Analysis of CO_2 Emissions from Fossil Fuel in Korea: 1961–1994

Ki-Hong Choi

1. Introduction

This study analyzes the trend of CO_2 emissions from energy (especially fossil-fuel) consumption in Korea to better understand the relationship between economic growth and CO_2 emissions in rapidly growing Asian economies. Korea is a particularly interesting example, as it typifies the export-led industrialization believed likely to be repeated elsewhere in East Asia.

The study spans the period 1961–94, during which Korea experienced dramatic changes in energy consumption stemming from rapid economic development. The former date is sufficiently far from the Korean War to avoid its distorting effect and the latter date is dictated by data availability. During this period, Korea shifted in common perceptions from a non-industrialized nation to one that would soon accede to membership in the Organization of Economic Cooperation and Development (OECD). Walt W. Rostow[1] has suggested that the Korean economy entered the "take-off stage" of sustained growth in 1961, estimating its drive to technical maturity to be essentially completed by the end of the 1980s—in roughly one-third the time required by currently industrialized countries.

---

[1] Rostow, W.W., *Korea and the Fourth Industrial Revolution, 1960–2000*, presented at the Federation of Korean Industries (September 1983, Seoul).

This study explores the relationship between national output and total CO_2 emissions by analyzing CO_2 intensity, which is defined as the ratio of CO_2 emissions to national output. The analytical method used is Divisia decomposition (or index) analysis, a useful tool for quantifying factors contributing to changes in a variable of interest. A number of studies have examined the two factors (*i.e.*, improvement in energy efficiency and structural change in industry) contributing to changes in aggregate energy intensity using this approach[2]. Only a few studies, however, notably Tornvager (1991), Ogawa (1990), and Shrestha and Timilsina (1996), have addressed the issue of changes in CO_2 emission intensity.

The following section describes the data set and analytical method employed by the present study. The third section first analyzes the changing pattern of energy consumption descriptively, then proceeds to a detailed analysis of CO_2 intensity by Divisia decomposition. The final section summarizes results of the analysis and their implications. Several appendices provide lengthy technical details and data used in the analysis.

2. Data and Analytical Method

2.1 Data

Our data set (depticted in Figure 1) includes sectorial energy data (collected over a longer period than is usually available for a rapidly industrializing country), real GNP, and CO_2 emission coefficients.

2.1.1 Energy Data

This study draws upon sectorial energy consumption data generated since the early 1960s that has not been readily available, which we obtained from:

- The official Yearbook of Energy Statistics, compiled by KEEI (Korea Energy Economics Institute), for the period 1975–94 (sectorial energy data began to be collected officially by Korea during 1975 as a result of the 1970s oil crisis—which also spurred the Korean government to establish its Ministry of Energy and Resources in 1978).
- A report by the Korea Institute of Energy and Resources (KIER), for the period 1961–74[3], a data set compiled by disaggregating the official energy supply data, based on a Korean input-output table produced by Bank of Korea.

---

[2] Ang (1995) surveys more than 50 studies with many different decomposition methods; recent studies tend to use the Divisia decomposition (index) method.

[3] *A Study on the Planning of Energy Demand and Supply* (in Korean), KE-82P-40, pp. 308–26 (KIER: Korea Institute of Energy and Resources, formerly KEEI).

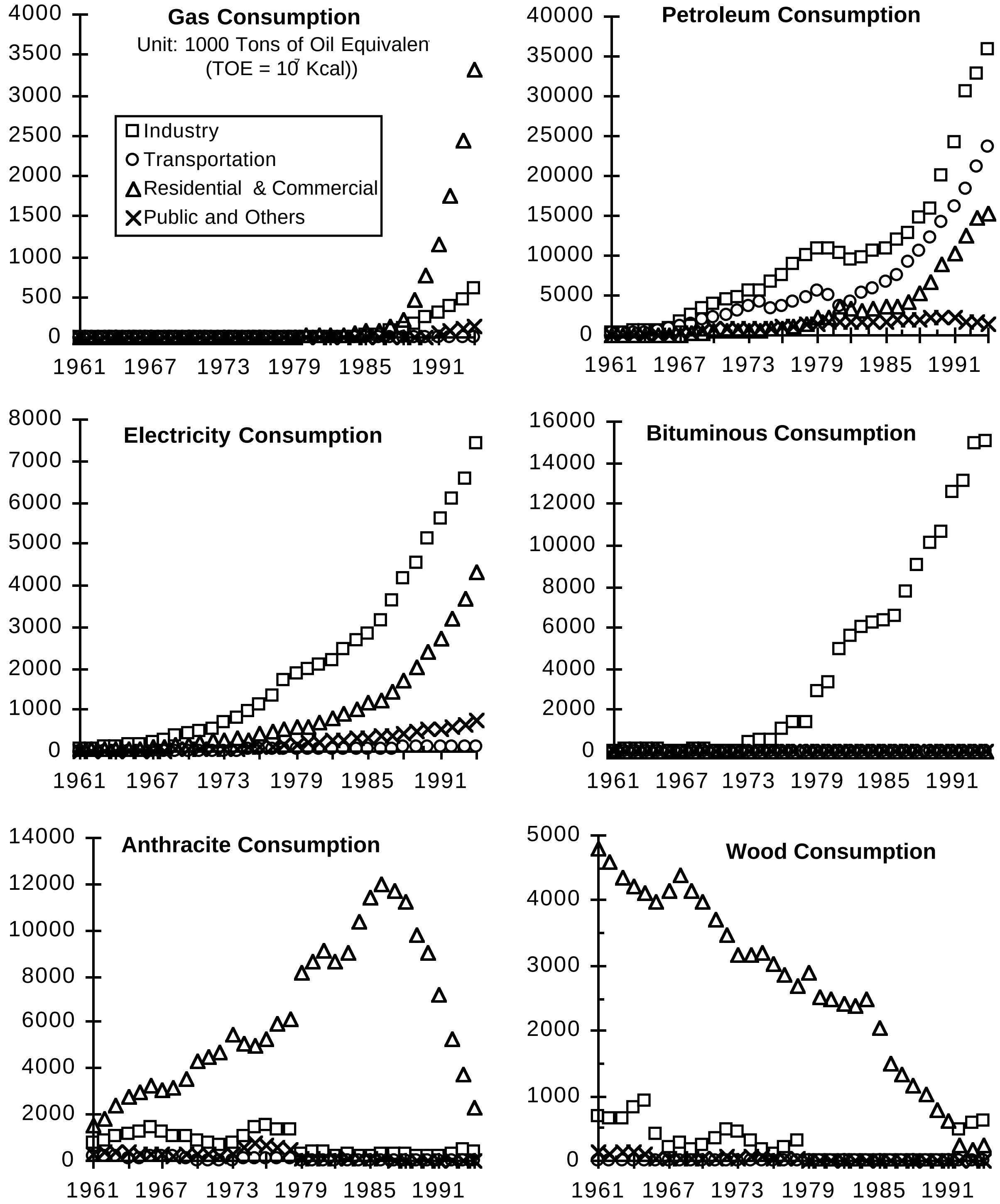


Figure 1. Graphical depiction of energy data used in this study (1961–94).

The “intersection” of these two smoothly connecting data sets defines the data used in this study (Table 1). Note that:

- The sectorial classification does not include the power sector, which consumes a huge amount of fossil fuel in the conversion to electricity. We therefore drew upon supplementary data from the *Yearbook of Energy Statistics* for power-sector fuel input, to include all the primary energy data needed to compute CO_2 emissions in Korea. The supplementary information is used indirectly, through the emission coefficient of electricity.
- Wood was used as fuel mostly for residential, noncommercial purposes; we include it because it has generally been replaced by commercial anthracite briquette.

Table 1. Specifications for Korean Energy Data (1961–94)

Number of sectors: 4	Industry; Transportation; Residential and commercial; Public, etc.
Number of fuel types: 6	Anthracite; Bituminous coal; Petroleum; Gas; Electricity; Wood
Unit: TOE	All fuel converted to tons of oil equivalent (TOE = 10^7 Kcal)

2.1.2 Emission Coefficients

The CO_2 emissions from fossil fuel are not so much related to specific burning conditions as they are proportional to the carbon content of the fossil fuel. Thus, the amount of carbon C emitted from a fossil fuel can be determined from the emission coefficient (in units of tons of carbon per ton of oil equivalent, TC/TOE) for the fossil fuel:

$$C = \sum_{ks} E_{ks}\,\theta_{ks} \qquad [1]$$

where E_{ks} is the energy of type k consumed in sector s, and θ_{ks} is the corresponding emission coefficient.

The emission coefficient of electricity is unique in this study, being defined as the amount of CO_2 emitted during the generation of one unit of electricity *consumed by a final user* (as noted above in the description of our data set, power sector emissions are included indirectly through the emission coefficient of electricity). According to this definition, the emission coefficient of electricity is determined by the formula (for k = electricity, s = all sectors):

$$\theta_{elec\,s,t} = \frac{(Total\,CO_2\ emissions\ in\ the\ power\ sector)_t}{(Total\ \ final\ electricity\ consumption)_t} \qquad [2]$$

The fossil-fuel input data necessary to compute this parameter are provided in Appendix 3. Figure 2 displays trends for all emission coefficients examined, during the study period. For electricity, the fuel mix used in power generation appears to be a determining factor[4] in the value of

---

[4] Another, much smaller, factor reducing the emission coefficient of electricity is the generation efficiency improvement of the power sector. Our estimate is that the conversion efficiency of the power sector improved 0.95% annually during 1970–95, on average.

the emission coefficient: nuclear power generation, in particular, has served a primary role in lowering the emission coefficient of electricity in Korea since the late 1970s—in fact, the sharp decrease in the emission coefficient of electricity to an all-time low in 1987 can be attributed primarily to two nuclear power units (2 × 900 MW) introduced in late 1986. (Only one unit generally has been introduced during any given year.)

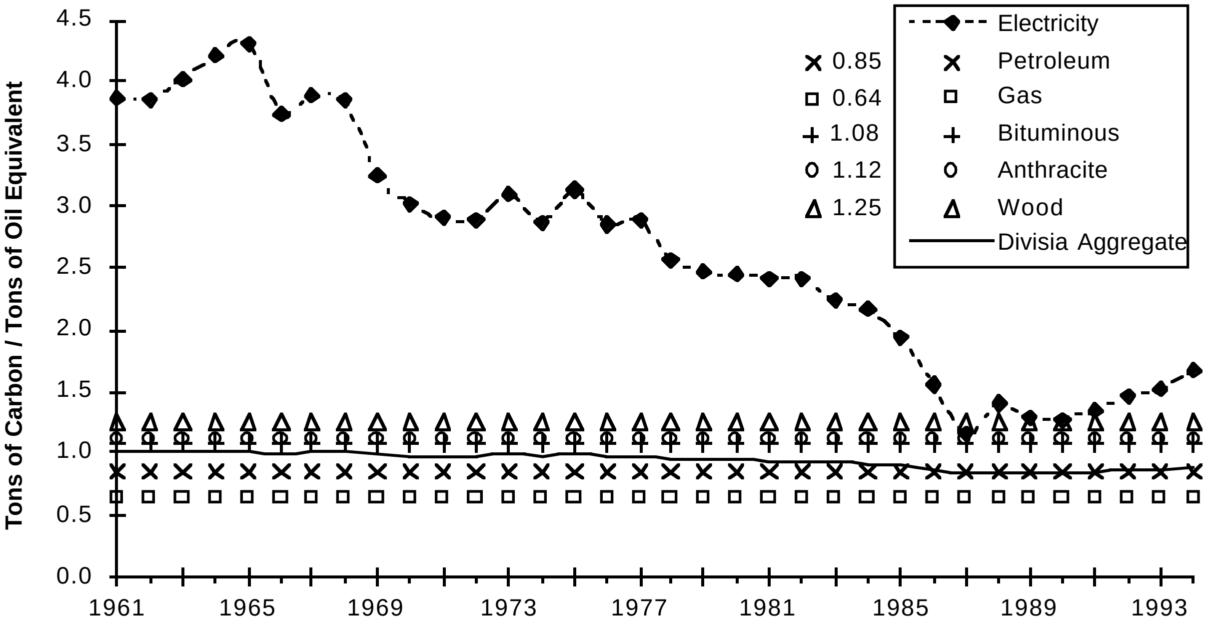


Figure 2. CO_2 emission coefficients for Korea (1961–94).

2.2 Analytical Method

This study employs Divisia decomposition (or index) analysis, a useful tool for quantifying factors contributing to changes in a variable of interest. Since Boyd *et al.* (1987) first applied the Divisia index[5] method to analyze sources of change in U.S. manufacturing energy intensity, a fair number of studies have utilized the method. A recent survey by Ang (1995) lists more than 50, among which a number have examined the factors (*i.e.*, improvement in energy efficiency and structural change in the industrial energy intensiveness) contributing to changes in aggregate energy intensity using this approach. However, only a few studies in the literature, notably Tornvager (1991), Ogawa (1990), and Shrestha and Timilsina (1996), have addressed the issue of changes in CO_2 intensity.

---

[5] The Divisia index is based on such basic economic principles as the linear homogeneity of an aggregate function, and competitive market prices.

2.2.1 CO$_2$ Intensity

CO$_2$ intensity, defined as the ratio of CO$_2$ emissions (*C*, defined in Equation [1]) to national output (*Y*, usually measured by gross national product, GNP, or gross domestic product, GDP), can be represented as the product of the term *C/E* and conventional energy intensity (*E/Y*) as follows:

$$\frac{C}{Y}=\frac{C}{E}\frac{E}{Y} \tag{3}$$

where $E=\sum_{ks}E_{ks}$ is the total energy consumtiopn of the (Korean) economy. Rewriting the first term on the right-hand side yields the following weighted average of individual emission coefficients:

$$\frac{C}{E}=\frac{\sum_{ks}E_{ks}\theta_{ks}}{\sum_{ks}E_{ks}}=\sum_{ks}\frac{E_{ks}}{E}\frac{C_{ks}}{E_{ks}}=\sum_{ks}f_{ks}\,\theta_{ks} \tag{4}$$

where $f_{ks}=E_{ks}/E$ is the share of energy type k consumed in sector s, from the total energy consumption (*cf.*, Table 1). Thus we define *C/E* as the *aggregate CO$_2$ emission coefficient.*

2.2.2 Divisia Analysis

Divisia analysis, which can be understood as a numerical technique for index analysis, assumes all variables to be functions of time, and positive[6]. Applying Divisia analysis to Equation [3] yields the following identity[7]:

$$\frac{\widehat{C}}{Y}=\frac{\widehat{C}}{E}+\frac{\widehat{E}}{Y}\Rightarrow\frac{C_T/Y_T}{C_0/Y_0}=\frac{C_T/E_T}{C_0/E_0}\frac{E_T/Y_T}{E_0/Y_0} \tag{5}$$

where we denote the logarithmic differentiation operator $d\log(\cdot)/dt$ by a “hat” ($\frown$) over variables. We can further analyze the aggregate emission coefficient identity, Eq. [4], as follows[8]:

$$\frac{C_T/E_T}{C_0/E_0}=\exp\left(\sum_{ks}\tilde{w}_{ks}(t^*)\ln\frac{f_{T,ks}}{f_{0,ks}}\right)\exp\left(\sum_{ks}\tilde{w}_{ks}(t^*)\ln\frac{\theta_{T,ks}}{\theta_{0,ks}}\right) \tag{6}$$

The right-hand side (RHS) of Eq. [6] is the product of two Sato-Vartia indices (*cf.* Ang and Choi, 1997), which can be interpreted as the *energy share effect* and the *Divisia aggregate emission coefficient*, respectively. Though the Tornqvist index has conventionally been used for such applications as this, we needed to use the Sato-Vartia formula here because of the following “zero-value problem.”

---

[6] This assumption is relaxed in the following *zero-value problem*.

[7] Integrating the first identity over the interval $[0,T]$ yields the second identity.

[8] See Appendix 1 for the derivation. It also explain how the special functional form of the weight function transforms the approximation formula into an algebraic identity.

2.2.3 Zero-Value Problem

As mentioned in the previous section, Divisia analysis assumes all variables to be positive. Our data set, however, contains 31% zero values[9] (mostly relating to emerging new gas energy and the disappearing use of traditional wood), so the Tornqvist index formula cannot be used consistently over the entire study period (*cf.* Shrestha and Timilsina, 1996, p. 290). In principle, this "zero-value problem" is trivial if the formula converges to some finite value when a variable tends from the positive toward zero[10]: though zero is not a legitimate argument of the logarithmic function, we can define the function at zero to be the limiting value. The problem lies in the fact that the conventional Tornqvist index formula has no limiting value at zero: the numerical experiment in Appendix 2 shows the formula to be unreliable for data including zero or near-zero values. The Sato-Vartia index formula, on the other hand, has a limiting value at zero, so we can apply Divisia analysis to the whole study period, regardless of zero values.

3. Analysis of Korean Emissions Growth

This section presents results of our case study of Korea to better understand the relationship between national output and total CO_2 emissions, based on the data and analytical method developed in the previous section. The approach is to analyze CO_2 intensity (the ratio between CO_2 emissions and national output), which can be represented as the product of conventional energy intensity and aggregate emission coefficients, as defined in the previous section. First, we provide a detailed descriptive analysis of the data, then present results of a Divisia decomposition analysis of CO_2 intensity.

3.1 Macro Trend

Figure 3 displays the GNP, energy consumption, and carbon emissions indices for Korea from 1961 through 1994. During this period, Korean GNP increased more than 14 times, at a rate of about 8.0% per annum. While the nation's well-known economic growth has served as its primary driver of energy demand and CO_2 emissions, these have grown more slowly (roughly 7.5% and 7.0% per annum, respectively) than GNP over the study period.

---

[9] Of 816 data elements (derived from 34 years, 6 energy types, and 4 sectors), 250 values are zero.

[10] This zero-value problem corresponds to the *determiniteness test* of index number theory. It should be noted that the determiniteness test is a bit controversial: Samuelson and Swamy (1974) disregard it as an old practice, saying "Frisch followed the old practice of adding a regularity condition… It is so-called *determiniteness test*, which requires that, as some $p_j \rightarrow 0$ or ∞, the index should not go to 0 or infinity. This condition, it seems to us, is an odd one and not at all a desirable one." Sato (1976, p. 224, footnote 9) also disregarded this problem, raised by Theil (1973), by referencing Samuelson and Swamy (1974).

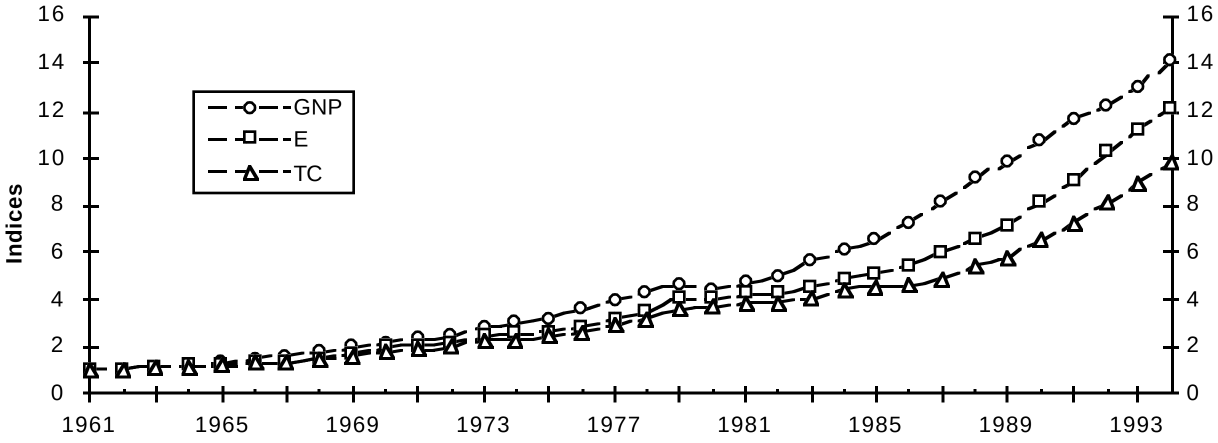


Figure 3. Aggregate GNP, energy consumption, and carbon emissions in Korea (1961–94).

3.2 Energy Consumption and CO_2 Emissions

3.2.1 Energy Consumption Pattern

During the 34-year study period, Korea's pattern of energy consumption changed completely, as Figure 4 depicts. Traditional energy sources such as wood and anthracite (South Korea's only native fossil fuels) were replaced by such imported fossil fuels as petroleum, bituminous coal, and liquefied natural gas (LNG). Non-carbon nuclear power plants' introduction to Korea in recent years has clearly played an important role in reducing CO_2 emissions.

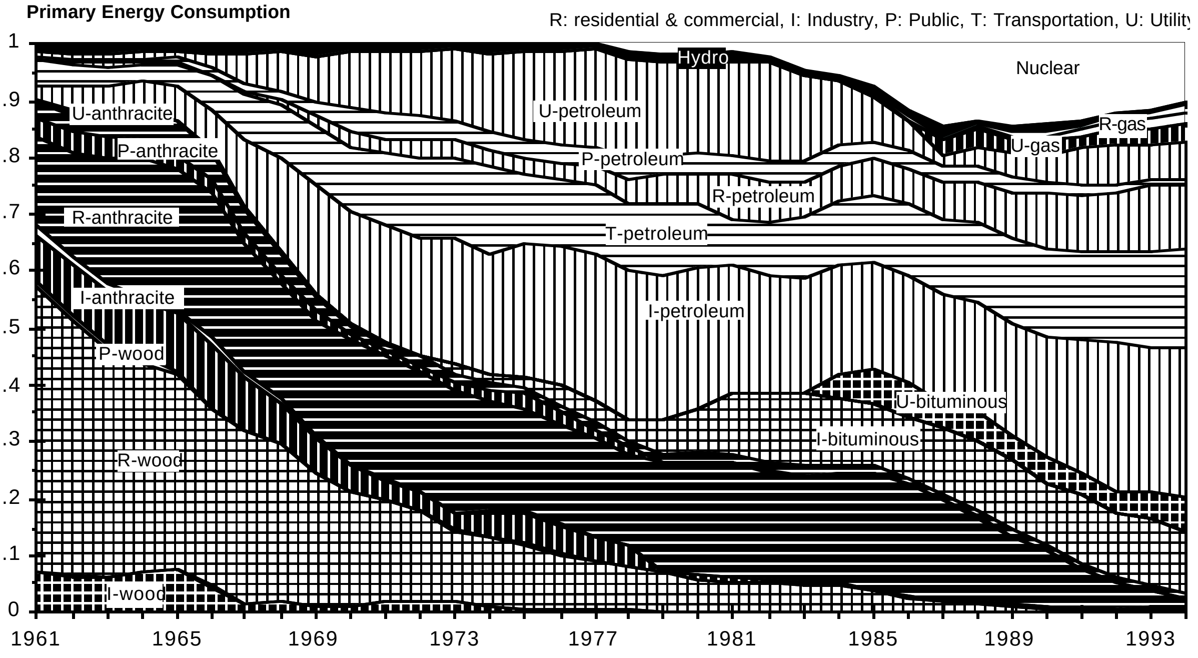


Figure 4. Primary energy consumption shares in Korea (1961–94).

3.2.2 CO_2 Emission Pattern

CO_2 emission was computed by applying the emission coefficients to the nation's energy consumption data. Figures 5 and 6 depict the sources of Korea's CO_2 emissions, by energy source (fossil fuel) and by sector, respectively. Figure 5 may illustrate three points:

- Korea's entire increase in carbon emissions during the 34-year study period is attributable to the use of imported fuels that accompanied the nation's economic transformation.
- CO_2 emissions rose sharply after the mid-1980s, mainly due to increased petroleum use (primarily for industry[11] and transportation purposes, as shown in Figure 6).
- Nuclear power has reduced the country's emissions significantly: had Korea installed bituminous-coal rather than nuclear-power plants, the nation would have emitted, as of 1994, more than 15% of its total CO_2 emissions *in addition to* its actual emissions, as shown by the hatched area.

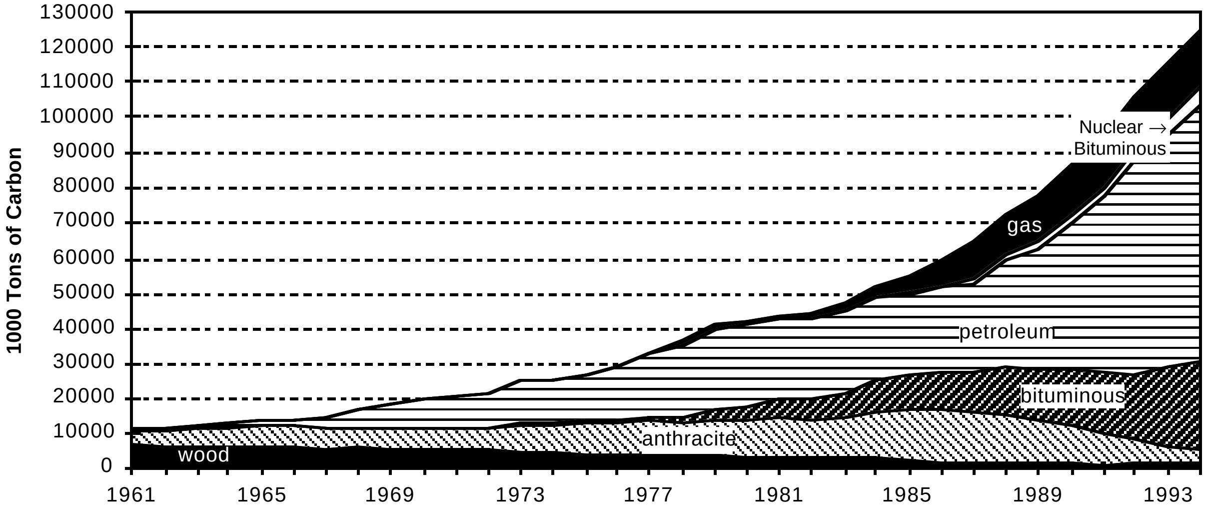


Figure 5. Korea's CO_2 emissions, by fossil fuel (1961–94).

Figure 6 illustrates the changes in sectorial composition that occurred. The residential and commercial (R&C) CO_2 emissions component—more than 80% in 1961—declined to less than 25% in 1994, while the industry component—less than 30% in 1961—increased to more than 60% in 1994. The transportation sector's change in share of emissions was also remarkable. Another point of note is that after the mid-1980s, emissions from R&C essentially stabilized, as the rapid drop in residential consumption of carbon-intensive anthracite (see Figure 1) essentially canceled out that sector's natural increase in energy demand.

---

[11] These rising trends in energy intensity were largely due to the completion of large petrochemical complexes.

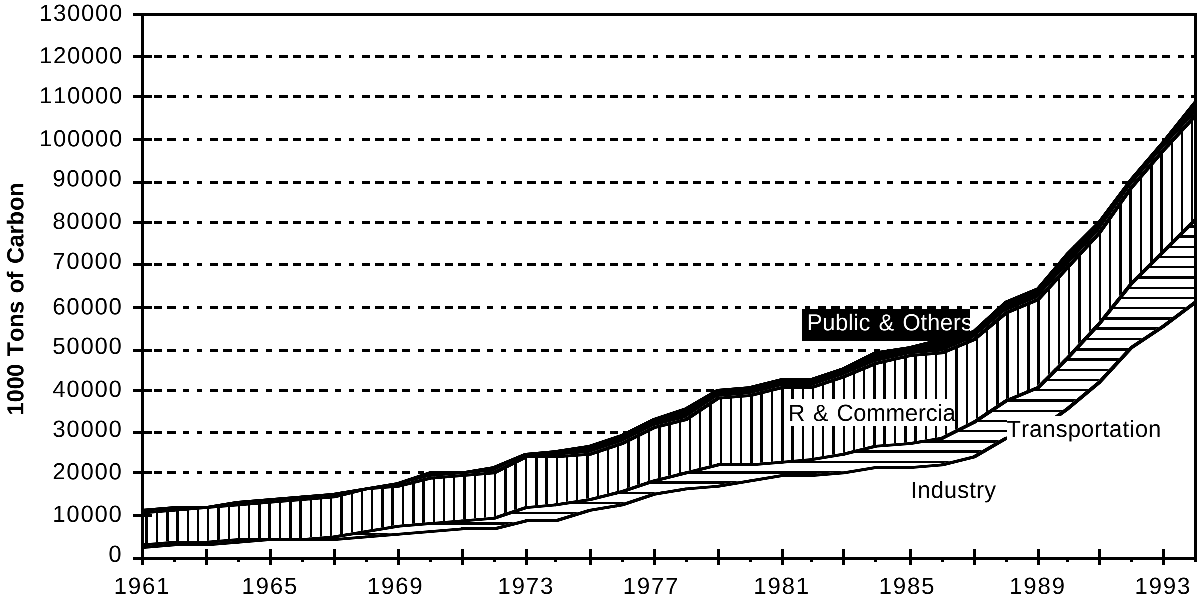
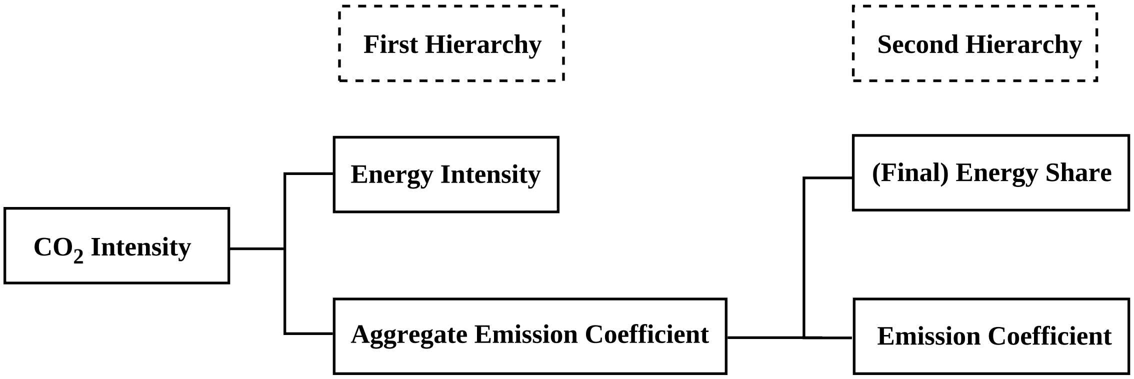


Figure 6. Korea's CO_2 emissions, by sector (1961–94).

3.3 Divisia Decomposition

The framework of our Divisia decomposition can be depicted as follows: Eqs. [5] and [6] correspond to the first level and the second level, respectively. Note that only the aggregate emission coefficient is analyzed to the second level (Eq. [6]). Most studies further analyze energy intensity, as well, to determine the contributions of individual energy intensities and industrial structure. However, we cannot analyze the energy intensity further, because our sectorial classification prevents a clear interpretation of sectorial output share.



3.3.1 First-Level Analysis

Figure 7 results from our index analysis based on the identity in Eq. [5], which indicates that changes in CO_2 intensity can be analyzed in terms of both the change in energy intensity (energy per unit of national output, *e.g.*, GNP) and the change in aggregate emission coefficients (CO_2 emission per unit of aggregate energy)[12]. We rewrite Eq. [5]:

$$\frac{C_T / Y_T}{C_0 / Y_0} = \frac{C_T / E_T}{C_0 / E_0} \frac{E_T / Y_T}{E_0 / Y_0} \qquad [5']$$

Figure 7 indicates that the energy intensity and aggregate emission coefficient, overall, combined to lower the CO_2 intensity more than 30% during 34 years of condensed growth. The analysis shows, in addition, that the aggregate emission coefficient contributed more to CO_2 intensity than did energy intensity.

The first component, energy intensity, which fell rapidly during the 1960s and 1980s, increased considerably in the early 1980s[13] and since the late 1980s. In fact, despite considerable fluctuation during the intervening years, energy intensity in 1994 was at the same level it had been in the late 1960s. The second component—aggregate emission coefficient (CO_2 emission per unit of aggregate energy input)—declined more steadily, proving by the end of the study period to be slightly more important than the decline in energy intensity.

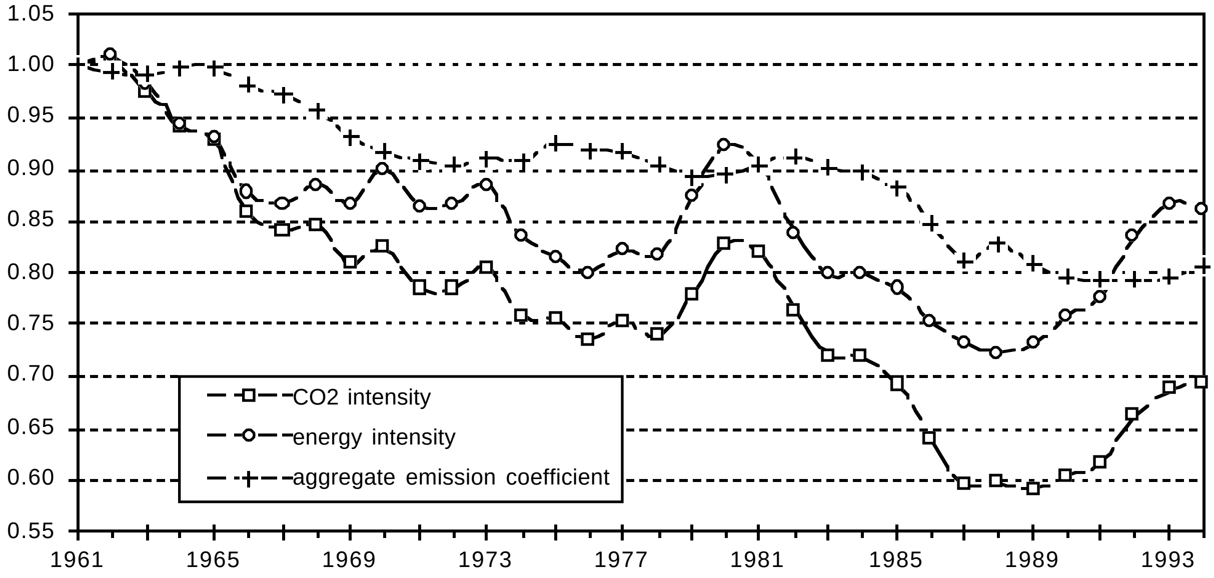


Figure 7. Analysis of CO_2 intensity of Korea (1961–94).

3.3.2 Second-Level Analysis

As explained in the previous section, the change in aggregate emission coefficient (as determined by our first-level analysis) can be analyzed further to yield the energy share effect

---

[12] This *aggregate energy* is sometimes referred to as the *energy balance aggregate* or *heat-sum aggregate*.

[13] During our 34-year study period, the Korean economy experienced only one period of negative growth, during 1980; that was due to political instability at the time.

(weighted changes in energy share, *e.g.*, substitutions of lower-carbon energy forms) and the emission coefficient effect (weighted changes in individual emission coefficients):

$$\frac{C_T / E_T}{C_0 / E_0} = \exp\left(\Sigma_{ks} \tilde{w}_{ks}(t^*) \ln \frac{f_{T,ks}}{f_{0,ks}} \right) \exp\left(\Sigma_{ks} \tilde{w}_{ks}(t^*) \ln \frac{\theta_{T,ks}}{\theta_{0,ks}} \right) \qquad [6]$$

Figure 8 results from our index analysis based on the identity in Eq. [6]. For purposes of comparison, the figure is drawn to the same scale as Figure 7. Figure 8 indicates that changes in energy share and in individual emission coefficients combined to lower the aggregate emission coefficient during the study period. Interestingly, until the first nuclear power plant was introduced in 1977, the effect of energy share on the aggregate emission coefficient overshadowed the effect of changes in the emission coefficient, while the relative magnitudes of these two factors reversed following the introduction of nuclear power.

Possible explanations follow for the trends in energy share:

- The increase from the mid-1970s through the mid-1980s resulted from rising use of bituminous coal, as well as electrification (electricity is a carbon-intensive energy source because of its significant conversion losses; see Figure 2).
- The decline after the mid-1980s reflects the rapid disappearance of anthracite (use of which peaked in 1987) in residential and commercial use, and rapid improvement in the electricity emission coefficient due to the introduction of nuclear power on a large scale.

The emission coefficient effect[14] derives essentially from the electricity emission coefficient and the share of electricity in total energy usage. The electricity emission coefficient declined steadily as the power sector began to use oil since the early 1960s, and then nuclear power after 1977. Since the early 1990s, however, the electricity emission coefficient has increased, reflecting the decline of nuclear power in electricity generation and increased use of more conventional fuels, including LNG.

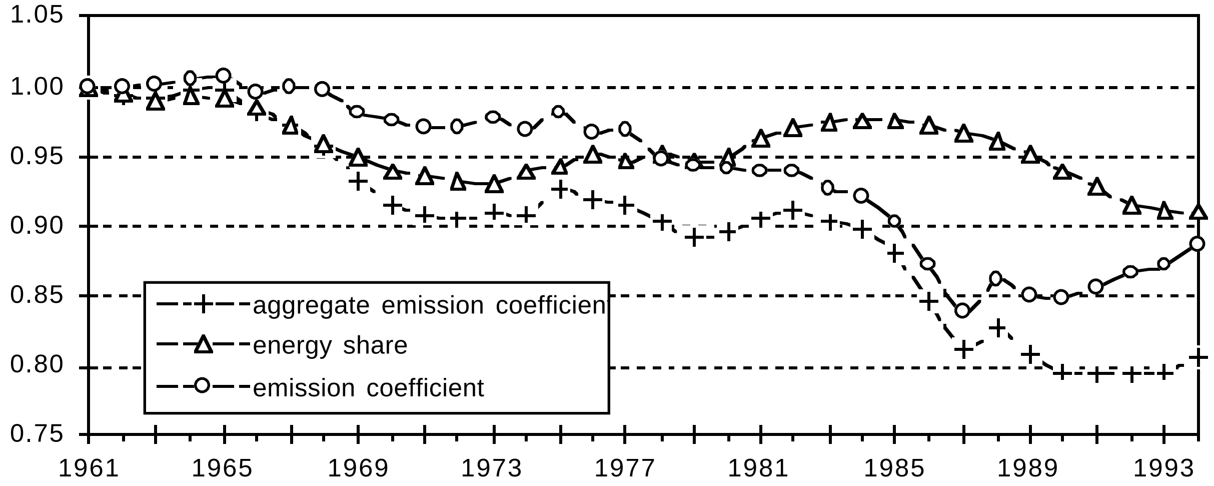


Figure 8. Analysis of the aggregate emission coefficient for Korea (1961–94).

---

[14] This term is designated in Figure 2 as *Divisia Aggregate*.

4. Summary and Conclusions

The present study was conducted to determine the relationship between national output and total CO_2 emissions from fossil-fuel consumption. For purposes of this research, Korea during 1961–94 seemed especially suitable, as that case typifies the export-led industrialization believed likely to be repeated elsewhere in East Asia: during the 34-year study period, Korea's energy consumption pattern changed completely—a phenomenon that generally required more than a century for countries that industrialized earlier.

We analyzed the observed CO_2 intensity (the ratio of CO_2 emission to national output) through two levels of Divisia decomposition:

- The first level splits CO_2 intensity into the contributions of energy intensity and aggregate emission coefficient (the ratio of CO_2 emissions to aggregate energy).
- The second level further analyzes the aggregate emission coefficient, splitting it into the contributions of energy share and individual emission coefficients.

Our major findings regarding the sources of change in Korean CO_2 intensity during 1961–94 are:

- The aggregate emission coefficient contributed to CO_2 intensity more than did energy intensity, emphasizing the significant role of energy substitution in reducing CO_2 emission in a rapidly developing economy.
- The emission coefficient contributed to the aggregate emission coefficient more than did energy share (mainly due to nuclear power's significant share in the Korean power sector), implying the importance of the power sector in reducing CO_2 emissions.

Since Korea has unique characteristics (in terms of natural resource endowment and industrial structure, for example), international comparisons using the type of analysis presented here would be helpful to determine the validity of these findings more broadly.

References

Anderson, R.G. and B.E. Jones and T.D. Nesmith (1997), "Monetary Aggregation Theory and Statistical Index Numbers," in *Review*, Federal Reserve Bank of St. Louis, January/February, pp. 31-51.

Ang, B.W. and Ki-Hong Choi (1997), "Decomposition of Aggregate Energy and Gas Emission Intensities for Industry: A Refined Divisia Index Method," *The Energy Journal*, Vol. 18, No. 3, pp. 59-73.

Barnett, W.A. (1982), "Divisia Monetary Aggregate: Compilation, Data, and Historical Behavior," Staff Study 116, Washington, Board of Governors of the Federal Reserve System.

Boyd, G., J.F. McDonald, M. Ross and D.A. Hanson (1987), "Separating the Changing Composition of US Manufacturing Production from Energy Efficiency Improvements: A Divisia approach," The *Energy Journal*, April, pp. 77-96.

Diewert, W.E. (1976), "Exact and Superlative Index Numbers," *Journal of Econometrics*, May, pp. 115-145.

Farr, T. and D. Johnson (1985), "Revision in the Monetary Services (Divisia) Indices of the Monetary Aggregate, Staff Study 147, Washington, Board of Governors of the Federal Reserve System.

Hulten, C.R. (1973), "Divisia Index Numbers," *Econometrica*, Vol. 41, No. 6, November, pp. 1017-1025.

Lau, L. (1979), "On Exact Index Numbers," *Review of Economics and Statistics*, Vol. 61, February, pp. 73-82.

Korea Institute of Energy and Resources (1982), "A Study on the Planning of Energy Demand and Supply," KE-82P-40, pp. 308-326.

Ministry of Trade, Industry, and Energy and Korea Energy Economics Institute (1996), *Yearbook of Energy Statistics*, Seoul, Republic of Korea.

Frisch, R. (1930), "Necessary and Sufficient Conditions Regarding the Form of and Index Number Which Shall Meet Certain of Fisher's Tests," *Journal of American Statistical Association*, December, pp. 397-406.

Frisch, R. (1936), "Annual Survey of General Economic Theory: The Problem of Index Numbers," *Econometrica*, January, Vol. 4, No. 1, pp. 1-38.

Samuelson, P.A., and S. Swamy (1974), "Invariant Economic Index Numbers and Canonical Duality: Survey and Synthesis," *American Economic Review*, Vol. 64, pp. 566-593.

Sato, K. (1976), "Ideal Log-Change Index Number," *The Review of Economics and Statistics*, 58, pp. 223-228.

Shrestha, R.M. and G.R. Timilsina (1996), "Factor affecting CO_2 intensities of power sector in Asia: A Divisia decomposition analysis," *Energy Economics*, 18, pp. 283-293.

Torvanger, A. (1991), "Manufacturing Sector Carbon Dioxide Emissions in Nine OECD Countries, 1973-87," *Energy Economics,* July, pp. 168-186.

Theil, H. (1973), "A New Index Number Formula," *Review of Economics and Statistics,* 55, November, pp. 498-502.

Vartia, Y.O. (1976), "Ideal Log-change Index Numbers," *Scandinavian Journal of Statistics,* pp. 121-126.

Appendix 1. Divisia Decomposition of the Aggregate Emission Coefficient

First, we apply Divisia analysis to the identity of the aggregate emission coefficient, breaking the coefficient down to two Divisia integral indices (see Eq. [5] in the main text). Our next task is to find a discrete approximation formula for the continuous integral index formula.

A1.1 Divisia Integral Index

Logarithmic differentiation (*dlog /dt*) of both sides of the aggregate emission coefficient identity, $C/E \equiv \theta = \sum_{ks} f_{ks}\, \theta_{ks}$ (see Eq. [3] in the main text), yields:

$$\widehat{\theta} = \sum_{ks} \frac{f_{ks}\,\theta_{ks}}{\theta} (\widehat{f}_{ks} + \widehat{\theta}_{ks}), \text{ where } (dlog\,/dt = \text{^}) \qquad \text{[A1-1]}$$

Integrating both sides of Eq. [A1-1] over the interval $[0, T]$ yields:

$$\ln \theta_T / \theta_0 = \sum_{ks} \int_0^T w_{ks}(t) \left(\frac{d \ln f_{ks}(t)}{dt} + \frac{d \ln \theta_{ks}(t)}{dt} \right) dt, \;\; w_{ks}(t) = \frac{f_{ks}(t)\theta_{ks}(t)}{\theta(t)} \qquad \text{[A1-2]}$$

Taking the natural exponential for both sides results in the form:

$$\frac{\theta_T}{\theta_0} = \exp\left(\sum_{ks} \int_0^T w_{ks}(t) \frac{d \ln f_{ks}(t)}{dt} dt \right) \exp\left(\sum_{ks} \int_0^T w_{ks}(t) \frac{d \ln \theta_{ks}(t)}{dt} dt \right) \qquad \text{[A1-3]}$$

The first term of the right-hand side (RHS) can be interpreted as the Divisia integral index of energy share, and the second term as the Divisia integral index of emission coefficients. We next determine a discrete version of this formula.

A1.2 Discretization

The following log-change identity approximates the Divisia integral index:

$$\frac{\theta_T}{\theta_0} \cong \exp\left(\sum_{ks} w_{ks}(t^*[0, T]) \ln \frac{f_{T,ks}}{f_{0,ks}} \right) \exp\left(\sum_{ks} w_{ks}(t^*[0, T]) \ln \frac{\theta_{T,ks}}{\theta_{0,ks}} \right) \qquad \text{[A1-4]}$$

where $w_{ks}(t^*[0, T])$ is the value of the weight function (see Eq. [A1-2]) at point $t^*[0,T]$; since the precise point is unknown, the log-change formula is an approximation. The conventional Tornqvist log-change formula uses a weight function that is the arithmetic average of two end-point weights:

$$\overline{w}_{ks}(t^*[0, T]) = \frac{w_{ks}(T) + w_{ks}(0)}{2} \qquad \text{[A1-5]}$$

The Tornqvist formula, however, has the functional flaw of the “zero-value problem” described in the main text—a weakness that necessitates our using a different weight function.

A1.3 Sato-Vartia index

Sato (1976[15]) proposed a weight function termed the *normalized logarithmic mean (log-mean) weight*[16]. The "log-mean" of two positive numbers is defined by:

$$L(x,y) = (y-x)/\log(y/x),\ \text{for}\ x,y>0\ \text{and}\ x \neq y \qquad \text{[A1-6]}$$

We define $L(x,x)=x$, the limit of $L(x,y)$ as $y \to x$. Substituting the normalized log-mean weight in Eq. [A1-4] produces an identity, even though we do not know the exact point $t^*[0,T]$.

The normalized log-mean weight is defined:

$$\tilde{w}_{ks}(t^*[0,T]) = L\left[w_{ks}(T), w_{ks}(0)\right] \alpha_{[0,T]} \qquad \text{[A1-7]}$$

where $\alpha_{[0,T]} = 1/\sum_{ks} L\left\lfloor w_{ks}(0), w_{ks}(T)\right\rfloor \geq 1$. Inserting the weights defined by Eq. [A1-7] into Eq. [A1-4] yields the following identity:

$$\frac{\theta_T}{\theta_0} \equiv \exp\left(\sum_{ks} \tilde{w}_{ks}(t^*[0,T]) \ln \frac{f_{T,ks}}{f_{0,ks}}\right) \exp\left(\sum_{ks} \tilde{w}_{ks}(t^*[0,T]) \ln \frac{\theta_{T,ks}}{\theta_{0,ks}}\right) \qquad \text{[A1-8]}$$

We can prove Eq. [A1-8] is an identity by comparing the natural exponents of its right- and left-hand sides:

$$\exp\left(\ln \frac{\theta_T}{\theta_0}\right) = \exp\left(\sum_{ks} \tilde{w}_{ks}(t^*[0,T]) \ln \frac{f_{T,ks}}{f_{0,ks}}\right) \exp\left(\sum_{ks} \tilde{w}_{ks}(t^*[0,T]) \ln \frac{\theta_{T,ks}}{\theta_{0,ks}}\right) \qquad \text{[A1-9]}$$

The exponent of the RHS in Eq. [A1-9] leads to that of the LHS, as follows:

$$\sum_{ks} \tilde{w}_{ks}(t^*[0,T])\ \ln\left(\frac{f_{T,ks}}{f_{0,ks}} + \frac{\theta_{T,ks}}{\theta_{0,ks}}\right) \qquad \text{[A1-10]}$$

$$\sum_{ks} \tilde{w}_{ks}(t^*[0,T])\ \ln\left(\frac{\theta_T w_{ks}(T)}{\theta_0 w_{ks}(0)}\right) \qquad \text{[A1-11]}$$

$$\sum_{ks} \tilde{w}_{ks}(t^*[0,T])\ \ln\left(\frac{\theta_T}{\theta_0}\right) + \sum_{ks} \tilde{w}_{ks}(t^*[0,T])\ \ln\left(\frac{w_{ks}(T)}{w_{ks}(0)}\right) \qquad \text{[A1-12]}$$

$$\ln\left(\frac{\theta_T}{\theta_0}\right) + \alpha[0,T]\sum_{ks}\left(w_{ks}(T) - w_{ks}(0)\right) = \ln\left(\frac{\theta_T}{\theta_0}\right) \qquad \text{[A1-13]}$$

Our analysis is based on the identity, Eq. [A1-8]; Appendix 2 shows that this Sato-Vartia formula does not have the zero-value problem.

---

[15] Y. Vartia is also credited for this index.

[16] According to Tornqvist *et al.* (1985), the "log-mean" concept was first advanced in Tornqvist (1935, in Swedish). It is interesting that he proposed the Tornqvist index (1936), which is based on arithmetic average weight function instead of his log-mean weight function.

Appendix 2. Numerical Treatment of a Zero-Value Problem with the Log-Change Index

This appendix explains the numerical techniques used in Divisia decomposition analysis, especially its second-level analysis, described in the main text. The mathematical definitions used here are identical to those given in Appendix 1.

Even though a zero value is not allowed in the log-change formula, the formula can be defined for zero if a limit (approached from the right-hand side of zero) for the formula exists. It can be shown that the Sato-Vartia index formula (defined in Appendix 1) has a limit at zero, by determining the limit of Eq. [A2-1] analytically:

$$\lim_{f_{0,ks}\to +0} \tilde{w}_{ks}(t^{*}[0,T]) \ln {}^{f_{T,ks}}\!\big/_{f_{0,ks}} \qquad \text{[A2-1]}$$

If the assumption $\lim_{f_{0,ks}\to +0} \theta_{0,ks} < \infty$ is plausible, we can proceed as follows:

$$\lim_{f_{0,ks}\to +0} \tilde{w}_{ks}(t^{*}[0,T]) \ln {}^{f_{T,ks}}\!\big/_{f_{0,ks}} + \lim_{f_{0,ks}\to +0} \tilde{w}_{ks}(t^{*}[0,T]) \ln {}^{\theta_{T,ks}}\!\big/_{\theta_{0,ks}} = \qquad \text{[A2-2]}$$

$$\lim_{f_{0,ks}\to +0} \tilde{w}_{ks}(t^{*}[0,T]) \ln {}^{f_{T,ks}\,\theta_{T,ks}}\!\big/_{f_{0,ks}\,\theta_{0,ks}} = \qquad \text{[A2-3]}$$

$$\lim_{w_{0,ks}\to +0} \tilde{w}_{ks}(t^{*}[0,T]) \ln {}^{\theta_{T} w_{T,ks}}\!\big/_{\theta_{0} w_{0,ks}} = \qquad \text{[A2-4]}$$

$$\lim_{w_{0,ks}\to +0} \tilde{w}_{ks}(t^{*}[0,T]) \ln {}^{w_{T,ks}}\!\big/_{w_{0,ks}} + \lim_{w_{0,ks}\to +0} \tilde{w}_{ks}(t^{*}[0,T]) \ln {}^{\theta_{T}}\!\big/_{\theta_{0}} = \qquad \text{[A2-5]}$$

$$\lim_{w_{0,ks}\to +0} \tilde{w}_{ks}(t^{*}[0,T]) \ln {}^{w_{T,ks}}\!\big/_{w_{0,ks}} = \qquad \text{[A2-6]}$$

$$\lim_{w_{0,ks}\to +0} \tilde{w}_{ks}(t^{*}[0,T]) \ln {}^{w_{T,ks}}\!\big/_{w_{0,ks}} = \alpha[0,T] \lim_{w_{0,ks}\to +0} \left(w_{T,ks} - w_{0,ks} \right) = \qquad \text{[A2-7]}$$

$$\alpha_{[0,T]}\, w_{T,ks} \cong w_{T,ks} \qquad \text{[A2-8]}$$

Thus, we can define $\tilde{w}_{ks}(t^{*}[0,T]) \ln {}^{f_{T,ks}}\!\big/_{0} \equiv \alpha[0,T] w_{T,ks}$. Such a definition is not possible for the Tornqvist formula, however, because $\overline{w}_{ks}(t^{*}[0,T]) \ln {}^{f_{T,ks}}\!\big/_{0} \equiv +\infty$. Since this limiting property is rather qualitative, we quantify its significance through the following numerical experiment.

A2.1 Numerical Experiment

The data set for this experiment is that specified in the main text, containing 31% zero values. In the identity of the aggregate emission coefficient (Eq. [6] in the main text). Obviously the right-hand side (RHS) cannot be applied to such a data set, since zero is not permitted for logarithmic functions.

$$\frac{\theta_T}{\theta_0} \equiv \exp\left(\Sigma_{ks}\, \tilde{w}_{ks}(t^*[0,T]) \ln \frac{f_{T,ks}}{f_{0,ks}} \right) \exp\left(\Sigma_{ks}\, \tilde{w}_{ks}(t^*[0,T]) \ln \frac{\theta_{T,ks}}{\theta_{0,ks}} \right) \qquad \text{[A2-9]}$$

Let us therefore denote the original data set by D and define a sequence of new data sets, D1, D2, D3,…, Dn, such that $(\mathrm{D_n} \to \mathrm{D})$ to be used for the RHS in place of the original data set. They are constructed by replacing every zero in the original data set D with an arbitrary small positive number, *e.g.*, 10^{-1}, 10^{-3}, 10^{-5}, 10^{-7}, 10^{-9}, 10^{-12}, 10^{-15}, 10^{-18}.

After applying the original D to the LHS of Eq. [A2-9] and the data set $\mathrm{D_n}$ constructed to the RHS, we check the discrepancy between the two sides of the equation. If the discrepancy shrinks as we apply $\mathrm{D_n} \to \mathrm{D}$ to the log-change formula of RHS, then the formula do not have the zero-value problem.

A2.1.1 Unsuitability of the Tornqvist Formula

The following figure was prepared by applying the Tornqvist formula to the RHS of Eq. [A2-9], for each data set, $\mathrm{D1},\ \mathrm{D2},\ \mathrm{D3},\ldots,\ \mathrm{Dn}$. Note that the discrepancy between the two sides of the equation increases as $\mathrm{D_n} \to \mathrm{D}$.

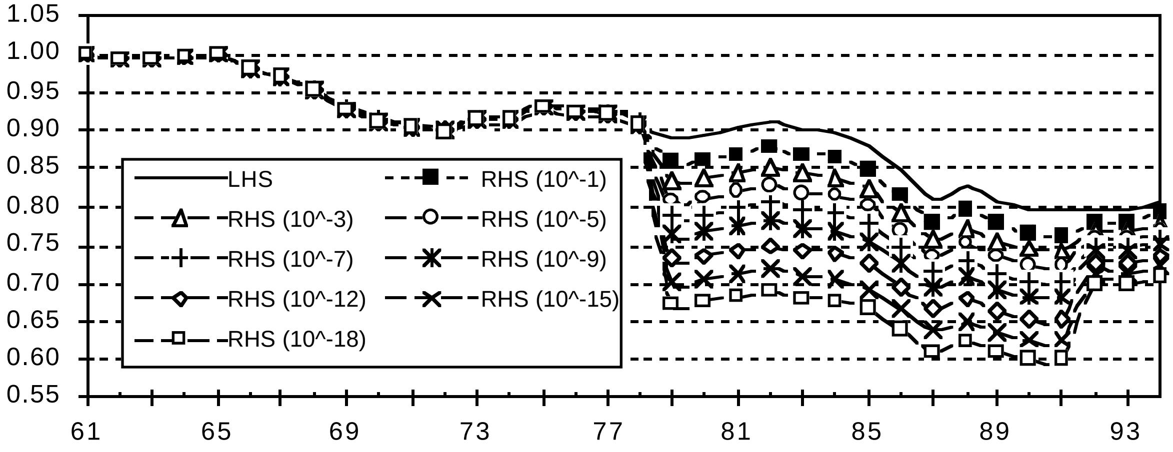


Figure A2-1. Test of the Tornqvist Formula for Zero Values

A2.1.2 Suitability of the Sato-Vartia Formula

Employing the Sato-Vartia formula in a similar experiment, we can confirm that the LHS rapidly converges to the RHS: Except for the case of a data set in which every zero of the original data set is replaced by a (rather large) 0.1, the RHS and LHS are essentially equal, within a precision range of 10^{-5}. Even in that case of 0.1, the maximum discrepancy between the LHS and RHS is negligible (less than 0.003%). Results of this experiment follow:

Table A2-1. Test of the Sato-Vartia Formula for Near-Zero Values

	LHS	RHS(10^-1)	Difference	% Difference
61	1.00000	1.00000	0.00000	0.00000%
62	0.99449	0.99449	0.00000	0.00000%
63	0.99226	0.99226	0.00000	0.00000%
64	0.99765	0.99765	0.00000	0.00000%
65	0.99801	0.99802	-0.00001	0.00100%
66	0.98005	0.98005	0.00000	0.00000%
67	0.97177	0.97178	-0.00001	0.00103%
68	0.95731	0.95732	-0.00001	0.00104%
69	0.93151	0.93152	-0.00001	0.00107%
70	0.91590	0.91592	-0.00002	0.00218%
71	0.90831	0.90832	-0.00001	0.00110%
72	0.90419	0.90420	-0.00001	0.00111%
73	0.90927	0.90929	-0.00002	0.00220%
74	0.90866	0.90868	-0.00002	0.00220%
75	0.92567	0.92568	-0.00001	0.00108%
76	0.91874	0.91876	-0.00002	0.00218%
77	0.91634	0.91636	-0.00002	0.00218%
78	0.90269	0.90271	-0.00002	0.00222%
79	0.89202	0.89203	-0.00001	0.00112%
80	0.89555	0.89557	-0.00002	0.00223%
81	0.90414	0.90416	-0.00002	0.00221%
82	0.91174	0.91176	-0.00002	0.00219%
83	0.90223	0.90225	-0.00002	0.00222%
84	0.89770	0.89772	-0.00002	0.00223%
85	0.88172	0.88174	-0.00002	0.00227%
86	0.84685	0.84687	-0.00002	0.00236%
87	0.81097	0.81099	-0.00002	0.00247%
88	0.82707	0.82709	-0.00002	0.00242%
89	0.80851	0.80853	-0.00002	0.00247%
90	0.79615	0.79617	-0.00002	0.00251%
91	0.79394	0.79396	-0.00002	0.00252%
92	0.79396	0.79397	-0.00001	0.00126%
93	0.79531	0.79533	-0.00002	0.00251%
94	0.80619	0.80621	-0.00002	0.00248%

Appendix 3. Emission Coefficient of Electricity

Table A3

	Input Energy (1000 TOE) (TOE = Ton of Oil Equivalent)								
	Anthracite	Bituminous	B-C	Other Oil	Diesel	Naptha	LNG	Nuclear	Hydro
1961	247.0	27.6	86.5	3.1	13.0	0.0	0.0	0.0	143.9
1962	302.9	33.9	106.1	3.8	16.0	0.0	0.0	0.0	176.4
1963	377.1	31.0	127.7	13.3	6.6	0.0	0.0	0.0	182.3
1964	513.6	14.1	145.4	12.3	7.9	0.0	0.0	0.0	187.7
1965	711.5	1.0	113.7	7.1	4.1	0.0	0.0	0.0	177.6
1966	605.4	0.0	321.7	9.5	4.7	0.0	0.0	0.0	245.7
1967	587.4	0.0	618.5	24.9	85.5	0.0	0.0	0.0	237.8
1968	592.8	0.0	791.1	26.4	228.4	18.9	0.0	0.0	230.3
1969	463.5	0.0	1218.0	15.7	134.3	49.3	0.0	0.0	358.2
1970	280.0	0.0	1822.5	10.0	52.5	30.0	0.0	0.0	305.0
1971	219.8	0.0	2165.4	2.7	24.7	5.5	0.0	0.0	329.8
1972	253.3	0.0	2406.8	0.0	15.1	0.0	0.0	0.0	340.8
1973	412.7	0.0	3072.1	0.0	19.1	0.0	0.0	0.0	317.1
1974	205.7	0.0	3539.4	0.0	60.0	0.0	0.0	0.0	479.9
1975	313.0	0.0	4256.3	5.0	50.5	5.0	0.0	0.0	419.1
1976	408.7	0.0	4835.9	0.0	51.8	11.5	0.0	0.0	449.0
1977	413.2	0.0	5657.7	0.0	219.9	6.7	0.0	20.0	346.5
1978	270.6	0.0	6040.1	8.0	612.8	0.0	0.0	580.9	445.6
1979	351.4	0.0	6703.0	8.8	351.4	0.0	0.0	790.7	579.8
1980	686.7	0.0	6731.1	153.6	108.4	0.0	0.0	867.4	487.9
1981	699.3	0.0	6992.7	411.9	67.1	0.0	0.0	728.0	680.1
1982	723.4	0.0	7325.9	611.3	91.7	0.0	0.0	947.6	489.1
1983	1110.5	335.5	6848.3	590.0	92.5	0.0	0.0	2244.2	347.0
1984	878.7	2292.3	5386.9	509.4	127.4	0.0	0.0	2954.5	585.8
1985	774.4	3318.7	4300.5	193.6	83.0	0.0	0.0	4189.9	968.0
1986	640.7	3625.5	2828.5	312.5	78.1	0.0	62.5	7079.0	1000.1
1987	723.8	3003.9	904.8	235.2	72.4	0.0	1972.5	9826.1	1357.2
1988	890.1	3767.6	2090.8	517.5	82.8	0.0	2442.7	10019.3	890.1
1989	824.3	3549.0	2793.4	480.8	91.6	0.0	2152.3	11837.7	1167.7
1990	703.5	3908.3	3595.6	573.2	234.5	0.0	2240.7	13209.9	1589.4
1991	686.0	3944.3	4830.4	1200.4	257.2	0.0	2315.1	14090.9	1257.6
1992	784.1	4328.0	5457.0	2007.2	564.5	0.0	2916.7	14144.3	1160.4
1993	924.8	6165.5	5549.0	1986.7	308.3	0.0	3288.3	14523.3	1507.1
1994	963.1	8514.0	6433.7	2195.9	385.3	0.0	4353.3	14678.0	1001.7

Source: Yearbook of Energy Statistics, Ministry of Trade, Industry, and Energy and Korea Energy Economics Institute, 1996.

[Table continued on next page]

Table A3 continued

	TC/TOE	CO_2 Emissions 1000TC	Output Energy 1000 TOE	TC/TOE
1961	1.12	396.5	102.2	3.880
1962	1.08	486.1	126.1	3.855
1963	0.88	585.5	145.5	4.024
1964	0.88	736.0	174.8	4.211
1965	0.85	907.7	210.5	4.312
1966	0.84	973.5	260.6	3.736
1967	0.64	1296.7	332.8	3.896
1968	0.00	1593.4	414.3	3.846
1969	0.00	1760.3	542.3	3.246
1970		1996.0	659.9	3.025
1971		2179.9	751.2	2.902
1972		2414.5	838.4	2.880
1973		3181.9	1029.7	3.090
1974		3396.0	1186.5	2.862
1975		4147.8	1321.7	3.138
1976		4767.1	1678.4	2.840
1977		5634.1	1953.9	2.884
1978		6146.2	2393.3	2.568
1979		6598.6	2678.5	2.464
1980		6919.7	2815.0	2.458
1981		7356.2	3046.5	2.415
1982		7872.9	3257.7	2.417
1983		8230.4	3665.3	2.245
1984		8756.8	4046.4	2.164
1985		8476.8	4363.0	1.943
1986		7503.6	4842.7	1.549
1987		6382.1	5518.5	1.156
1988		8995.0	6391.3	1.407
1989		9092.9	7068.5	1.286
1990		10310.7	8117.0	1.270
1991		12035.6	8976.3	1.341
1992		14467.3	9911.0	1.460
1993		16692.5	10985.1	1.520
1994		20981.5	12602.5	1.665

Source: Yearbook of Energy Statistics, Ministry of Trade, Industry, and Energy and Korea Energy Economics Institute, 1996

Appendix 4. Energy Consumption Data: 1961–94

Table A4

		1961	1962	1963	1964	1965	1966	1967
Industry	Anthracite	764.1	898.1	1021.3	1133.5	1243.5	1456.7	1286.4
	Bituminous	29.2	80.8	63.1	81.5	56.3	42.8	31.6
	Petroleum	268.2	394.6	508.3	595.2	689.0	932.7	1648.2
	Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Electricity	55.2	75.1	92.7	112.0	136.2	169.8	221.5
	Wood	690.4	638.5	653.8	813.5	909.3	400.0	208.5
	Sum	1807.1	2087.1	2339.2	2735.7	3034.3	3002.0	3396.2
Transportation	Anthracite	167.0	160.2	151.4	118.0	97.6	159.6	180.2
	Bituminous	5.4	11.2	6.6	6.6	5.4	4.5	1.6
	Petroleum	392.8	403.7	373.6	333.2	493.6	761.7	1047.2
	Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Electricity	2.4	2.9	2.8	2.9	3.8	4.4	5.8
	Wood	11.5	10.8	10.6	10.7	10.5	5.7	1.8
	Sum	579.1	588.8	545.0	471.4	610.9	935.9	1236.6
R&Commercial	Anthracite	1489.1	1863.0	2414.1	2802.6	2987.0	3299.2	3064.1
	Bituminous	0.4	0.6	0.9	0.8	0.7	0.6	0.3
	Petroleum	30.4	42.8	55.1	41.6	35.8	29.3	90.3
	Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Electricity	36.1	37.1	37.1	45.5	54.7	68.5	85.0
	Wood	4808.4	4580.2	4355.9	4234.6	4117.0	3976.2	4161.0
	Sum	6364.4	6523.7	6863.1	7125.1	7195.2	7373.8	7400.7
Public & Others	Anthracite	318.3	356.6	401.4	352.3	273.4	299.8	277.0
	Bituminous	0.0	0.1	0.0	0.0	0.0	0.0	0.1
	Petroleum	18.9	31.2	44.5	42.8	98.2	129.9	192.8
	Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Electricity	8.5	11.0	12.9	14.4	15.8	17.9	20.5
	Wood	124.7	118.6	126.7	123.4	104.5	46.2	22.4
	Sum	470.4	517.5	585.5	532.9	491.9	493.8	512.8
All Sectors	Anthracite	2738.5	3277.9	3988.2	4406.4	4601.5	5215.3	4807.7
	Bituminous	35.0	92.7	70.6	88.9	62.4	47.9	33.6
	Petroleum	710.3	872.3	981.5	1012.8	1316.6	1853.6	2978.5
	City Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Electric	102.2	126.1	145.5	174.8	210.5	260.6	332.8
	Wood	5635.0	5348.1	5147.0	5182.2	5141.3	4428.1	4393.7
Total	Sum	9221.0	9717.1	10332.8	10865.1	11332.3	11805.5	12546.3
Industry		1807.1	2087.1	2339.2	2735.7	3034.3	3185.0	3396.2
Transportation		579.1	588.8	545.0	471.4	610.9	935.9	1236.6
R&Commercial		6364.4	6523.7	6863.1	7125.1	7195.2	7373.8	7400.7
Public & Others		470.4	517.5	585.5	532.9	491.9	493.8	512.8
Total		9221.0	9717.1	10332.8	10865.1	11332.3	11988.5	12546.3

[Table continued on following pages]

Table A4 continued

		1968	1969	1970	1971	1972	1973	1974
Industry	Anthracite	1069.9	1042.7	863.3	748.3	653.7	769.5	1074.5
	Bituminous	67.3	60.0	52.8	37.0	21.7	428.4	553.6
	Petroleum	2553.8	3329.2	3861.5	4316.3	4638.0	5670.4	5455.4
	Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Electricity	277.6	358.5	426.3	482.3	535.7	688.4	777.8
	Wood	270.9	172.1	246.7	353.3	481.2	455.5	293.2
	Sum	4239.5	4962.5	5450.6	5937.2	6330.3	8012.2	8154.5
Transportation	Anthracite	152.0	115.1	30.0	20.1	16.4	36.3	59.3
	Bituminous	0.8	0.4	0.0	0.0	0.0	0.0	0.0
	Petroleum	1490.4	1873.4	2317.7	2630.7	3122.3	3649.2	4065.7
	Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Electricity	6.8	6.2	5.1	5.5	6.5	8.1	20.4
	Wood	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Sum	1650.0	1995.1	2352.8	2656.3	3145.2	3693.6	4145.4
R&Commercial	Anthracite	3195.0	3560.5	4291.9	4468.4	4690.2	5485.8	5096.4
	Bituminous	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Petroleum	151.1	302.7	520.6	594.9	633.7	684.8	673.2
	Gas	0.0	0.0	0.0	0.5	1.1	1.3	2.1
	Electricity	106.3	144.6	185.3	218.0	248.9	283.7	322.3
	Wood	4375.7	4164.7	3979.5	3717.0	3455.2	3169.6	3176.0
	Sum	7828.1	8172.5	8977.3	8998.8	9029.1	9625.2	9270.0
Public & Others	Anthracite	219.3	265.7	275.3	249.2	237.7	331.3	557.1
	Bituminous	0.4	0.4	0.0	0.0	0.0	0.0	0.0
	Petroleum	252.0	482.5	832.9	905.8	948.8	944.3	902.9
	Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Electricity	23.6	33.0	43.2	45.4	47.3	49.5	66.0
	Wood	27.5	18.3	25.0	36.8	53.8	46.9	55.9
	Sum	522.8	799.9	1176.4	1237.2	1287.6	1372.0	1581.9
All Sectors	Anthracite	4636.2	4984.0	5460.5	5486.0	5598.0	6622.9	6787.3
	Bituminous	68.5	60.8	52.8	37.0	21.7	428.4	553.6
	Petroleum	4447.3	5987.8	7532.7	8447.7	9342.8	10948.7	11097.2
	Gas	0.0	0.0	0.0	0.5	1.1	1.3	2.1
	Electric	414.3	542.3	659.9	751.2	838.4	1029.7	1186.5
	Wood	4674.1	4355.1	4251.2	4107.1	3990.2	3672.0	3525.1
Total	Sum	14240.4	15930.0	17957.1	18829.5	19792.2	22703.0	23151.8
Industry		4239.5	4962.5	5450.6	5937.2	6330.3	8012.2	8154.5
Transportation		1650.0	1995.1	2352.8	2656.3	3145.2	3693.6	4145.4
R&Commercial		7828.1	8172.5	8977.3	8998.8	9029.1	9625.2	9270.0
Public & Others		522.8	799.9	1176.4	1237.2	1287.6	1372.0	1581.9
Total		14240.4	15930.0	17957.1	18829.5	19792.2	22703.0	23151.8

[Table continued on next page]

Table A4 continued

		1975	1976	1977	1978	1979	1980	1981
Industry	Anthracite	1418.3	1488.2	1381.4	1387.7	302.1	339.9	369.6
	Bituminous	518.8	1046.8	1386.0	1431.5	2870.4	3321.1	4906.4
	Petroleum	6555.6	7460.6	8855.3	10053.5	10812.0	10947.7	10140.5
	Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Electricity	945.7	1136.1	1334.3	1682.9	1869.6	1970.5	2089.4
	Wood	161.6	118.4	214.9	296.5	0.0	0.0	0.0
	Sum	9600.0	11250.1	13171.9	14852.1	15854.1	16579.2	17506.0
Transportation	Anthracite	52.0	51.5	59.5	65.1	1.4	2.4	1.9
	Bituminous	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Petroleum	3237.1	3544.7	4225.0	4605.2	5575.5	4868.5	3679.5
	Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Electricity	28.3	28.7	32.8	36.9	33.4	34.2	39.8
	Wood	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Sum	3317.4	3624.9	4317.3	4707.2	5610.3	4905.1	3721.1
R&Commercial	Anthracite	4970.0	5272.9	5920.4	6140.8	8172.0	8659.5	9104.8
	Bituminous	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Petroleum	802.7	899.6	1068.9	1397.7	2162.3	2221.7	3525.4
	Gas	4.2	5.8	6.5	7.3	8.1	14.7	23.1
	Electricity	266.6	417.5	472.4	536.2	593.9	610.9	690.8
	Wood	3185.8	3018.4	2854.8	2691.4	2892.1	2516.9	2492.0
	Sum	9229.3	9614.2	10323.0	10773.4	13828.4	14023.7	15836.2
Public & Others	Anthracite	756.8	647.7	568.7	483.6	80.7	103.2	94.9
	Bituminous	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Petroleum	910.9	1043.9	1230.7	1450.6	1415.3	1786.7	1566.9
	Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Electricity	81.1	96.1	114.4	137.3	181.6	199.4	226.5
	Wood	62.5	38.4	47.4	50.1	0.0	0.0	0.0
	Sum	1811.3	1826.1	1961.2	2121.6	1677.6	2089.3	1888.3
All Sectors	Anthracite	7197.1	7460.3	7930.0	8077.2	8556.2	9105.0	9571.2
	Bituminous	518.8	1046.8	1386.0	1431.5	2870.4	3321.1	4906.4
	Petroleum	11506.3	12948.8	15379.9	17507.0	19965.1	19824.6	18912.4
	City Gas	4.2	5.8	6.5	7.3	8.1	14.7	23.1
	Electric	1321.7	1678.4	1953.9	2393.3	2678.5	2815.0	3046.5
	Wood	3409.9	3175.2	3117.1	3038.0	2892.1	2516.9	2492.0
Total	Sum	23958.0	26315.3	29773.4	32454.3	36970.4	37597.3	38951.7
Industry		9600.0	11250.1	13171.9	14852.1	15854.1	16579.2	17506.0
Transportation		3317.4	3624.9	4317.3	4707.2	5610.3	4905.1	3721.1
R&Commercial		9229.3	9614.2	10323.0	10773.4	13828.4	14023.7	15836.2
Public & Others		1811.3	1826.1	1961.2	2121.6	1677.6	2089.3	1888.3
Total		23958.0	26315.3	29773.4	32454.3	36970.4	37597.3	38951.7

[Table continued on next page]

Table A4 continued

		1982	1983	1984	1985	1986	1987	1988
Industry	Anthracite	231.8	242.8	206.3	182.7	248.4	242.4	276.3
	Bituminous	5612.0	5997.4	6206.0	6307.6	6551.9	7772.4	9038.8
	Petroleum	9321.9	9671.0	10443.6	10697.3	11857.2	12915.3	14599.8
	Gas	0.0	0.0	1.0	15.1	39.9	75.0	110.1
	Electricity	2187.9	2435.1	2650.8	2812.0	3167.7	3642.6	4175.2
	Wood	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Sum	17353.5	18346.4	19507.7	20014.7	21865.0	24647.8	28200.3
Transportation	Anthracite	1.9	0.0	0.0	0.0	0.0	0.0	0.0
	Bituminous	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Petroleum	4173.2	5390.3	5954.9	6645.1	7623.7	9201.0	10667.0
	Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Electricity	40.4	44.2	51.9	62.3	75.7	74.2	80.1
	Wood	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Sum	4215.5	5434.5	6006.8	6707.4	7699.4	9275.2	10747.1
R&Commercial	Anthracite	8629.3	9040.2	10322.9	11399.3	12032.9	11721.3	11205.0
	Bituminous	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Petroleum	3344.3	3073.1	3438.4	3524.8	3746.7	4284.4	5330.8
	Gas	27.5	37.4	50.6	69.1	92.4	124.1	228.8
	Electricity	778.6	909.9	1038.3	1155.4	1252.6	1434.6	1709.8
	Wood	2417.2	2377.8	2492.0	2031.4	1480.4	1318.5	1163.7
	Sum	15197.0	15438.4	17342.2	18180.0	18605.0	18882.9	19638.0
Public & Others	Anthracite	73.5	55.3	70.8	50.4	54.3	42.2	45.3
	Bituminous	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Petroleum	1620.4	1786.5	1765.3	1712.5	1953.8	1971.6	1913.2
	Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Electricity	250.8	276.1	305.4	333.3	346.8	367.1	426.2
	Wood	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Sum	1944.6	2118.0	2141.5	2096.1	2354.8	2380.9	2384.7
All Sectors	Anthracite	8936.5	9338.4	10600.0	11632.3	12335.6	12006.0	11526.6
	Bituminous	5612.0	5997.4	6206.0	6307.6	6551.9	7772.4	9038.8
	Petroleum	18459.8	19920.9	21602.2	22579.7	25181.4	28372.2	32510.9
	City Gas	27.5	37.4	51.6	84.2	132.3	199.1	338.9
	Electric	3257.7	3665.3	4046.4	4363.0	4842.7	5518.5	6391.3
	Wood	2417.2	2377.8	2492.0	2031.4	1480.4	1318.5	1163.7
Total	Sum	38710.7	41337.2	44998.1	46998.1	50524.2	55186.8	60970.2
Industry		17353.5	18346.4	19507.7	20014.7	21865.0	24647.8	28200.3
Transportation		4215.5	5434.5	6006.8	6707.4	7699.4	9275.2	10747.1
R&Commercial		15197.0	15438.4	17342.2	18180.0	18605.0	18882.9	19638.0
Public & Others		1944.6	2118.0	2141.5	2096.1	2354.8	2380.9	2384.7
Total		38710.7	41337.2	44998.1	46998.1	50524.2	55186.8	60970.2

[Table continued on next page]

Table A4 continued

		1989	1990	1991	1992	1993	1994
Industry	Anthracite	204.4	145.5	165.7	257.1	447.8	398.0
	Bituminous	10058.9	10662.0	12578.6	13131.0	14878.3	15005.1
	Petroleum	15935.5	20014.0	24250.8	30514.4	32654.2	35881.2
	Gas	158.3	234.2	313.0	377.2	460.0	600.4
	Electricity	4513.9	5095.4	5605.8	6063.4	6581.2	7397.6
	Wood	0.0	0.0	0.0	482.2	569.0	626.1
	Sum	30871.1	36151.0	42914.0	50825.3	55590.5	59908.5
Transportation	Anthracite	0.0	0.0	0.0	0.0	0.0	0.0
	Bituminous	0.0	0.0	0.0	0.0	0.0	0.0
	Petroleum	12186.5	14086.3	16062.2	18429.8	21010.9	23735.8
	Gas	0.0	0.0	0.0	0.0	0.0	0.0
	Electricity	82.6	87.0	93.8	101.1	108.2	124.4
	Wood	0.0	0.0	0.0	0.0	0.0	0.0
	Sum	12269.1	14173.3	16156.0	18530.8	21119.1	23860.2
R&Commercial	Anthracite	9810.7	9027.0	7169.9	5288.4	3731.3	2266.8
	Bituminous	0.0	0.0	0.0	0.0	0.0	0.0
	Petroleum	6694.4	8875.7	10161.3	12404.9	14669.1	15375.2
	Gas	461.1	776.9	1159.6	1760.0	2450.1	3313.2
	Electricity	2011.2	2420.6	2732.2	3174.3	3663.1	4321.4
	Wood	1032.6	796.6	617.4	239.3	172.0	237.7
	Sum	20009.9	21896.9	21840.4	22866.9	24685.5	25514.3
Public & Others	Anthracite	42.2	21.1	0.0	12.0	0.0	0.0
	Bituminous	0.0	0.0	0.0	0.0	0.0	0.0
	Petroleum	2150.9	2276.1	2200.5	1590.2	1541.4	1518.5
	Gas	0.0	0.0	67.6	82.0	117.2	143.3
	Electricity	460.9	513.9	544.4	572.2	632.7	759.1
	Wood	0.0	0.0	0.0	0.0	0.0	0.0
	Sum	2654.0	2811.1	2812.5	2256.5	2291.3	2420.9
All Sectors	Anthracite	10057.3	9193.6	7335.6	5557.6	4179.1	2664.9
	Bituminous	10058.9	10662.0	12578.6	13131.0	14878.3	15005.1
	Petroleum	36967.3	45252.1	52674.8	62939.3	69875.7	76510.9
	City Gas	619.4	1011.0	1540.3	2219.2	3027.3	4056.9
	Electric	7068.5	8117.0	8976.3	9911.0	10985.1	12602.5
	Wood	1032.6	796.6	617.4	721.5	741.0	863.8
Total	Sum	65804.1	75032.3	83722.9	94479.6	103686.5	111704.0
Industry		30871.1	36151.0	42914.0	50825.3	55590.5	59908.5
Transportation		12269.1	14173.3	16156.0	18530.8	21119.1	23860.2
R&Commercial		20009.9	21896.9	21840.4	22866.9	24685.5	25514.3
Public & Others		2654.0	2811.1	2812.5	2256.5	2291.3	2420.9
Total		65804.1	75032.3	83722.9	94479.6	103686.5	111704.0