25E+006	4.7467	1.84E+006	8.75E+006
23	3.3571	2.98E+006	1.00E+007	0.8486	4.21E+005	3.57E+005	1.5198	2.27E+005	3.45E+005
24	2.4550	1.26E+007	3.09E+007	0.9778	7.24E+006	7.08E+006	0.4311	2.74E+006	1.18E+006
25	1.7651	1.01E+008	1.78E+008	0.5651	9.27E+007	5.24E+007	1.2508	1.27E+007	1.58E+007
26	1.4884	2.74E+007	4.08E+007	0.5309	7.60E+007	4.03E+007	1.2845	1.48E+007	1.90E+007
27	1.8405	3.12E+007	5.73E+007	0.5120	3.42E+007	1.75E+007	0.5979	4.04E+006	2.42E+006
28	0.9670	3.25E+007	3.15E+007	0.3691	5.30E+007	1.96E+007	0.3283	1.45E+007	4.78E+006
29	1.1564	3.42E+006	3.96E+006	0.3188	2.41E+007	7.67E+006	0.1802	1.30E+006	2.34E+005
30	1.8547	1.29E+007	2.40E+007	0.5139	9.60E+006	4.93E+006	0.2025	7.34E+005	1.49E+005
31	1.6827	3.69E+006	6.21E+006	0.4683	4.12E+008	1.93E+008	0.8683	3.97E+007	3.45E+007
32	2.4386	2.43E+008	5.93E+008	0.4039	1.72E+007	6.96E+006	1.5207	5.75E+005	8.74E+005
33	3.0523	9.28E+006	2.83E+007	1.0656	1.87E+007	1.99E+007	2.8762	1.11E+006	3.20E+006
34	1.7730	9.54E+006	1.69E+007	1.4056	1.55E+007	2.17E+007	2.8106	4.30E+006	1.21E+007
35	1.6261	3.84E+006	6.24E+006	2.1155	8.69E+006	1.84E+007	1.0202	1.17E+006	1.20E+006
36	1.8727	1.56E+006	2.92E+006	2.0969	1.60E+006	3.36E+006	1.7753	2.55E+006	4.52E+006
37	1.4842	6.83E+006	1.01E+007	0.3159	2.11E+006	6.65E+005	0.9171	3.55E+005	3.25E+005
38	0.8149	2.01E+006	1.64E+006	0.1410	1.44E+007	2.03E+006	0.3802	1.48E+006	5.61E+005
39	0.7411	1.95E+007	1.44E+007	0.2148	2.49E+008	5.35E+007	1.8778	1.61E+007	3.03E+007
40	0.7910	2.81E+007	2.23E+007	0.3388	5.58E+007	1.89E+007	1.0136	1.20E+006	1.22E+006
41	1.2758	4.42E+007	5.64E+007	0.1471	2.65E+008	3.90E+007	1.7094	1.60E+007	2.73E+007
42	1.2445	9.32E+007	1.16E+008	0.2698	3.06E+008	8.24E+007	1.3062	1.77E+007	2.31E+007
43	0.0915	1.02E+006	9.31E+004	0.1065	4.30E+007	4.57E+006	1.8790	2.43E+006	4.57E+006
44	0.8603	3.79E+007	3.26E+007	0.2611	1.33E+008	3.48E+007	0.3463	1.47E+007	5.08E+006
45	0.0000	0.00E+000	0.00E+000	0.4667	1.30E+005	6.05E+004	1.3662	6.82E+005	9.32E+005
total	106.4780	1.32E+009	1.89E+009	40.7927	2.14E+009	8.75E+008	74.6115	2.32E+008	2.69E+008

note: Total emission intensities(TEI) are in toe/million Korean won, sectoral GDP(Y) is in million Korean won, and sectoral CO2 emission is in CO2-tons.

Appendix 3

Intermediate Demand Sectors' CO2 Emission Intensities: Korea, Japan, and China (tons/million Korean won)

	Korea 1990			Japan 1990			China 1987		
sectors	DEI	IEI	TEI	DEI	IEI	TEI	DEI	IEI	TEI
1	0.106	0.929	1.035	0.083	0.219	0.303	0.150	0.401	0.551
2	0.836	0.068	0.904	1.140	0.278	1.418	0.170	0.311	0.481
3	0.100	1.879	1.979	0.044	0.651	0.695	2.347	1.547	3.893
4	0.000	3.259	3.259	0.052	0.366	0.418	0.987	0.697	1.684
5	0.140	0.430	0.570	0.052	0.564	0.616	0.686	1.715	2.401
6	0.506	1.142	1.648	0.082	0.488	0.571	0.461	1.394	1.855
7	0.144	0.954	1.098	0.072	0.384	0.456	0.204	0.640	0.844
8	0.304	0.643	0.947	0.133	0.476	0.610	0.215	0.767	0.982
9	0.082	0.076	0.157	0.035	0.343	0.378	0.102	0.661	0.763
10	0.161	0.284	0.446	0.021	0.410	0.431	0.877	1.362	2.240
11	0.488	1.467	1.955	0.290	0.607	0.897	1.244	1.287	2.531
12	0.113	0.132	0.245	0.013	0.344	0.357	0.116	1.398	1.514
13	5.962	2.172	8.134	4.429	0.236	4.665	15.137	1.099	16.237
14	0.547	3.375	3.922	0.143	0.288	0.430	0.484	1.013	1.496
15	0.601	0.279	0.880	1.840	0.914	2.755	2.184	3.049	5.232
16	0.531	0.662	1.193	2.121	0.182	2.303	3.916	3.564	7.480
17	0.657	2.835	3.492	0.238	0.656	0.894	1.223	1.666	2.889
18	0.081	0.095	0.176	0.017	0.326	0.344	0.363	0.927	1.290
19	0.167	0.673	0.840	0.053	0.524	0.577	0.337	1.281	1.618
20	7.593	0.305	7.898	2.479	0.886	3.364	3.598	2.814	6.412
21	1.097	0.528	1.625	0.294	0.696	0.990	3.063	2.010	5.073
22	1.292	3.455	4.747	1.137	1.732	2.870	2.476	1.902	4.378
23	0.513	1.006	1.520	0.196	0.653	0.849	0.945	2.412	3.357
24	0.093	0.338	0.431	0.040	0.938	0.978	0.501	1.954	2.455
25	0.069	1.182	1.251	0.022	0.543	0.565	0.369	1.397	1.765
26	0.068	1.216	1.285	0.021	0.510	0.531	0.187	1.301	1.488
27	0.080	0.518	0.598	0.021	0.491	0.512	0.218	1.623	1.841
28	0.029	0.299	0.328	0.013	0.356	0.369	0.067	0.900	0.967
29	0.052	0.128	0.180	0.012	0.307	0.319	0.147	1.009	1.156
30	0.161	0.041	0.203	0.032	0.482	0.514	0.519	1.336	1.855
31	0.106	0.763	0.868	0.031	0.437	0.468	0.496	1.187	1.683
32	1.381	0.140	1.521	0.045	0.359	0.404	0.146	2.293	2.439
33	2.252	0.624	2.876	0.791	0.275	1.066	2.441	0.611	3.052
34	2.667	0.144	2.811	1.092	0.313	1.406	1.030	0.743	1.773
35	0.827	0.193	1.020	1.609	0.507	2.116	0.894	0.732	1.626
36	1.536	0.239	1.775	1.371	0.726	2.097	1.216	0.657	1.873
37	0.361	0.557	0.917	0.033	0.283	0.316	0.901	0.584	1.484
38	0.057	0.323	0.380	0.013	0.128	0.141	0.296	0.519	0.815
39	0.347	1.530	1.878	0.036	0.179	0.215	0.178	0.563	0.741
40	0.869	0.144	1.014	0.068	0.271	0.339	0.100	0.691	0.791
41	0.144	1.565	1.709	0.027	0.120	0.147	0.415	0.861	1.276
42	0.187	1.119	1.306	0.063	0.206	0.270	0.228	1.017	1.244
43	0.083	1.796	1.879	0.004	0.102	0.106	0.022	0.069	0.091
44	0.256	0.090	0.346	0.069	0.193	0.261	0.286	0.574	0.860
45	0.100	1.266	1.366	0.081	0.385	0.467	0.000	0.000	0.000
sum	33.747	40.865	74.612	20.459	20.333	40.793	51.943	54.535	106.478

note. DEI: Direct Emission Intensity, IEI: Indirect Emission Intensity, TEI: Total Emission Intensity

References

Bank of South Korea (1993), *Inter-industry Transactions Table, 1990* (in Korean)

Chung, Hyun Sik, Yu-Bai Kim, Hae-Chun Rhee (1995), 'Environmental Regulation and Structural Change in the South Korean Manufactural Industries,' *South Korea Resource Economic Journal,* vol. 4, no.2: 307–344(in Korean).

Climate Protection in Germany, National Report of the Federal Government for the Federal Republic of Germany in anticipation of Article 12 of the United Nations Framework Convention on Climate Change, Aug. 1993.

Common, Mick, John L. R. Proops, and Stefan Speck, 'A Comparative Analysis of Carbon Dioxide Emissions in Australia, Germany, and the U. K.,' Dept. of Economics, Keele University Working Paper no. 93-1, Feb. 1993.

Hayami, H., T. Kiji, and Wang W. C. (1995), 'An Input-Output Analysis on Japan-China Environmental Problem (1):Compilation of the Input-Output Table for the Analysis of Energy and Air Pollutants,' Keio Economic Observatory, *KOE Discussion Paper* No. 39.

Institute of Developing Economies (1996), *International Input-Output Table for South Korea-Japan*, Tokyo, Japan.

International Financial Statistics (IFS)(1992).

Keio University Economic Observatory, Keio University (1995) 1985 Inter-industry Transaction Table for Analysing Energy Use and Air Pollution.

Keio University Institute of Industrial Development (KUIID) (1995), *Inter-industry Relation Table to Analyse Energy Consumption and Atmospheric Pollution* (in Japanese).

South Korea Energy Economic Research Institute (1995), *Country Report of Convention on Climate Change and Policy Measures to Comply therewith* (in Korean).

South Korea Energy Economic Research Institute (1990), *Report on Energy Census* (in Korean).

Kuroda, M., W. C. Wang and T. Kiji (1995), 'Issues in the Joint Implementation Program,' Keio Economic Observatory, *Discussion Paper* # 95-DOF-21.

Lio, Xiannuan (1996), *China's Energy Strategy: Economic Structure, Technological Choices, and Energy Consumption*, Praeger.

Moriguchi et al. (1993), 'Estimation of CO_2 Emission by Sectors and Sources in our Country,' *Energy Resources*, vol. 14, no.2 (in Japanese).

Oh, Jin-Gyu, 'Response Strategies to the Climate Change Convention', presented at the 4th Northeast Asian Conference on the Environment, September 1995. Pusan, South Korea, Korea Energy Economic Institute.

Proops, John L. R., Malte Faber, and Gerhard Wagenhals (1993), *Reducing CO_2 Emissions*, Springer-Verlag.

Selden Thomas M. and Daqing Song (1994), 'Environmental Quality and Development: Is There a Kuznets Curve for Air Pollution Emissions?', *Journal of Environmental Economics and Management*, vol 27, no.2, September 1994: 147–162

Zhang Z.Y.and Henk Folmer (1995), 'The Chinese Energy System: Implications for Future Carbon Dioxide Emissions in China,' *Journal of Energy and Development*.

OXFORD INSTITUTE FOR ENERGY STUDIES
57 WOODSTOCK ROAD, OXFORD OX2 6FA ENGLAND
TELEPHONE (01865) 311377
FAX (01865) 310527
E-mail: publications@oxfordenergy.org
http://www.oxfordenergy.org