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AGGREGATE ENERGY EFFICIENCY IN PAKISTAN:
An Application of Decomposition Approach

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The paper examines the role of structural changes and improvement in energy efficiency of individual sectors in aggregate energy intensity changes in, Pakistan, during 1960-1998. Using a decomposition approach, this study attempts to provide insights into the changes in the structure of the economy and energy intensity that occurred in the economy, during the period under consideration. The estimation identifies and measures cyclical and trend components for both the structural and intensity indices. The cyclical component is being due to changes in output and the trend component is probably due to changes in technology and consumer preferences.

I. Introduction

In recent years, it has become apparent that the economic potential for energy efficiency[1] has barely been tapped, and it has become a big politics [Douglas, (1993); Bajpai, (1994); Barker, (1992); Lee, (1993); and Jenne and Cattell, (1983)]. The benefits are widely broad-based and so much appealing that, the banner of energy efficiency has become something of a unifying theme among widely disparate consumers, industry, policymakers, environmentalists, energy experts and utilities, who, at least for the moment, find themselves sharing a common pathway towards divergent goals [Choe, et al., (1981); World Bank, (1993); Yates, (1989); Lee, (1993); and Jenne and Cattell, (1983)]. Energy efficiency is now widely recognized as a

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[1] Energy efficiency is the inverse of energy intensity. Improvement in the energy efficiency entails a decreasing ratio of energy consumed to output produced [Lee, (1993)].

boon to the economy, providing savings to the consumers, competitive advantage to the producers and profit to the shareholders. Moreover, energy efficiency has also acquired the mantle of being the fastest, cheapest, and perhaps the most durable route to environmental protection. As a result, it has become a cornerstone of policy formulation at the country and the global level [Choe, et al., (1981); Barker, (1992); Douglas, (1993); Corazon, (1990); Munasighe and Saunders, (1989); Yates, (1989); and Fallen-Bailey and Byer, (1979)].

It is unavoidable that developing countries will have to increase the amount of commercial energy they consume, in order to improve the welfare of their people [World Bank, (1993); Bates and Moor, (1992); Behram, et al., (1983); Fallen-Bailey and Byer, (1979); Li, et al., (1990); and Boyd, et al., (1987)]. On an overall, per capita basis, developing countries annually consume 0.4 toe of commercial energy or 0.6 toe including biofuels, compared with more than 3.2 toe in Western Europe and 7.4 toe in the United States [World Bank, (1993)]. Given the relative low consumption base the growth in demand for commercial energy in the developing countries is increasing significantly. This demand-growth is driven by several related factors, including the growth of populations and per capita incomes; the migration to urban areas, which in many instances leads to substitution of commercial energy for fuelwood; the increasing penetration of energy-intensive products and technologies; and poor efficiency with which energy is produced and consumed in the developing world. Because of the low efficiency base, the developing countries have the potential to achieve significant energy efficiency gains.

The economic impact of policies and investments that improve energy efficiency in developing countries can be substantial, first, because of the possibilities of delaying capital-intensive investments in energy supply, and second, because of the potential saving in fuels. On an average, energy supply and end-use efficiencies and industrial energy efficiency rates are two-thirds to one-half of what would be considered best practice in the developed world, regardless of the process involved [Asian Development Bank, (1987); Delucia and Jacoby, (1982); and Yates, (1989)].

Pakistan is an energy deficient country, one of the lowest in the world as far as consumption of energy is concerned. Its per capita energy consumption is less than half of the average for the developing countries, about 1/8th of the world average, and 1/25th of the developed nations. Inspite of an extremely small per capita energy consumption, demand-growth for energy is increasing at a rate of 10 per cent, annually. Major reasons for the high rates of demand growth are the continued growth in GNP and the population. Growth in per capita income leads to increased penetration of energy-using durable goods; increased rural electrification; increased urbanization of the economy; increased load of electric tube wells; tractors replaced animals as part of a general farm mechanization drive; and structural changes in the composition of GNP, as the share of manufacturing sector increased from 7.8 per cent in 1950 to 18.3 per cent in 1998 [GOP (1999)].

The relationship between structural changes[2] and energy efficiency will provide insight into the changes in the structure of the economy, and the intensity of energy use, that occurred in Pakistan over the last four decades. The structural shift of the production process and changes in production technology all affect total energy use in an economy. The present empirical study examines explicitly the relative importance of these factors in explaining how the intensity of total energy-use has evolved in the country during the period under consideration. It provides a mechanism for analysis of the effectiveness of various macroeconomic management policy measures for the development of the energy sector. This would be much needed information in developing a framework for the development of various sectors of the economy with respect to energy development planning in a country, like Pakistan. It is well known that aggregate energy intensity[3] may change due to changes in the structure of production (structural effect)[4] and energy intensities of individual sectors (intensity effect).[5] This paper focuses on the relative impacts of changes in output, the economy's structure and energy intensities of individual sectors during 1960-1998 for Pakistan. To disentangle the contribution to the change of aggregate energy intensity from the intensity effect and the structural effect, a Divisia index approach is employed. The rest of the paper proceeds as follows. Section II discusses previous research, Section III describes the analytical framework, followed by a discussion of the empirical results and concluding remarks in Section IV and Section V, respectively.

II. Previous Work

In recent years, a number of studies have analysed the relative influence of the intensity and structural effects on changes in the manufacturing sector energy intensity over time [Bending, et al., (1987); Bossany, (1979); Boyd, et al., (1987); Jenne and Cattell, (1983); Lee and Chiou, (1985); Liu and Wang, (1986); Motamen and Schaller, (1985); Reitler, et al., (1987) and Sterner, (1985)]. However, only few studies have focused on the manufacturing sector of developing and newly industrialised economies as compared to those for industrialised countries, but none has analysed these effects at the national level. Energy use may be viewed as a function of total output, the composition of that output, and the means by which that output is produced [Gardner, (1993)]. A large number of studies have estimated the relative importance of these factors in explaining how industrial energy use has

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[2] See, Appendix.

[3] Energy Intensity is a measure of energy efficiency defined as energy consumption per unit production of output. It is the amount of energy used per unit of activity.

[4] Changes in structure of production over time.

[5] Changes in intensities of individual sectors.

evolved in different localities [Marlay, (1984); Ang, (1987); Boyd, et al., (1987); Li, et al., (1990); Howarth, et al., (1991); Gardner, (1993)]. Werbos, (1987), with a different methodology than the one used here; and has analysed structural shifts in the US economy over the 1958-1983 period and found that growth in GNP, real interest rates and time, were the major factors, while the price of energy was not. Boyd, et al., (1988), estimated the impact of the relative price of materials versus all commodities, GNP, and time on an energy structural index for the US over the 1958-1985 period and found that only time was statistically significant in explaining structural shifts of energy consumption.

The World Bank's (1990) study on energy demand estimated potential savings of primary energy from energy efficiency, in eight developing countries (Brazil, China, India, Malaysia, Pakistan, Philippines, and Thailand) is about 100 MTOE at current consumption levels, equivalent to $16 billion per year through the mid-1990's. This could be achieved by structural and energy price change, a faster rate of technology transfer, and fuel substitution [Imran and Barnes, (1990)]. Structural change played a small role in increasing aggregate intensity in the developed countries, but it had major effects in developing countries (Lee, 1993). Jin-ping Huang (1993), found that most of the changes in aggregate energy, electricity, coal, oil and gas intensity can be attributed to changes in individual industry sector intensities during 1980-88 in China. Structural change accounted for only a small fraction of the changes in aggregate intensities. Gardner (1993), uses a Divisia index approach to disaggregate changes in the aggregate energy intensity of the Ontario industrial sector into structural and intensity components. Of particular interest, he found changes between the pre-oil-shock period (1962-73) and post-oil-shock period (1973-84). Structural changes were found to be of little importance in the pre-oil-shock period, but of substantial importance in the post-oil-shock period in reducing the aggregate energy intensity of the Ontario industrial sector. Changes in the intensity of individual industries, on the other hand, were found to be significant in the earlier period but were of lesser importance in the later period.

III. Analytical Framework

The aggregate energy intensity index (A_t) is simply the ratio of total energy use (C_t) to total output in real value added terms (Y_t).

$$A_t = \frac{C_t}{Y_t} \qquad (1)$$

The Divisia index approach[6] is employed for the estimation of the aggregate energy intensity index (A_t), which is then represented as the product of a structural

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[6] The Divisia index is a continuous time index and holds a prominent place in the literature because

Index (S_t) and an Intensity Index (I_t):

$$A_t = S_t * I_t \tag{2}$$

The structural index (S_t) measures changes due to shifts in the composition of output; the intensity index (I_t) reflects changes in technology and product mix within individual sectors. The Divisia index decomposition of the aggregate intensity index is derived in the Appendix. It is one of several different methods that have been used to decompose changes in aggregate energy use into structural and intensity factors [Boyd, et al., (1988); Howarth, et al., (1991); Liu, et al., (1992)].

Following Fuss (1977) an aggregate energy price index,[7] based on the concept of a unit cost function was constructed, to be included in the structural index model and intensity index model in order to capture the effect of changes in the aggregete energy price. Since P is the price per unit of energy, it is also the cost per unit to the optimizing agent.

$$\ln P = \ln\alpha_0 + \sum_i \alpha_i \ln P_i + \frac{1}{2} \sum_i \sum_j \alpha_{ij} \ln P_i \ln P_j \tag{3}$$

where

P = Aggregate energy price index,
i,j = E(electricity), O(oil) and G(gas).

Cost minimizing behavior implies that demand functions for individual energy types in terms of shares in the cost of energy aggregate, take the form:

$$h_i = \alpha_i + \sum_j \alpha_{ij} \ln P_j \tag{4}$$

subject to constraints: $\sum_i \alpha_i = 1$, $\sum_i \alpha_{ij} = \sum_j \alpha_{ij} = 0$ and $\alpha_{ij} = \alpha_{ji}$.

The estimated parameters will be obtained from the share equation (4). These estimated parameters are substituted in equation (3) to estimate the aggregate energy price index.

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the Divisia line integral produces the unique exact index number formula for any neoclassical aggregator function. These result imply that the Divisia integral index is the prototype economic index number. For general use, however, the Divisia continuous time index must be adapted to apply to discrete data. The advantage of the Divisia index approach, is that the weights are not tried to base year values, and hence we expect the residual to be small. The disadvantage of the Divisia approach is that it arbitrarily assigns interaction terms to the structural and intensity indices. The intensity index in the Divisia decomposition contains elements of changes in structure, and the structure index, reflects changes in intensities. [For detail, see Richard, et al., (1991)].

[7] The prices of various energy carriers were available, but aggregate price of energy was needed for structural index and intensity index models to capture the effect of changes in price of energy. Therefore, an aggregate price index was constructed.

a) Structural Index Model

For structural changes, there may exist many different factors. One possibility is a growing consumer preference for services and high value added, low material-intensive, products [Williams, et al., (1987)]. The emergence of new improved materials, better manufacturing technology, and improved products design and services that have tended to reduce the quantity of materials and energy, might also be the contributing factors [Ross, et al., (1987); and Gardner and Robinson, (1993)]. If such changes in technology and consumer preferences have occurred at a relatively constant rate over time, as is perhaps reasonable, a time trend may serve to model the impact of these factors. The price of energy is another possible factor. Changes in the price of energy may be expected to affect the price of energy-intensive products and services significantly, leading to lower sales if energy prices increase and higher sales if energy prices decrease. Lastly, energy-intensive sectors such as transport, industry and other government sectors are sensitive to investment in structures and machinery. Since investment is related to growth in economic output, economic growth is another possible factor, to be considered. The model, which is to be tested, is as follows:

$$\ln S_t = \beta_1 + \beta_2 \ln Q'_t + \beta_3 \ln P'_t + \beta_4 \text{Trend} \qquad (5)$$

where,

S_t = Structural change index,
Q'_t = Q_t / Q_{t-1} (Growth in economic output),
P'_t = P_t / P_{t-1} (Growth in price of aggregate energy),
Trend = Time trend variable which measures technological change, and changes in consumer preferences.

b) Intensity Index Model

Several possible explanatory factors for the energy intensity indices exist. Economic growth affects energy intensity in two ways. First, it tends to increase the efficient use of manufacturing facilities, and hence lowers the intensity. Second, it stimulates investment in new and more efficient technology, thus tending to lower the intensity index once again. Another factor is the price of energy. A time trend term is included in the intensity index model, which captures the impact of non-price induced changes on energy intensity. These changes are called 'autonomous energy efficiency improvements.[8] It measures the impact of at least three factors:

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[8] There is some contradiction among findings as to whether the term should be reserved for the impact of efficiency improvements within individual sectors or whether it should also be included for estimating the effect of structural change.

technological development that increase energy productivity, structural change and policy-driven uptake of more efficient technologies [Grubb, et al., (1993)].

The intensity index equation is thus of the following form:

$$\ln I_t = \gamma_1 + \gamma_2 \ln Q'_t + \gamma_3 \ln P'_t + \gamma_4 \text{ Trend} \tag{6}$$

where,

I_t = Energy intensity index,
$Q'_t = Q_t / Q_{t-1}$ (Growth in economic output),
$P'_t = P_t / P_{t-1}$ (Growth in price of aggregate energy),
Trend = Time trend variable which measures technological changes and change in consumer preferences.

The aggregate intensity index coefficients can be obtained by simply summing up the respective coefficients from the structural and intensity indices, since the aggregate intensity is the product of these.

c) Data Sources

The study is based on annual data covering a time period from 1960-1998 for Pakistan. Total energy consumption is the aggregate of oil, gas and electricity consumption, which comprises above 90 per cent of the total commercial energy consumption. The aggregate energy price is generated by the Fuss approach, by using the prices of the same carriers of energy. All energy consumption data are compiled from the Pakistan Energy Data Book and Pakistan Energy Yearbook, produced by the Pakistan Ministry of Petroleum and Natural Resources. Data on petroleum prices was collected from the Transport Bulletin General, produced by the National Transport Research Centre, and data on electricity prices was taken from the Power System Statistics, produced by the Karachi Electric Supply Corporation. The data on gross national product (GNP), gross domestic product (GDP) and sectoral GDP were collected from the Pakistan Economic Survey and 50 Years of Pakistan, published by the Federal Bureau of Statistics.

IV. Empirical Results and Discussion

The estimated parameters from equation (4) are presented in Table 1. These parameters are substituted in equation (3), for estimating the aggregate energy price index. Table 2 reports the estimation results for the structural index equation. Economic growth and the time trend are highly significant and have the expected negative signs. The negative sign of the economic growth term indicates that energy-intensive sectors are less sensitive to growth in economic output than the non-energy-intensive sectors. The negative time trend shows that if changes in technology and consumer preferences have occurred, at a relatively constant rate over time, the shift in sectoral output tends to reduce. On the other hand, the price of energy is statistically insignificant, i.e., the price of energy has no effect on structural change in Pakistan. Energy consumption has continued to grow, in spite of a consistent rise in energy prices, under the prevailing monopoly system. An auto-regressive parameter is fitted to improve the Durbin-Watson statistic (to correct auto-correlation). The first order auto-regressive term is significant.

The estimation results for the intensity index equation are reported in Table 3. The t-ratio for economic growth is statistically significant at the one per cent level and has a positive sign, showing that economic growth tends to increase energy consumption, increasing energy intensity, because Pakistan is in the process of industrialization, urbanization and modernization. The time term is also statistically

TABLE 1

Estimated Parameters of Share Equations

$$h_i = \alpha_i + \sum_j \alpha_{ij} \ln P_j$$

Parameters	Estimates	t-Statistics
α_O	1.456*	10.588
α_{OO}	0.125*	4.035
α_{OG}	-0.021	-0.737
α_{OE}	-0.195*	-7.726
α_G	0.152**	2.392
α_{GO}	-0.033**	-2.287
α_{GG}	0.082*	6.134
α_{GE}	-0.033*	-2.787
α_E	-0.608*	-7.227
α_{EO}	-0.092*	-4.865
α_{EG}	-0.060*	-3.433
α_{EE}	0.228*	14.732

Note: O = Oil; G=Gas, E=Electricity.

*Significant at 1per cent level. ** Significant at 5 per cent level.

TABLE 2

Estimation Results for the Structural Index Equation

$(\ln S_t = \beta_1 + \beta_2 \ln Q'_t + \beta_3 \ln P'_t + \beta_4 \text{ Trend})$

Parameters	Coefficients	t-Statistics
β_1 (Constant)	-0.0798*	-4.5862
β_2 (Economic Growth)	-0.0761*	-5.7560
β_3 (Price)	0.0088	0.2197
b_4 (Time Trend)	-0.0089*	-4.6923
AR (1)	0.2921*	2.3342
R^2	0.9394	
Adjusted R^2	0.9318	
DW-Statistic	1.8683	Critical Value: d_U=1.72, 4-d_U=2.28
Prob. (F-Statistic)	0.0000	
__Breusch-Godfrey Serial Correlation LM Test__		
F-Statistic		0.0023
n*R-square		0.0028
__Chow Breakpoint Test: 1980__		
F-Statistic		1.5905
__Ramsey's RESET Test__		
F-Statistic		0.0082

*Significant at 1per cent level.

DW-Critical Values are at 5 per cent level. AR(1) is the auto-regressive term of order 1.

DW is the Durbin-Watson statistic. RESET is the Regression Specification Test.

Chow Breakpoint Test is the F-statistic for structural stability in both time periods.

TABLE 3

Estimation Results for the Intensity Index Equation

$$(\ln I_t = \gamma_1 + \gamma_2 \ln Q'_t + \gamma_3 \ln P'_t + \gamma_4 \text{ Trend})$$

Parameters	Coefficients	t-Statistics
γ_1 (Constant)	-0.0666	-1.5384
γ_2 (Economic Growth)	0.1659*	4.5126
γ_3 (Price)	0.0092	0.0803
γ_4 (Time Trend)	-0.0150*	-8.3854
R^2	0.7062	
Adjusted R^2	0.6803	
DW-Statistic	2.1391	Critical Value: d_U=1.65, 4-d_U= 2.35
Prob. (F-Statistic)	0.0000	
Breusch-Godfrey Serial Correlation LM Test		
F-Statistic		0.2207
n*R-square		0.2525
Chow Breakpoint Test: 1980		
F-Statistic		1.7077
Ramsey's RESET Test		
F-Statistic		4.3394

*Significant at 1 per cent level. DW-Critical Values are at 5 per cent level. DW is the Durbin-Watson statistic. RESET is the Regression Specification Test. Chow Breakpoint Test is the F-statistic for structural stability in both time periods.

significant at one per cent level and has the expected negative sign, reflecting technological improvement which tends to reduce the required input of all factors of production. The price term is again insignificant. Change in energy prices has no impact on energy intensity in Pakistan.

In the structural and intensity equations, all specification and diagnostic tests are satisfactory and give no indication of any problem of mis-specification with the estimated equations. Choosing 1980 as the sample breaking date, the Chow F-statistics confirm that the estimated values of the parameters yield a stable solution which is not sensitive to changes in the sample range. The RESET statistics reveal the correct specification of the model. The BG tests give no evidence of significant serial correlation in disturbance of the error term.

In order to focus on the statistically significant results, the insignificant explanatory variables are dropped from the two index equations and both the equations are re-estimated. Table 4 presents the re-estimated regression coefficients. The reported coefficients in both the equations are highly significant (at less than one per cent level). The aggregate intensity index coefficients are obtained by simply summing the respective coefficients from the structural and intensity indices, since the aggregate intensity index is the product of these two indices. In the intensity

TABLE 4

Results of Re-Estimated Regression Coefficients

	Coefficients	t-Statistics
Intensity Index:		
Economic Growth	0.1666*	4.7084
Time	-0.0150*	-8.5067
Structural Index:		
Economic Growth	-0.0755*	-5.9203
Time	-0.0089*	-4.7563
Aggregate Intensity Index:		
Economic Growth	0.0911	
Time	-0.0239	

*Significant at less than 1 per cent level.

index, the long-term time trend has been declining at a rate of 1.5 per cent per year, and the growth of output has been increasing at a rate of 16.7 per cent per year. Hence, the change in intensity index is due, very largely to the change (or increase) in output growth. In the structural index, the long-term time trend and the growth of output decrease at a rate of 0.9 per cent and 7.5 per cent per year, respectively. The intensity index is considerably more sensitive to changes in output and time trend than the structural index.

The overall impact of different factors on the aggregate intensity index is quite interesting. The economic growth component of the aggregate intensity index tends to decrease due to the negative impact of the structural index, but the overall impact of economic growth is positive due to the positive intensity index. The impact of time on the aggregate intensity index is negative due to the negative effect on both, the structural and the intensity indices. The results indicate that the autonomous time trend has led to a decrease in the aggregate intensity index at a rate of 2.4 per cent per year. Almost, 63 per cent of this amount is due to the intensity index and the remainder, due to structural change.

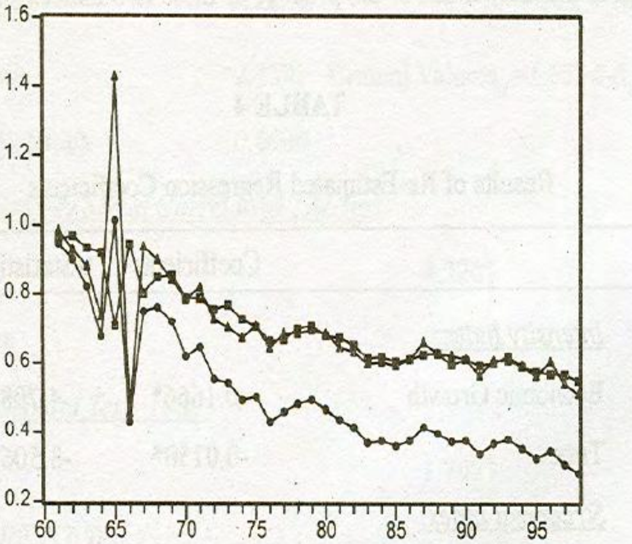

Figure 1

V. Concluding Remarks

The present analysis provides some insight into changes in the economic structure and the energy intensity that occurred in Pakistan over the 1960 to 1998 period. The results show that the cyclical component of the aggregate intensity index which is due to the changes in economic output tends to increase the aggregate intensity index at the rate of 9 per cent per year. The result implies that the efficiency of energy use decreases at the same rate, while the trend component which is due to changes in consumer preferences and technology improvements leads to a decrease in the aggregate intensity index by 2.4 per cent per year. Energy efficiency thus increases at the same rate. The results suggest that economic growth does not improve the efficiency of energy use within individual sectors, thus increasing the intensity index, because in Pakistan non-energy-intensive sectors are found to be particularly sensitive to economic growth. This means that energy intensive sectors play a dominant role in improving energy efficiency in the country. The time trend is also a major factor in the change in the intensity index. The critical point for policy planning is better understanding of changes in energy use. If autonomous time trends, due to whatever reasons, may reasonably be expected to reduce energy intensity in the future significantly, then the cost of energy production could be reduced significantly. The present analysis suggests that autonomous efficiency improvement on non-price induced changes could play a significant role in improving aggregate energy efficiency in the country in future.

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APPENDIX

Derivation of Aggregate Intensity Index

The derivation of aggregate intensity index is adopted from Boyd, et al., (1987). Suppose C, Y and A be the rate of aggregate energy use, output and aggregate energy intensity, respectively all being implicit functions of time. Further, let C_i and Y_i be the rate of energy use and output, respectively in sector i,

$$i_i = \frac{C_i}{Y_i} \text{ the energy intensity in sector i,}$$

and $$s_i = \frac{Y_i}{Y} \text{ the output share of sector i.}$$

The aggregate energy intensity:

$$A = \frac{C}{Y} = \sum_i \frac{C_i}{Y_i} \cdot \frac{Y_i}{Y} = \sum_i i_i s_i \qquad (7)$$

Differentiating with respect to time t and dividing by A gives:

$$\frac{dA}{dt} \cdot \frac{1}{A} = \sum_i \frac{di_i}{dt} \cdot \frac{s_i}{A} + \sum_i \frac{ds_i}{dt} \cdot \frac{i_i}{A}$$

$$= \sum_i \left(\frac{di_i}{dt} \cdot \frac{1}{i_i}\right)\left(\frac{i_i s_i}{A}\right) + \sum_i \left(\frac{ds_i}{dt} \cdot \frac{1}{s_i}\right)\left(\frac{i_i s_i}{A}\right)$$

$$= \sum_i \left(\frac{di_i}{dt} \cdot \frac{1}{i_i}\right) x_i + \sum_i \left(\frac{ds_i}{dt} \cdot \frac{1}{s_i}\right) x_i \qquad (8)$$

where $$x_i = \frac{i_i s_i}{A}$$

$$= \frac{C_i}{Y_i} \cdot \frac{Y_i}{Y} \cdot \frac{1}{A}$$

$$= \frac{C_i}{Y_i} \cdot \frac{Y_i}{Y} \cdot \frac{Y}{C}$$

$$= \frac{C_i}{C} \tag{9}$$

$x_i = \frac{C_i}{C}$ is the energy consumption share of sector *i*. Integrating the right-hand-side expression of (8) over time interval (t-1,t) exactly requires explicit expression, for i_i, s_i and x_i as functions of time. Since these are unavailable, the integral is commonly approximated as follows:

$$\ln\left(\frac{A_t}{A_{t-1}}\right) = \sum_i \ln\left(\frac{i_{i,t}}{i_{i,t-1}}\right)\left(\frac{x_{i,t-1} + x_{i,t}}{2}\right) + \sum_i \ln\left(\frac{s_{i,t}}{s_{i,t-1}}\right)\left(\frac{x_{i,t-1} + x_{i,t}}{2}\right) \tag{10}$$

where, with a slight abuse of notation, all variables are now indexed according to year. Taking the antilog then gives:

$$\frac{A_t}{A_{t-1}} = \exp\left[\sum_i \ln\left(\frac{i_{i,t}}{i_{i,t-1}}\right) \cdot \left(\frac{x_{i,t-1} + x_{i,t}}{2}\right)\right] \cdot \exp\left[\sum_i \ln\left(\frac{s_{i,t}}{s_{i,t-1}}\right) \cdot \left(\frac{x_{i,t-1} + x_{i,t}}{2}\right)\right. \tag{11}$$

$$\frac{A_t}{A_{t-1}} = \frac{I_t}{I_{t-1}} \cdot \frac{S_t}{S_{t-1}}$$

where,

$$\frac{I_t}{I_{t-1}} = \exp\left[\Sigma \ln\left(\frac{i_{i,t}}{i_{i,t-1}}\right)\left(\frac{x_{i,t-1} + x_{i,t}}{2}\right)\right]$$

$$\frac{S_t}{S_{t-1}} = \exp\left[\Sigma \ln\left(\frac{s_{i,t}}{s_{i,t-1}}\right)\left(\frac{x_{i,t-1} + x_{i,t}}{2}\right)\right].$$