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An Overview for Decomposition of Industry Energy Consumption

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Abstract: This study is to overview several methodological related to the decomposition approach based on the energy consumption. Based on a comparison of the size of the residual term that the adaptive weighting Divisia and the simple average Divisia index method, is most robust, exhibiting the smallest residual term. A complete decomposition model also introduced here has solved a residual problem.

Key words: Decomposition model, Energy consumption

INTRODUCTION

Industry is a major consumer of energy and its pattern of energy consumption has a great bearing on the energy balance of an economy. It is becoming increasingly clear that the quantitative assessment of various factors affecting industrial energy consumption is essential not only for a better understanding of past behaviors of industrial energy consumption, but also for forecasting industrial energy demand and particularly estimating energy requirements of alternative industrialization strategies in developing countries.

Recently, Reitler, Rudolph and Schaefer[1] (designated the RRS method hereafter) proposed a method for decomposing industrial energy consumption into three major components; output level, energy intensity and structural change (or a change in the industrial composition) where disaggregated industrial data are available. But the residual in most studies was omitted. The residual is omitted that causes a large estimation error, the residual is regarded as an interaction that still leaves a new puzzle for the reader. The Residual term is a common problem in the general decomposition models.

The objective of this study is to discuss several methodological related to the decomposition approach based on the energy consumption. Based on a comparison of the size of the residual term that the adaptive weighting Divisia and the simple average Divisia index method, is most robust, exhibiting the smallest residual term. A complete decomposition model also introduced here has solved a residual problem.

Previous studies: A number of studies have been conducted involving the decomposition of energy consumption and energy intensity. Such studies are useful for understanding evolving energy consumption patterns, the relative contribution of different factors affecting changes in energy consumption and for predicting future energy demand. Related studies include Reitler *et al.*[1], Li[2], Howarth[3], Torvanger[4], Park[5], Liu *et al.*[6], Ang and Lee[7], Ang[8], Greening[9] and Sun[10,11].

For example, Reitler *et al.*[1] proposed a method to decompose changes in industrial energy consumption into three factors, namely production quantity, production structure and specific consumption. Li[2] used the Divisia index approach to examine the structural change and energy intensity of 17 manufacturing sectors in Taiwan during 1971 to 1985. Their study found that changes in sectoral energy intensities played a major role in affecting Taiwan's manufacturing aggregate fuel and electricity intensities during that period, while the structural effect was relatively insignificant. Howarth *et al.*[3] decomposed the manufacturing energy use change in eight OECD countries from 1973 to 1987 by the Laspeyres index method and compared the results to those obtained by using the Divisia index method. They discussed the output, industry structure and energy intensity effects and found minor differences between the Laspeyres index and the Divisia index calculations. Another study for nine OECD countries was conducted by Torvanger[4]. He used the Divisia approach to decompose the change of CO_2 emissions related to energy use. His study found that the major contribution to reducing CO_2 intensity m the studied countries was a reduction in energy intensity and a reduced production share of energy intensive sectors. Park[5] selected three factors, including structural change, energy intensity and output level, to decompose the industrial energy consumption in Korea for 1973-89. Liu *et al.*,[6] proposed two parametric Divisia index methods that transformed the integral path problem in the Divisia index into a parametric estimation. Also, an adaptive weighting Divisia method was introduced with detailed mathematical analysis to estimate the parameter values in the case of Singapore industry. Ang and Lee[7] extended the work of Liu *et al.*[6] and compared five specific decomposition methods by using data from singapore and Taiwan. They concluded that the

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decomposition results were method dependent. Ang[8] also extended the methods to deal with the decomposition of industrial energy consumption at multiple levels of sector disaggregation, which allowed the more adequate use of the decomposition method if the energy and output data were available. Greening[9] proposed comparison of six decomposition methods for manufacturing in 10 OECD countries. Sun[10,11] presented a complete decomposition model to solve residual terms.

Methods of decomposition: In Fig. 1 summarizes the general framework of decomposition.

In multiplicative (Additive) decomposition, the decomposed components are estimated independently and their product(sum) will normally be different from I_{tot} ($\triangle E_{tot}$) . Thus, we have:

$$I_{tot} = R_{pdn}R_{str}R_{int}D_m$$
$$E_{tot} = \triangle E_{pdn} + \triangle E_{str} + \triangle E_{int} + D_a$$

where D_m and D_a are respectively the residual terms which in multiplicative and additive decomposition.

Let E_0 and E_1 denote the total energy consumption in industry in year 0 and year t respectively. In the energy consumption approach, the change energy consumption between the two years, $\Delta E_{tot} = E_t - E_0$, is split into the following components:

$$\Delta E_{tot} = \Delta E_{pdn} + \Delta E_{str} + \Delta E_{int} + D \quad (1)$$

where the four terms on the right-hand side of Eq. 1 are changes in energy consumption arising from aggregate production (production effect), production structure (structural effect) and energy intensity (intensity effect) and a residual term respectively. The residual term D is given by the difference between ΔE_{t0t} and the sum of the estimates of the three effects. Decomposition methods based on Eq. 1 have been proposed in Boyd *et al.*[12], Hankinson and Rhys[13], Liu *et al.*,[6], Park[5] and Reitler *et al.*[1].

The decomposition formulae for the two general parametric Divisia methods, referred to as the PDM1 and the PDM2, are as follows:

Parametric Divisia Methods 1 (PDM1)

$$\Delta E_{pdn} = [E_o + \alpha(E_t - E_o)] \ln (y_t/y_0) \quad (2)$$

$$\Delta E_{str} = \sum[E_{i,0} + \beta_i(E_{i,t} - E_{i,0})] \ln(S_{i,t}/Si_{,0}) \quad (3)$$

$$\Delta E_{int} = \sum[E_{i,0} + \tau_i(E_{i,t} - E_{i,0})] \ln(I_{i,t}/I_{i,0}) \quad (4)$$

Parametric Divisia methods 2 (PDM2):

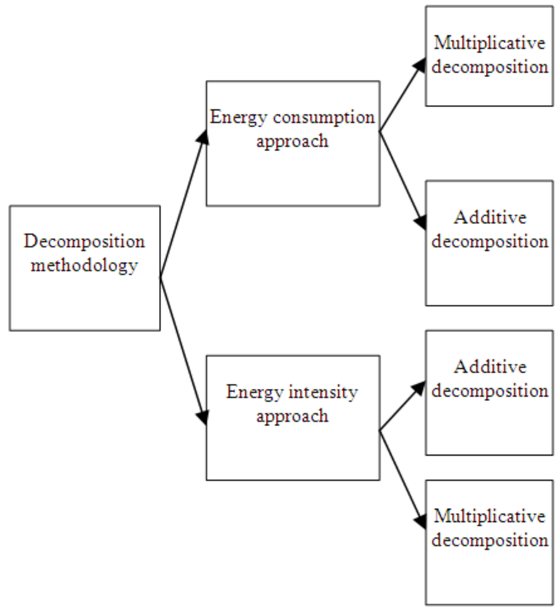

Fig. 1: Decomposition mythology: A general network

$$\Delta E_{pdn} = [I_0 + \alpha(It - I_0)] (Y_t - Y_0) \quad (5)$$

$$\Delta E_{str} = \sum[I_{i,0}Y_0 + \beta_i(I_{i,t}Y_t - I_{i,0}Y_0)](S_{i,t} - S_{i,0}) \quad (6)$$

$$\Delta E_{int} = \sum[Y_{i,0} + \gamma_i(Y_{i,t} - Y_{i,0})](I_{i,t} - I_{i,0}) \quad (7)$$

where $0 \leq \alpha$, β_i and $\gamma_I \leq 1$ and the summations are taken with respect to subscript I and overall industrial sectors at the level of disaggregation considered.

The values of the parameters in Eq. 2-7 can also be treated as weights assigned to the appropriate variable(s) in year 0 and in year t in the decomposition.

We consider the following five specific decomposition methods, in both additive and multiple forms:

(1) Laspeyres Based Parametric Divisia Method 1 (LAS-PDM1):

a special case of PDM1 with $\alpha = \beta_i = \gamma_i = 0$

(2) Simple Average parametric Divisia Method 1 (AVE-PDM1):

a special case of PDM1 with $\alpha = \beta_i = \gamma_i = 0.5$

(3) Laspeyres Based Parametric Divisia Method 2 (LAS-PDM2):

a special case of PDM2 with $\alpha = \beta_i = \gamma_i = 0$

(4) Simple Average Parametric Divisia Method 2 (AVE-PDM2):

a special case of PDM2 with $\alpha = \beta_i = \gamma_i = 0$

(5) Adaptive Weighting Parametric Divisia Method (AWT-PDM1):

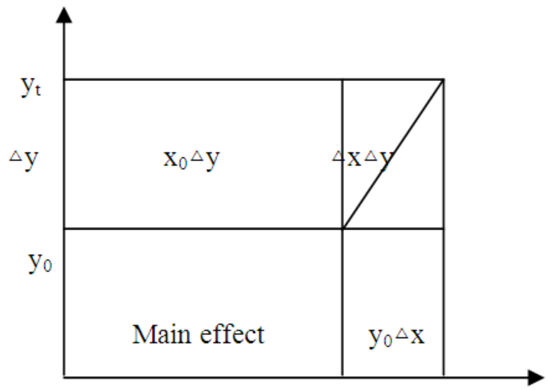

Fig. 2: Complete decomposition process of the change

The parameter values are obtained by equating Eq. 2 with 5, Eq. 3 with 6 and Eq. 4 to 7.

Time series decomposition: In time series analysis, decomposition is carried out between years t and t + 1, where t varies from the first year (year 1) to the year preceding the last year (year N) of a time series. There are altogether (N – 1) sets of decomposition results from which the overall or cumulative decomposed effects from year 1 to any year in the series can be constructed.

A complete decomposition model: The basic thinking is to decompose the residual according to the principle of jointly created and equally distributed

Assume that V= x-y, i.e. variable V is determined by factor x and y. During the time period [0, t], the change of variable ΔV can be calculated by:

$$\Delta V=V_t-V_0=x_t y_t-x_0 y_0=(x_t-x_o)y_0+(y_t-y_0)x_0+(x_t-x_0)(y_t-y_0) \quad (8)$$

Or:

$$=y_0\Delta x+x_0\Delta y+\Delta x\Delta y \quad (9)$$

where $y_0\Delta x$ and $x_0\Delta y$ are the contributions of the change of factor x and y to the total change of variable V, respectively. The third term$\Delta x\Delta y$ is the residual in the general decomposition model.

Figure 2 illustrated the process of the change.

According to the principle of jointly created and equally distributed. The decomposition model for the two-factor system is as follows:

$$\Delta V=V_t-V_0 \quad (10)$$

And the contributions of the factors are:

$$X \text{ effect} == y_0\Delta x+1/2\Delta x\Delta y \quad (11)$$

$$Y \text{ effect} = x_0\Delta y+1/2\Delta x\Delta y \quad (12)$$

And:

$$\Delta V= X \text{ effect} + Y \text{ effect}$$

CONCLUSION

As to the choice between multiplicative or additive form, from previous studies show that time series decomposition is superior to period wise decomposition and the AVE- PDM1, AVE-PDM2 and AWT-PDM is superior to the Laspeyres.

The complete decomposition model provides an available method of factor analysis, the advantage of model is that there is no residual term, but it is not infeasible. We can use try error method to amend to weight.

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