An Inquiry into the Sources of Change in Industrial Energy Use in the Japanese Economy: Multiple Calibration Decomposition Analysis

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Abstract: Decomposition methodologies are necessary to examine the causal factors of energy use trends in an economy. This paper suggests a new approach -the Multiple Calibration Decomposition Analysis (MCDA)- to investigate the sources of change in industrial energy use in the Japanese economy. The multiple calibration technique is utilized for an *ex post* decomposition analysis of structural change between periods, enabling distinction between price substitution and technological change for each sector. This paper explains the theoretical properties of MCDA and applies it to an empirical case -the change in energy use in Japanese industry from 1970 to 1990. This paper clarifies how industrial energy use was affected by price substitution or technological change through the experience of the two oil crises, focusing on energy-intensive industry. The paper shows that technological change played an important role in reducing industrial energy use in the Japanese economy. Remarkably, oil-saving technological change advanced by 60% or more in energy-intensive industry during the 1980s.

Keywords: *calibration, decomposition, industrial energy efficiency, price substitution, technological change*

1. Introduction

New interest has arisen in energy demand analysis, reflecting the rapid fluctuation of oil prices, and by the same token the problem of climate change (e.g., Dowlatabadi and Oravetz [1], Metcalf [2], Sue Wing [3]). From a historical point of view, discussions of energy demand analysis have been lively since the oil crises of the 1970s. A vast amount of literature has been devoted to such analyses, including classic works by Hudson and Jorgenson [4] Berndt and Wood [5], Manne [6], Borges and Goulder [7], and Solow [8].

Change in energy use is caused by various factors, including price substitution and autonomous technological development. Determining the contribution of these factors to energy use trends is a difficult but necessary quest, for which decomposition techniques are required. In this context, many decomposition methodologies have been accepted for the quantification of causal factors: for example, Index Decomposition (ID; see, e.g., Ang and Zhang [9], Hoekstra [10]) and Structural Decomposition Analysis (SDA; see, e.g., Rose and Casler [11], Rose [12], Hoekstra [10]), which are well-established decomposition methodologies for this purpose.

This paper proposes a new approach -the Multiple Calibration Decomposition Analysis (MCDA)- to investigate the driving forces of change in industrial energy use in the Japanese economy. The MCDA methodology was originally proposed by Okushima and Tamura [13]. The multiple calibration technique is applied to an *ex post* decomposition analysis of structural change between periods, enabling distinction between price substitution and technological change for each sector. This approach has sounder microtheoretical foundations than conventional methods.

In this paper, the MCDA methodology is applied to the decomposition analysis of change in industrial energy use following the oil crises of 1970-1990, focusing on energy-intensive industry. This period includes two oil crises, during which a rise in oil prices influenced the

Japanese economy to an enormous extent. Moreover, energy use by industry, especially energy-intensive industry, is a key factor of change in energy use in the economy. This is an appropriate area to apply this method to evaluate the extent to which industrial energy use was affected by price substitution or technological change. Besides that, this kind of analysis may add to our stock of information for future Japanese energy or environmental policy.

The remainder of the paper is structured as follows. Section 2 explains the MCDA methodology. Section 3 applies the method to an empirical case, energy use in Japanese industry from 1970 to 1990. The final section provides concluding remarks.

2. Methodology

This section outlines a new decomposition methodology -the Multiple Calibration Decomposition Analysis (MCDA)- originally proposed by Okushima and Tamura [13]. The method explicitly defines two-tier constant elasticity of substitution (CES) production functions as an underlying model to separate price substitution effects from other types of technological change. For more information on CES functions, see, e.g., Shoven and Whalley [14]. The MCDA decomposes structural change in the economy, shown by the change in factor inputs per unit of output between periods (CFI), into two parts: one attributable to price substitution (PS) and the other attributable to technological change (TC).

This paper assumes the model structure in the MCDA to be as shown in Fig. 1. The two models which are identical except for the number of sectors are employed in the following section. The production functions are given by two-tier constant-returns-to-scale CES functions. The model comprises capital *K*, labor *L*, energy aggregate *E*, and material aggregate *M*, as well as energy and material inputs. Capital *K* and labor *L* are the primary factors of production.

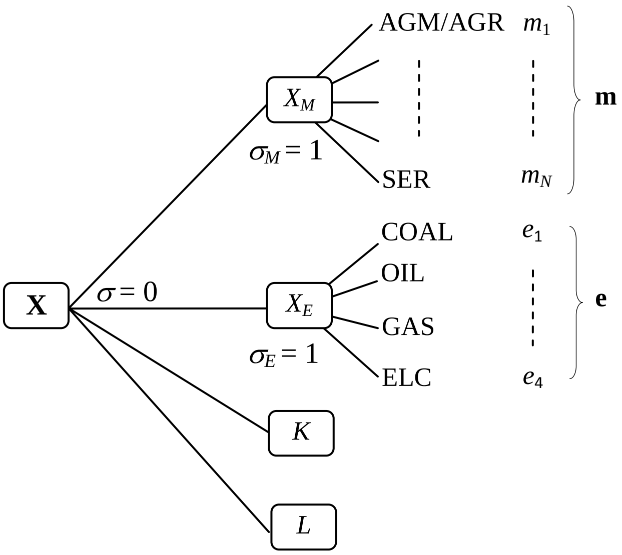

Fig. 1. The model (N = 5 in the 9-sector model and N=14 in the 18-sector model)

Fig. 2 illustrates the MCDA methodology. The MCDA can exactly decompose the CFI into PS and TC. PS, which depends upon the elasticity of substitution (σ) and the change in relative prices between the periods ($p^{t-1} \to p^t$), represents the price substitution effects, while TC represents those portions of the factor input change that cannot be interpreted by the price substitution effects ($\lambda^{t-1} \to \lambda^t$), including autonomous technological development. The counterfactual points of the MCDA mean the junctures into which the effects of the relative price change between the initial and terminal periods are incorporated. From a theoretical perspective, PS means a change in factor inputs along the production function, while TC refers to shifts in the production function. Therefore, the decomposition of the MCDA is consistent with production theory in microeconomics. The method has clear microtheoretical foundations; then, the decomposition components can be interpreted in a theoretically meaningful way. For more details of the MCDA methodology, see Okushima and Tamura [13].

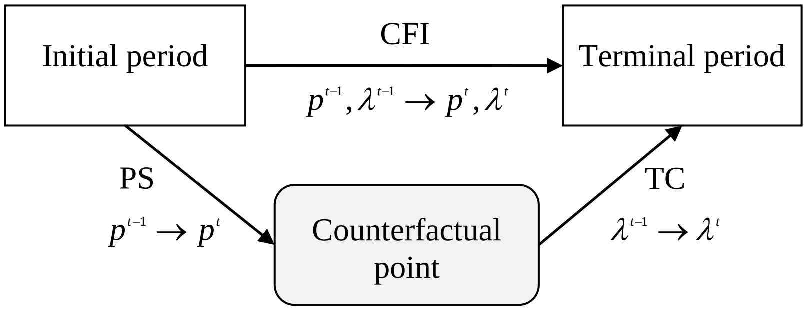

Fig. 2. The methodology

3. Empirical results

This paper applies the Multiple Calibration Decomposition Analysis (MCDA) to investigate the sources of change in industrial energy use in Japan. While Okushima and Tamura [13] is a comprehensive study of changes in energy use and carbon dioxide emissions in the Japanese economy from 1970 to 1995, this paper centers on the change in industrial energy use, especially energy-intensive industry, in the 1970-1990 period. This period includes two oil crises: one in 1973 and a second in 1979. It is widely recognized that skyrocketing oil prices had a huge influence on the Japanese economy during this time, and that the structural changes had a great impact on manufacturing energy use (see, e.g., IEA [15]). This situation presents a typical context in which to apply the method, which can provide a detailed analysis of how change in industrial energy use was caused by price substitution or technological change.

This section analyzes the change in industrial energy use, using data from 1970 to 1990. Nominal outputs (factor inputs) are obtained from the 1970-75-80 and 1985-90-95 Linked Input-Output Tables (Management and Coordination Agency). Real outputs (factor inputs) are obtained by deflating the nominal values by the corresponding prices. Prices of goods and services are from the Domestic Wholesale Price Index (Bank of Japan) or Deflators on Outputs of National Accounts (Economic Planning Agency). Capital and labor prices are estimated following Ito and Murota [16]. In the MCDA, these prices are normalized such that the prices in the initial period are at unity. This units convention, originally proposed by Harberger [17] and widely adopted since (Shoven and Whalley[14], [18], Dawkins et al. [19]), permits the analysis of consistent units across time. The elasticities of substitution are assumed, for the purposes of simplicity, to be $\sigma = 0$ and $\sigma_E, \sigma_M = 1$ as in Fig. 1; nevertheless, these estimates are not significantly different from those in the previous literature that econometrically estimates these elasticities for the Japanese economy (see, e.g., Okushima and Goto [20]).

As in Fig. 1, the sectors are classified into five industries and four energy inputs in the 9-sector model. On the other hand, the sectors are classified into fourteen industries and four energy inputs in the 18-sector model. Please see the notes accompanying Table 1 and Table 2 for the sector classification.

First, Fig. 3 is a summary of the trends in Japan’s energy use (see, e.g., IEA[15]). Energy use in the Japanese economy has continuously increased in volume since the 1970s. However, the growth rate in the early 1980s after the oil crises was lower than in other periods. It is recognized that Japan succeeded in the field of energy conservation and substitution from oil as a result of the lessons of the oil crises (see, e.g., Gregory [21]). The proportion of oil in both primary supply and final consumption has decreased after the oil crises, while the proportions of gas and electricity have increased, mainly owing to the use of natural gas and nuclear power. The primary supply of coal, such as for power generation, is gradually increasing while final consumption has remained almost unchanged, and its share of final consumption is diminishing. Following the trend of final energy consumption, the changes in factor inputs (CFIs) also reflect this experience. Table 1 shows that the CFIs for coal and oil are mostly negative while those for gas and electricity are the opposite. The CFIs should be caused by various effects such as price substitution or technological change.

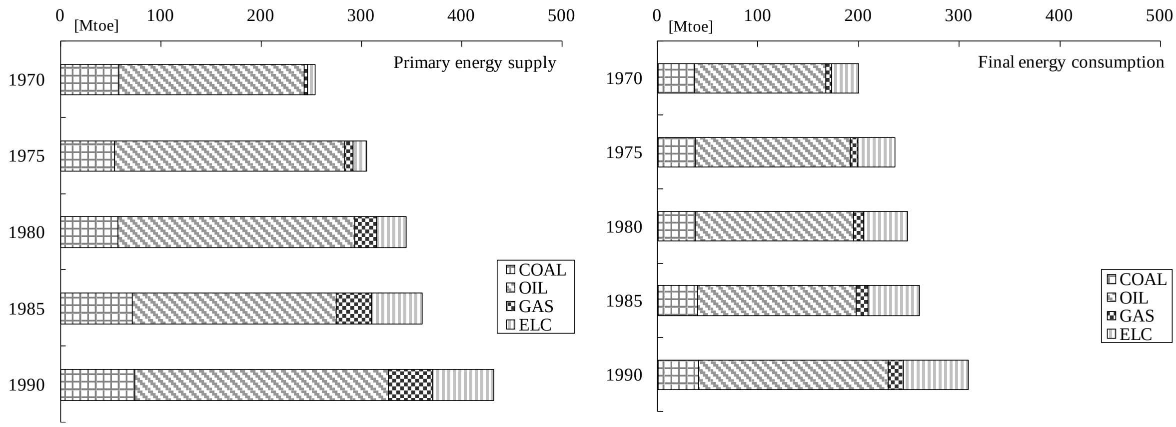

Fig. 3. Primary energy supply and final energy consumption in Japan (Source: IEA[22])

Table 1 illustrates the decomposition of the CFIs by the MCDA with the 9-sector model. The MCDA decomposes the CFI into technological change (TC) and price substitution (PS). The advantage of the method is that it can evaluate these causal factors in terms of types of energy, sectors, or periods, respectively. Table 1 demonstrates that in the 1970s the PSs for oil are negative in all sectors while those for the other types of energy are mostly positive. This means that the rise in oil prices decreased the factor inputs of oil while the demand for coal, gas, and electricity increased because of relatively low prices. Conversely, the PSs for oil become positive in the 1980s, reflecting the fall in oil prices, while those for other types of energy, coal and electricity, become negative. It is remarkable that the PSs for coal form a sharp contrast with those for oil. The PSs for gas are mostly positive. This indicates that the industries had expanded their use of gas because of its price advantage. Thus, the MCDA can clearly show the price substitution effect consistent with the production theory; that is, substitution from inputs with higher prices to those with lower prices.

Table 1 also reveals that the TCs for oil are largely negative in the 1980s. Theoretically, this means that the CFIs for oil had decreased to a greater degree than was expected from the price substitution effect (PS). This is consistent with other empirical studies, such as Han and Lakshmanan [23] and Unander et al. [24], which suggest that improvements in energy efficiency took place in the period even without higher prices. The result indicates that oil-saving technological change had occurred primarily in the 1980s rather than in the 1970s. In addition, the TCs for coal are almost all negative throughout the periods. The result shows the importance of technological change in reducing industrial energy use.

Table 1. Decomposition of the changes in energy inputs

	Sector														
Input/	AGM			EII			MAC			OMF			SER		
Period	CFI	TC	PS	CFI	TC	PS	CFI	TC	PS	CFI	TC	PS	CFI	TC	PS
COAL															
(i)	-59.5	-89.7	30.2	29.6	22.9	6.7	-70.1	-77.6	7.5	-43.6	-50.8	7.1	-5.2	-22.6	17.4
(ii)	-23.6	-67.4	43.8	-31.7	-54.3	22.6	-19.2	-52.6	33.4	-14.1	-49.1	35.0	-0.3	-36.4	36.0
(iii)	-68.5	-59.4	-9.1	-36.1	-29.9	-6.2	-60.1	-52.7	-7.4	-36.8	-29.4	-7.4	-32.7	-24.8	-7.8
(iv)	32.2	57.8	-25.6	-25.4	-6.4	-19.0	-3.6	18.1	-21.7	-22.5	-0.4	-22.1	-19.3	3.9	-23.2
OIL															
(i)	-9.2	-5.2	-4.0	0.6	21.9	-21.3	-51.0	-30.3	-20.7	-6.6	14.4	-21.0	-22.0	-8.5	-13.4
(ii)	-1.5	-0.5	-1.1	-8.2	7.4	-15.7	-36.8	-28.6	-8.2	7.6	14.8	-7.1	-23.2	-16.8	-6.4
(iii)	-43.2	-43.6	0.3	-23.9	-27.5	3.5	-28.0	-30.2	2.2	-38.8	-41.0	2.1	-15.2	-16.9	1.7
(iv)	-4.1	-5.2	1.1	-32.0	-41.9	9.9	-41.8	-48.2	6.3	-31.1	-36.9	5.8	-22.9	-27.2	4.4
GAS															
(i)	14.3	-33.0	47.3	2.8	-17.9	20.7	-36.3	-57.9	21.6	-13.2	-34.4	21.2	49.1	16.3	32.8
(ii)	30.6	2.6	27.9	34.0	25.0	9.0	-13.4	-32.0	18.7	62.0	41.9	20.1	15.4	-5.6	21.0
(iii)	-24.7	-23.8	-0.9	-51.0	-53.3	2.3	-42.8	-43.8	1.0	84.7	83.8	0.9	-17.8	-18.3	0.5
(iv)	-40.2	-43.6	3.4	88.3	75.8	12.4	-41.9	-50.6	8.8	19.0	10.8	8.2	-15.5	-22.2	6.7
ELC															
(i)	7.5	-32.8	40.3	12.9	-2.1	15.0	-17.9	-33.8	15.9	20.9	5.5	15.5	21.0	-5.5	26.5
(ii)	23.3	12.4	10.9	-9.1	-3.6	-5.4	-16.4	-19.3	2.9	19.2	15.1	4.1	1.3	-3.6	4.9
(iii)	-24.5	-21.2	-3.2	-7.7	-7.5	-0.1	37.0	38.4	-1.4	-6.3	-4.9	-1.5	-2.9	-1.0	-1.9
(iv)	25.8	33.0	-7.2	0.5	-0.4	0.9	-24.0	-21.7	-2.4	-6.1	-3.3	-2.8	8.3	12.5	-4.2

Note: (1) The values are percentage changes.
(2) Classifications are as follows.
AGM: Agriculture, forestry, fishery, and mining; EII: Energy-intensive industry (paper and pulp, chemical, ceramics, and iron and steel); MAC: Machinery; OMF: Other manufacturing; SER: Services and others (including construction); COAL: Coal and coal products; OIL: Oil and oil products; GAS: Gas; ELC: Electricity.
(3) Periods are as follows. (i): 1970-75; (ii): 1975-80; (iii): 1980-85; (iv): 1985-90.

Next, this paper investigates the details of energy use in energy-intensive industry (EII), using the 18-sector model. Here, EII represents the following four industries: paper and pulp (PAP), chemical (CHM), ceramics (CRM), and iron and steel (IAS). These industries account for a large proportion -i.e., about seventy percent- of the industrial energy use in the Japanese economy. It is widely known that EII contributed greatly to the reduction of energy consumption in the period. METI [25] shows that energy efficiency rose dramatically by 42% in PAP, 34% in CHM, 26% in CRM, and 17% in IAS between 1973 and 1990 (see also, e.g., Toichi [26]). Unander et al. [24] examines such improvements in energy efficiency and implies that both price change and other factors induce it. The MCDA has the advantage of enabling the decomposition of CFI, i.e., the change in energy efficiency, into PS and TC. Hence, this section examines the energy use of EII more closely using the MCDA.

Table 2 illustrates the decomposition result. The PSs for oil are negative in all sectors in the 1970s, while they all become positive in the 1980s. Among the other types of energy, coal shows a clear contrast in terms of PSs during these periods. This shows an offsetting effect of a demand for coal as a substitute for oil, because of its price advantage. The trend in PSs nearly corresponds with that of the EII total in Table 1.

Table 2 also shows that the TCs for oil are strongly negative in the 1980s. Corresponding with the above result in Table 1, oil-saving technological change was primarily developed in the 1980s for those industries. These results are supported by engineering studies indicating that energy conservation was attained by means of an improvement in operations in the 1970s, while full-scale energy conservation was advanced by the introduction of various kinds of energy-saving technology in the 1980s after the second oil crisis (see, e.g., the Study Group on Energy and Industry [27]). In fact, multifarious technological innovations took place during that period; specifically, the continuous casting or waste heat recovery in IAS, and the waste heat recovery equipment of plants in CHM (see, e.g., METI [25]).

There is a point of contrast regarding PAP and CRM: the TCs for coal in these industries from 1975 to 1985 are sizably positive, although those in other EIIs are mostly negative. At this point, engineering studies indicate that PAP and CRM increased the use of coal by installing new combustion equipment in that period (see, e.g., the Study Group on Energy and Industry [27], METI [25]). The trend is reflected in these backgrounds. As a result, the CFIs for coal in PAP and CRM greatly increased; the TCs also increased without regard to the trend of PSs. The results in this section indicate that technological change is important for diminishing industrial energy use.

Table 2. Decomposition of the changes in energy inputs in energy-intensive industry

	Sector											
Input/		PAP			CHM			CRM			IAS	
Period	CFI	TC	PS	CFI	TC	PS	CFI	TC	PS	CFI	TC	PS
COAL												
(i)	-89.4	-92.6	3.2	-20.0	-34.9	14.9	-51.9	-65.2	13.3	25.2	23.9	1.3
(ii)	158.6	125.6	33.1	-13.3	-51.2	37.9	333.6	295.5	38.1	-31.1	-42.4	11.3
(iii)	277.7	285.3	-7.6	-4.1	4.2	-8.3	10.4	17.9	-7.5	-32.6	-29.1	-3.6
(iv)	-14.5	8.4	-22.9	-26.1	-2.7	-23.4	-24.6	-3.3	-21.4	-16.5	-4.8	-11.6
OIL												
(i)	-28.8	-4.8	-23.9	2.6	17.9	-15.3	17.8	34.3	-16.5	-5.1	20.2	-25.3
(ii)	81.5	90.0	-8.4	-12.2	-7.1	-5.1	-25.6	-20.7	-5.0	-28.6	-5.2	-23.4
(iii)	4.7	2.7	2.0	-31.4	-32.6	1.2	-28.0	-30.1	2.1	-47.4	-53.9	6.4
(iv)	-59.1	-63.8	4.7	-31.2	-35.3	4.1	-40.5	-47.3	6.8	-40.4	-60.4	20.0
GAS												
(i)	1.7	-15.0	16.7	6.8	-23.2	30.0	-11.5	-39.6	28.2	16.1	1.5	14.6
(ii)	-16.7	-35.0	18.4	-5.0	-27.7	22.7	-3.8	-26.7	22.9	181.2	182.2	-1.0
(iii)	21.6	20.8	0.7	-66.0	-65.9	-0.1	6.5	5.6	0.9	-62.3	-67.4	5.1
(iv)	7.8	0.7	7.1	71.6	65.1	6.4	78.2	69.0	9.2	173.7	150.9	22.8
ELC												
(i)	17.8	6.6	11.2	2.7	-21.1	23.8	26.9	4.8	22.1	13.4	4.3	9.2
(ii)	-14.1	-16.8	2.7	-24.2	-30.6	6.4	5.4	-1.2	6.6	-5.4	8.7	-14.1
(iii)	-15.0	-13.4	-1.6	7.0	9.4	-2.4	-26.5	-25.0	-1.5	-6.6	-9.3	2.7
(iv)	9.2	13.1	-3.9	-14.3	-9.8	-4.5	-6.8	-4.8	-1.9	15.8	5.6	10.2

Note: (1) The values are percentage changes.
(2) Classifications are as follows.
PAP: Paper and pulp; CHM: Chemical; CRM: Ceramics; IAS: Iron and steel.
(3) Periods are as follows. (i): 1970-75; (ii): 1975-80; (iii): 1980-85; (iv): 1985-90.

4. Conclusions

This paper suggests a new approach -the Multiple Calibration Decomposition Analysis (MCDA)- to investigate the sources of change in industrial energy use in the Japanese economy during the 1970-1990 period. The primary contribution of this paper is to use the new methodology to examine the causal factors of energy use change in energy-intensive industry (EII) following the oil crises. The MCDA can decompose the change in factor inputs per unit of output (CFI) into price substitution (PS) and technological change (TC) in a multisector general equilibrium framework. The empirical result in Section 3 shows how industrial energy use was influenced by price substitution or technological change through the experience of the two oil crises. It illustrates that price substitution from oil to other types of energy occurred in the 1970s, while the reverse occurred in the 1980s. Nevertheless, factor inputs of oil decreased in the 1980s, because oil-saving technological change primarily occurred in that period. Notably, oil-saving technological change in EII advanced by 60% or more in the 1980s. This paper casts light on EII and investigates the details of its contribution. The results show the important role of technological change in curtailing industrial energy use in the Japanese economy.

This study presents the MCDA, which could serve as a practical tool for energy analysis. Finally, it clarifies the assumptions upon which the MCDA depends. It is notable that the method employs a deterministic procedure, and the reliability of empirical results depends on the empirical validity of elasticity parameters. Hence, the MCDA has similar defects to applied general equilibrium analysis. In practice, there are still problems in acquiring reliable elasticity parameters. Nevertheless, the method would be a great help in energy analysis with the support of other conventional methods.

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