A New Approach to Measuring the Energy Productivity of an Economy

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Introduction

Energy Productivity, which is defined as the ratio of output divided by energy consumption, is a useful indicator for understanding the energy efficiency of an industry or an economy.

Conventionally, to measure the energy productivity for an economy, we take **the GDP** from the National Income Accounts as output and **the energy consumption** in terms of liter oil equivalent of an economy from the Energy Balance Table as energy consumption.

The ***GDP*** *from the National Income Accounts*

The ***energy consumption*** *from the Energy Balance Table*

However, this conventional approach ignores the heterogeneous characteristics of energy inputs as well as outputs.

1. Christensen and Jorgenson (1970)

2. Gollop and Jorgenson (1980)

3. Liang and Jorgenson (1998)

All above have taken into account the heterogeneous characteristics of the inputs to calculate the total factor productivity.

4. Liang (2005) further considers the **heterogeneous characteristics** of the output as well as inputs related with industrial structure changes to measure the total factor productivity.

However, few, if any, researches have actually considered the industrial structure changes' effect to measure the energy productivity.

Consequently, **the objective of this paper** is:

1. To propose a new method to incorporate the changes in industrial structure as well as the energy quality changes into the measurement of energy production.

2. An empirical study, which employs the industry-level data of Taiwan during 1981-99, is also conducted.

Methodology

Given the energy consumption as E and value added as Y, the energy productivity (PDE) of an industry can be defined as:

$$PDE = \frac{Y}{E} \tag{1}$$

This Conventional approach ignores the **heterogeneous characteristics** of energy inputs as well as outputs. Taking the logarithms of equation (1), we get:

$$\ln PDE = \ln Y - \ln E \tag{2}$$

For the data at discrete points in time, the difference between successive logarithms of energy productivity or energy productivity changes can be expressed as:

$$\begin{aligned} \ln PDE(T) - \ln PDE(T-1) &= (\ln Y(T) - \ln E(T)) - (\ln Y(T-1) - \ln E(T-1)) \\ &= (\ln Y(T) - \ln Y(T-1)) - (\ln E(T) - \ln E(T-1)) \end{aligned} \tag{3}$$

For considering the heterogeneous characteristics of energy inputs, the aggregate energy (E) has to be decomposed into **component energy**, such as **coal, oil products, natural gas, and electricity** before aggregation. Following Gollop and Jorgenson (1980), we employ the translog index to do the aggregation. The translog index of changes in energy inputs can be expressed as:

$$\ln E(T) - \ln(E(T-1) = \sum_{i=1}^{m} S_{E_i} (\ln E_i(T) - \ln E_i(T-1) = \ln E^c(T) - \ln E^c(T) + EQ \qquad (4)$$

Where, $S_{E_i} = \frac{1}{2}\left[S_{Ei}(T) - S_{Ei}(T-1)\right] = \frac{P_{E_i} \times E_i}{\sum_{i=1}^{m} P_{E_i} \times E_i}$

= The share of energy i in the aggregation energy cost (i = 1,…m)

EQ = Energy quality change effect due to changes in energy consumption structure of an industry

$E^c(T)$ = Conventional energy consumption (in liter oil equivalent).

For taking care of the reallocation effect among industries, or energy reallocation effects, this paper employs the following translog index to aggregate the industry-level energy input into the energy input of the whole economy:

$$\begin{aligned}\ln E^A(T)-\ln(E^A(T-1)) &= \sum_{x=1}^{P} S_{E_x}(\ln E_x(T)-\ln E_x(T-1)) \\ &= \ln E(T)-\ln E(T-1)+ERE \\ &= \ln E^C(T)-\ln E^C(T-1)+EQ+ERE\end{aligned} \quad ,\ x=1,\ldots,P \qquad (5)$$

Where **ERE = Energy quality changes due to energy reallocation among industries, or energy reallocation effects**.

And $$\bar{S}_{EX}=\frac{1}{2}\left[S_{EX}(T)+S_{EX}(T-1)\right]$$

$$S_{EX}=\frac{P_{EX}\times E_X}{\sum_{X=1}^{P}P_{EX}\times E_X}$$

= The share of industry x's energy cost in the aggregate industry or the whole economy.

Similarly, since the output of an aggregate industry or the whole economy is an aggregate of individual industry-level output, this paper employs the translog index to aggregate its output. The translog index of **output change** can be expressed as:

$$\ln Y^{A}(T)-\ln Y^{A}(T-1)=\sum_{X=1}^{P}\bar{S}_{YX}\left[\ln Y_{X}(T)-\ln Y_{X}(T-1)\right]=\ln Y(T)-\ln Y(T-1)+OQR \qquad (6)$$

x = 1, …, P industry

Where **OQR = output quality changes due to output reallocation among industries or output reallocation effect**.

And $\bar{S}_{YX}=\frac{1}{2}\left[S_{YX}(T)+S_{YX}(T-1)\right]$

$\bar{S}_{YX}$ = the value share of industry x's total output in the aggregate industry or the whole economy

Finally, we define **the new energy productivity (PDE^N)** indicator of the whole economy as follows:

$$PDE^N = \frac{Y^A}{E^A} \tag{7}$$

And, the change rate of PDE^N is:

$$\ln PDE^N(T) - \ln PDE^N(T-1) = \left[\ln Y^A(T) - \ln Y^A(T-1)\right] - \left[\ln E^A(T) - \ln E^A(T-1)\right] \tag{8}$$

The difference between equation (3) and equation (8) reveals that the difference between the new energy productivity growth and the conventional is:

$$\begin{aligned}&\left[\ln PDE^N(T) - \ln PDE^N(T-1)\right] - \left[\ln PDE(T) - \ln PDE(T-1)\right]\\ &= OQR - ERE - EQ\\ &= (\text{Output reallocation effect} - \text{Energy reallocation effect}) - \text{Energy quality change rate}\\ &= \text{Industrial structure change effect} - \text{Energy quality change rate}\end{aligned} \tag{9}$$

Equation (9) implies that the energy productivity measured by the new method differs with the conventional one by industrial structural change effect minus energy quality change effect.

Data Compilation

The [redacted] runs from 1981 to 1999.

The [redacted] ted into the following 32 sectors:

[redacted] ture, industry (including mining, manufacturing, water, electricity & g [redacted] onstruction), transportation and services],

(food processing, beverage & tobacco, textiles, clothes & wearing apparel, leather & leather products, wood & furniture products, paper & printing, chemicals & plastics, rubber products, non-metallic minerals, basic metals, metal products, machinery & equipment, electrical machinery & electronics, transportation equipment, and miscellaneous),

(commerce, finance & insurance, and personal services),

(coal, natural gas, oil refining, and electricity).

It is noted that , because the profit- maximizing rule is not applicable to the government service sector. In addition, in the National Income Account, the output of the government service sector is identical with its labor compensation.

Real Value Added

The industry-level for value added at constant prices (1996 prices) during 1981-99 comes from the DGBAS.

Energy Input

Energy input consists of [redacted], [redacted], [redacted] and [redacted]. We calculated the traslog index of energy. [redacted] c [redacted] e [redacted] sume [redacted] able in Energy Balance in Taiwan, R.O. [redacted] s [redacted] E [redacted] mmiss [redacted] A.

Special treatment for the [redacted] rg [redacted] ti [redacted] the u [redacted] or: consumption o [redacted] ai [redacted] ri [redacted] mptio [redacted] er generation, pumping storage and tran [redacted] ss [redacted] s [redacted] types [redacted] y are calculated by using the energy consum [redacted] n [redacted] on [redacted] nd th [redacted] prices of types of energy.

The price of [redacted] on [redacted] e [redacted] al, ar [redacted] omes from Commodity Price Monthly [redacted] C [redacted] m [redacted] rt Tra [redacted] ly, MOF. The price of coal gas is impute [redacted] as [redacted] a [redacted] rice, [redacted] price of electricity varies with its usage, beca [redacted] e [redacted] p [redacted] denti [redacted] commercial use is adopted.

The data on prices of [redacted] obtai [redacted] the Chinese Petroleum Corporation and Ener [redacted] earbook, En [redacted] Com [redacted]

Empirical Result

1. registered **1.61** percent per annum during 1981-99. In contrast, the conventional energy productivity was 1.03 percent per annum (see Table 1). The energy productivity growth by the new method in Taiwan was 0.58 percentage point or 36.1 percent greater than that of the conventional one during 1981-99.

2. and contributed to a **0.39** percentage and **0.19** percentage differences between the new energy productivity and the conventional one during 1981-99 in Taiwan.

3. The energy productivity growth by the new method recorded 1.31 percent per annum and 1.91 percent per annum during 1981-90 and 1990-99 respectively, . In the meantime, the energy productivity growth by the conventional method was 1.33 percent and 0.73 percent per annum respectively, . **And hence, the policy implication by using the conventional energy productivity method might be misled**.

Table 1. The Growth of Energy Productivity in Taiwan, 1981-1999

Year	1981-99	1981-90	1990-99	1981-85	1986-90	1991-95	1996-99
(1) Growth of Energy Productivity (New Method)	**1.61**	1.31	1.91	1.10	1.47	1.52	2.40
(2) Growth of Energy Productivity (Without Structural Change)	1.22	0.38	2.07	0.27	0.46	2.66	1.32
(3) Growth of Energy Productivity (Conventional)	1.03	1.33	0.73	1.33	1.33	1.22	0.12
(4)=(2)-(3) Energy Quality Change Effect	**0.19**	-0.95	1.34	-1.06	-0.86	1.45	1.21
(5)=(1)-(2) The Effect of Structural Changes	**0.39**	0.93	-0.16	0.84	1.00	-1.14	1.07
(¡ Ï Output Reallocation	**0.27**	0.19	0.35	0.29	0.11	0.48	0.20
(¡ Ð Energy Reallocation	**-0.12**	-0.74	0.51	-0.55	-0.89	1.62	-0.88

4. From the findings of (1) to (3), we conclude that the energy efficiency of Taiwan during 1981-99 performed better if the new method was employed instead of the conventional one.

5. As forementioned, the effect of a structural change is the difference between output reallocation effect and energy reallocation effect. [redacted] was positive (**0.27** percent per annum), while [redacted] was negative (**-0.12** percent per annum) in Taiwan during 1981-99. (See Table1) The positive output reallocation effect could be contributed to the increase in the share of high value-added industries in GDP during 1981-99. Conversely, the negative energy reallocation effect indicated that the share of energy intensive industries in final energy consumption had decreased during 1981-99. Both effects help to push up the energy productivity by the new method greater than the conventional energy productivity in Taiwan during 1981-99.

6. Since the energy efficiency measured by new method can analyze the contribution of the industrial structure changes via output reallocation effect and input reallocation effect on the energy productivity of an economy. [redacted] blem of energy efficiency of an economy and p [redacted] for government to adopt so as to increase its [redacted].

<u>The End</u>