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Multiple Calibration Decomposition Analysis: Energy Use and CO_2 Emission in the Japanese Economy[*]

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Abstract. The purpose of this paper is to present a new approach to evaluating structural change of the economy in a multisector general equilibrium framework. The multiple calibration technique is applied to an *ex post* decomposition analysis of structural change between periods, enabling the distinction between price substitution and technological change to be made for each sector. This approach has the advantage of sounder microtheoretical underpinnings when compared with conventional decomposition methods. The proposed technique is empirically applied to changes in energy use and carbon dioxide emission in the Japanese economy following the oil crises. The results show that technological change is of great importance for curtailing energy use and carbon dioxide emission in Japan. While economic growth increased CO_2 emission by itself, other effects such as technological change for labor or energy mitigated increases in that period.

Key words: calibration, decomposition, energy use

JEL classification: C67, D58, Q40

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1. Introduction

Ever since the oil crises in the 1970s, a large amount of research has been conducted in energy demand studies, including Hudson and Jorgenson's (1974) seminal work. Furthermore, it is well known that there has been renewal of interest in the matter, driven by the recent escalation in energy prices. Economic analyses such as these often focus on price changes, which lead to the price substitution effect affecting the overall economy. In fact, it has dramatically changed energy usage patterns during the past few decades. On the other hand, it is clear that the changes in the patterns of energy use are caused by a multitude of factors, including autonomous technological development. Accordingly, decomposition methods are necessary if we want to understand the contribution of these various explanatory factors to structural change in the economy or changes in energy use.

The purpose of this paper is to suggest a new approach to such decomposition. Many decomposition methods have already been proposed to disentangle and quantify the impacts of causal factors. Of these, one of the more well-known methods is the Total Factor Productivity or Growth Accounting approach put forward by Solow (1957), which decomposes output growth into measured increases in factor inputs and technical change (see, e.g., Denison 1967; Jorgenson and Griliches 1967). This method is of great significance with regard to the explicit integration of economic theory into such decomposition (Griliches 1996). This paper is motivated by Solow's idea. The 'new wrinkle' we wish to describe is a way of separating structural change due to price substitution from that due to technological change by capturing the interdependence among economic sectors or factor inputs in a general equilibrium framework. The multiple calibration technique enables us to decompose structural change in such a manner.[1]

This method also takes over the inheritance of Input-Output (I-O) analysis. In the I-O framework, Structural Decomposition Analysis (SDA) has recently developed into a major tool for decomposition, as it overcomes the static features of I-O analysis and enables the examination of structural change (Rose and Casler 1996; Rose 1999). However, "a rigorous grounding in economic theory is lacking for SDA", as pointed out by Rose and Casler (1996). This method may then provide some additional microtheoretical underpinnings to conventional decomposition methods such as SDA. In addition, the method has an advantage in terms of data availability or efficiency. Although the attempt to conduct econometric studies often suffers from data

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[1] For more information on the calibration technique, see Mansur and Whalley (1984), Shoven and Whalley (1992), and Dawkins et al. (2001). Only a few studies are known to incorporate the multiple calibration technique: Piggott and Whalley (2001) analyzed the effects of Canadian tax reform and Abrego and Whalley (2005) decomposed the wage inequality change in the UK. However, to the authors' best knowledge, no studies have attempted to apply the multiple calibration technique to the decomposition of structural change as in the present paper.

insufficiency, the approach requires only a two-period dataset. It therefore may provide a practical alternative to econometric approaches.

This paper applies the proposed methodology to the Japanese economy during 1970-95 to evaluate the factors responsible for changes in energy use and carbon dioxide emission. The period includes two oil crises, the first in 1973 and the second in 1979, when the oil price escalation had a tremendous impact on the Japanese economy. The experience serves to illustrate the methodology's forte, which is to provide a better understanding of how much the economy was affected by price substitution or technological change. On top of this, this kind of analysis may have some implications for current Japanese environmental policy. The empirical result quantitatively shows that technological change is the principal factor in diminishing energy use and CO_2 emission in that period.

The remainder of the paper is structured as follows. Section 2 explains the methodology. Section 3 applies the methodology to the post-oil crisis Japanese economy. Section 4 identifies the causal factors to change in carbon dioxide emission in Japan with the methodology. The final section includes some concluding remarks.

2. Decomposition Technique

This paper suggests a new methodology for decomposing structural change in a multisector general equilibrium framework, namely the Multiple Calibration Decomposition Analysis (MCDA). The distinguishing feature of the MCDA technique is that it explicitly defines two-tier CES production functions to separate price substitution effects (hereafter, PS) from other types of technological change (hereafter, TC). In other words, the MCDA decomposes structural change in the economy, shown by the change in factor inputs per unit of output between periods, into one part attributable to price substitution and another attributable to technological change.[2]

The MCDA technique itself is described as follows. The model structure is assumed in Figure 1. The production functions are given by two-tier constant-returns-to-scale CES functions.[3] The model is composed of capital K, labor L, energy aggregate E, and material aggregate M, as well as energy and material subaggregates. Capital K and labor L are the primary factors of production.

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[2] In the paper, like other literature on this subject, structural change (total change) is defined as changes in factor inputs per unit output, which is identical to the changes of input coefficients in I-O tables. This definition is a purely economic one.

[3] In this paper, the production structure is given by two-tier constant-returns-to-scale CES functions, and the elasticities of substitution are assumed to be constant in all sectors and to be zero or unity between inputs. As mentioned after, this is for the purpose of simplicity, and this production structure resembles the one inferred from the extant literature. However, the MCDA methodology could be applied to the more delicate production structure, for example, where elasticities are different in each sector and between inputs, or using more complicated production functions.

Industries are assumed to act to maximize their profits in competitive markets. The factor inputs per unit (hereafter, factor inputs) in the top tier in the initial period ($t-1$) are derived by Equation (1):

$$A_{Ij}^{t-1} = \frac{X_{I(j)}^{t-1}}{X_{j}^{t-1}} = \lambda_{Ij}^{t-1} \beta_{j}^{\sigma-1} \left(\alpha_{Ij} \frac{p_{j}^{t-1}}{p_{I(j)}^{t-1}} \right)^{\sigma}, I = K, L, E, M, \tag{1}$$

where A_{Ij}^{t-1} is the factor input (input coefficient) of *I* per unit output by the sector *j* in $t-1$, $X_{I(j)}^{t-1}$ is the aggregate or input of *I* by the sector *j* in $t-1$, X_{j}^{t-1} is the output of the sector *j* in $t-1$, p_{j}^{t-1} is the price of the good *j* in $t-1$, $p_{I(j)}^{t-1}$ is the price of *I* in the sector *j* in $t-1$, σ is the elasticity of substitution, α_{Ij} is the share parameter ($\sum_{I} \alpha_{Ij}$=1), and β_j is the scale parameter of the CES functions. λ_{Ij}^{t-1} is the TC parameter in the top tier, as explained below, and is set at unity in $t-1$. p_{j}^{t-1} and $p_{I(j)}^{t-1}$ are also as one because they are from the actual price data, which are normalized so that the prices in the initial period are in unity. When the values of $X_{I(j)}^{t-1}$ and X_{j}^{t-1} are obtained from the dataset, and the substitution parameters σ are exogenously given, all parameters of the production functions, α_{Ij} and β_j, are determined so as to reproduce the actual economic structure in $t-1$ as an equilibrium. This is the same procedure followed under conventional single calibration techniques (Mansur and Whalley 1984; Shoven and Whalley 1992; Dawkins et al. 2001). The production functions are thus specified. The parameters, α_{Ij}, β_j, and σ, are assumed to be time invariant.

The factor inputs of capital and labor are expressed as in Equation (2), which is the same as in Equation (1), because there is no bottom tier with regard to capital *K* and labor *L*:

$$a_{ij}^{t-1} = A_{Ij}^{t-1} = \frac{X_{I(j)}^{t-1}}{X_{j}^{t-1}} = \lambda_{Ij}^{t-1} \beta_{j}^{\sigma-1} \left(\alpha_{Ij} \frac{p_{j}^{t-1}}{p_{I(j)}^{t-1}} \right)^{\sigma}, I = K, L; i = K, L. \tag{2}$$

Next, the bottom tier will be explained. As in Figure 1, energy aggregate *E* and material aggregate *M* are assumed to be weakly separable. The factor inputs of energy **e** (= {e_1,...,e_4}) and material **m** (= {m_1,...,m_5}) in the bottom tier in the initial period are given by Equation (3):

$$a_{I(ij)}^{t-1} = \frac{x_{ij}^{t-1}}{X_{I(j)}^{t-1}} = \lambda_{I(ij)}^{t-1} \beta_{I(j)}^{\sigma_I-1} \left(\alpha_{I(ij)} \frac{p_{I(j)}^{t-1}}{p_{i}^{t-1}} \right)^{\sigma_I}, I = E, M; i = \mathbf{e}, \mathbf{m}, \tag{3}$$

where $a_{I(ij)}^{t-1}$ is the factor input (input coefficient) of energy **e** and material **m** per the corresponding aggregate by the sector *j* in $t-1$, x_{ij}^{t-1} is the input of energy **e** and material **m** by the sector *j* in $t-1$, p_{i}^{t-1} is the price of energy **e** and material **m** in $t-1$, σ_I is the elasticity of substitution, $\alpha_{I(ij)}$ is the share parameter ($\sum_{i} \alpha_{I(ij)}$=1), and $\beta_{I(j)}$ is the scale parameter of the CES functions. $\lambda_{I(ij)}^{t-1}$ is the TC parameter in the bottom tier. $\lambda_{I(ij)}^{t-1}$ and p_i^{t-1} are set at unity in $t-1$. The parameters $\alpha_{I(ij)}$ and $\beta_{I(j)}$ in the bottom tier are then specified by using the same procedure as in Equation (1) in the top tier. The parameters, $\alpha_{I(ij)}$, $\beta_{I(j)}$, and σ_I, are also assumed to be time invariant.

Therefore, the factor inputs of energy **e** and material **m** per unit output in the initial period are expressed as in Equation (4):

$$a_{ij}^{t-1} = \frac{X_{I(j)}^{t-1}}{X_j^{t-1}} \cdot \frac{x_{ij}^{t-1}}{X_{I(j)}^{t-1}} = \lambda_{Ij}^{t-1} \beta_j^{\sigma-1} \left(\alpha_{Ij} \frac{p_j^{t-1}}{p_{I(j)}^{t-1}} \right)^{\sigma} \cdot \lambda_{I(ij)}^{t-1} \beta_{I(j)}^{\sigma_I - 1} \left(\alpha_{I(ij)} \frac{p_{I(j)}^{t-1}}{p_i^{t-1}} \right)^{\sigma_I}, \qquad (4)$$
$$I = E, M; i = \mathbf{e}, \mathbf{m}.$$

One notable characteristic of the MCDA at this point is that another period's dataset is used to specify the TC parameters λ^t. The factor inputs in the terminal period (t) are given by:

$$a_{ij}^{t} = \frac{X_{I(j)}^{t}}{X_j^{t}} = \lambda_{Ij}^{t} \beta_j^{\sigma-1} \left(\alpha_{Ij} \frac{p_j^{t}}{p_{I(j)}^{t}} \right)^{\sigma}, I = K, L; i = K, L, \qquad (5)$$

$$a_{ij}^{t} = \frac{X_{I(j)}^{t}}{X_j^{t}} \cdot \frac{x_{ij}^{t}}{X_{I(j)}^{t}} = \lambda_{Ij}^{t} \beta_j^{\sigma-1} \left(\alpha_{Ij} \frac{p_j^{t}}{p_{I(j)}^{t}} \right)^{\sigma} \cdot \lambda_{I(ij)}^{t} \beta_{I(j)}^{\sigma_I - 1} \left(\alpha_{I(ij)} \frac{p_{I(j)}^{t}}{p_i^{t}} \right)^{\sigma_I}, \qquad (6)$$
$$I = E, M; i = \mathbf{e}, \mathbf{m}.$$

As in the initial period ($t-1$), the values of x_{ij}^t, X_j^t, and p_i^t (= p_j^t) are obtained from the dataset. The price of capital and labor $p_{I(j)}^t$ (I = K, L) are the same as p_i^t (i = K, L), while the price of energy and material aggregate $p_{I(j)}^t$ (I = E, M) in the terminal period is represented by the CES cost functions in the bottom tier of the model:

$$p_{I(j)}^{t} = \frac{1}{\beta_{I(j)}} \left(\sum_i \alpha_{I(ij)}^{\sigma_I} p_i^{t\,1-\sigma_I} \right)^{1/(1-\sigma_I)}, I = E, M; i = \mathbf{e}, \mathbf{m}. \qquad (7)$$

Therefore, the TC parameters λ_{ij}^t (= λ_{Ij}^t for I = K, L, or = $\lambda_{Ij}^t \cdot \lambda_{I(ij)}^t$ for I = E, M) are endogenously determined to replicate the economic structure in the terminal period as another equilibrium. In other words, λ_{ij}^t are chosen to fill the gap between the counterfactual point associated with the price change under the specified production functions and the actual equilibrium in the terminal period.

In the MCDA, as shown in Equation (8), the changes in factor inputs (CFI) can be decomposed into TC and PS:

$$\begin{aligned} & a_{ij}^{t} - a_{ij}^{t-1} = \left(a_{ij}^{t} - a_{ij}^{c}\right) + \left(a_{ij}^{c} - a_{ij}^{t-1}\right),\ i = K, L, \mathbf{e}, \mathbf{m}, \\ & \Leftrightarrow \mathrm{CFI} = \mathrm{TC} + \mathrm{PS}. \end{aligned} \tag{8}$$

a_{ij}^{c} is the counterfactual point, created as:

$$a_{ij}^{c} = \lambda_{Ij}^{t-1} \beta_{j}^{\sigma-1} \left(\alpha_{Ij} \frac{p_{j}^{t}}{p_{I(j)}^{t}} \right)^{\sigma},\ I = K, L; i = K, L\,, \tag{9}$$

$$a_{ij}^{c} = \lambda_{Ij}^{t-1} \beta_{j}^{\sigma-1} \left(\alpha_{Ij} \frac{p_{j}^{t}}{p_{I(j)}^{t}} \right)^{\sigma} \cdot \lambda_{I(ij)}^{t-1} \beta_{I(j)}^{\sigma_I - 1} \left(\alpha_{I(ij)} \frac{p_{I(j)}^{t}}{p_{i}^{t}} \right)^{\sigma_I},\ I = E, M; i = \mathbf{e}, \mathbf{m}\,. \tag{10}$$

In decomposition analysis, it is important to make counterfactual points and indicate what the counterfactual points actually mean. The counterfactual points of the MCDA are constructed by incorporating the effect of relative price change between the initial period and the terminal period. As shown in Equation (8), the change in the factor input between the initial and terminal periods is represented as CFI, with the difference between the counterfactual point and the initial period as PS and the difference between the terminal period and the counterfactual point as TC. Thus, the MCDA can exactly decompose CFI into PS and TC. PS, which depends upon the elasticity of substitution and the change in relative prices over the periods, embodies the price substitution effects. On the other hand, TC embodies those parts of the factor input change that cannot be explained by the price substitution effects, including autonomous technological change.

From a theoretical viewpoint, PS represents the change in factor inputs along the production function while TC represents shifts in the production function.[4] The decomposition of the MCDA provided is then consistent with the production theory in microeconomics. The prominent feature of the method is that it has clear theoretical underpinnings, and allows the decomposition components to be interpreted in a theoretically meaningful way.

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[4] With regard to terminology, Carter (1970, p.10) mentions the same distinction between ‘substitution’ and ‘technological change’, namely, between ‘choice within the context of a given production function’ and ‘changes in production function itself’.

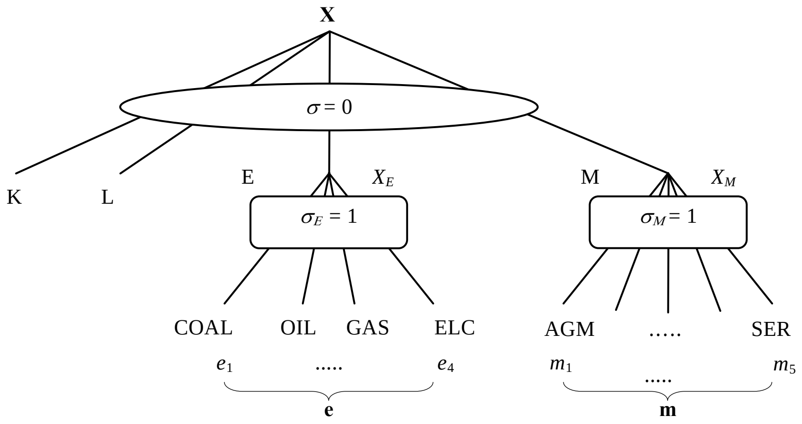

Figure 1. **The model**

3. Decomposing the Change in Energy Use

This section applies the methodology to the post-oil crisis Japanese economy to decompose the changes in energy use. The period includes two oil crises: the first in 1973 and the second in 1979. It is generally recognized that skyrocketing oil prices greatly influenced the Japanese economy during this time and structural changes have had an important impact on manufacturing energy use (IEA 2004). However, economic structure is known to be influenced by a multitude of factors other than price change. This situation then offers a typical context upon which to apply our methodology, which can specifically evaluate how much the Japanese economy was influenced by the price substitution or technological change.

This paper focuses on the analysis of energy as has been explained in Section 1. In the beginning, it gives an outline for the circumstances of Japan's energy use in advance of the result of the MCDA. Figure 2 indicates the primary energy supply and final energy consumption in 1970-95. Energy consumption in Japan has been a consistent rising trend in volume, still the rate of growth in the early 1980s, i.e., after the two oil crises, is lower than in other periods. It is said that Japan accomplished energy conservation and conversion from OIL through the lessons of the oil crises. Evidently, the share of OIL has declined on both primary supply and final consumption after the oil crises meanwhile those of GAS and ELC have increased mainly due to use of natural gas and nuclear power. The primary supply of COAL such as power generation is gradually increasing while the final consumption of COAL remains almost at the same level and the share of COAL in the final consumption is declining.

Next, this paper analyzes the change in energy use in the Japanese economy with the MCDA methodology. Data from 1970 to 1995 are used in the analysis. 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 (1984). 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 (1962) and widely adopted since (Shoven and Whalley 1992; Dawkins et al. 2001), permits the analysis of consistent units across time. The sectors are classified into five industries and four energy inputs as in Figure 1. The elasticities of substitution are assumed, for the purposes of simplicity, to be $\sigma = 0$ and $\sigma_E, \sigma_M = 1$; nevertheless, these estimates are not so different from those in the extant literature that econometrically estimates these elasticities for the Japanese economy (e.g., Okushima and Goto 2001).[5]

Table I shows the decomposition of changes in energy inputs in the Japanese economy. The sectors are classified into five industries and four energy inputs (see the notes accompanying Table I for more details). In relation to the final energy consumption in Figure 2, changes in factor inputs (CFIs) for COAL and OIL are mainly negative while those for GAS and ELC are positive in most cases. Change in factor inputs (CFIs) should be produced by substitution effects due to price changes or other effects such as technological change. CFIs are generally the significant object for decomposition analyses.

The MCDA methodology can divide the CFIs in Table I into technological change (TC) and price substitution (PS), as explained in Section 2. The PSs for OIL are negative in all sectors during the 1970s. This means that the rise in oil prices decreased the factor inputs of OIL. On the other hand, the TCs for OIL in EII and OMF are positive. This is theoretically explained by the fact that the price substitution effects were expected to induce a larger decrease in the factor inputs of OIL whereas they did not decrease to the extent that was expected from these effects in these sectors. Meanwhile, the TCs for OIL in the other sectors, i.e. AGM, MAC, and SER are all negative. This implies the opposite; that is, the CFIs for these had decreased more than the extent that was expected from the price substitution.

The PSs for OIL turn positive after the 1980s, reflecting the fall in the price of oil. By contrast, the TCs for OIL are negative in all sectors. This indicates that oil-diminishing technological change had occurred in the Japanese economy after the 1980s. This would reflect various technological innovations taken place in these days, such as the continuous casting or waste heat

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[5] See also footnote 3.

recovery in the iron and steel industry, and waste heat recovery equipment of plants in the chemical industry (see, e.g., MITI 1985).[6]

The PSs for COAL are positive in the 1970s while both CFIs and TCs for COAL are mainly negative, regardless of the period or industry. This implies that coal-diminishing technological change has continued after the 1970s. There may be some kinds of alternation or innovation in that period as the backgrounds. For instance, the rationalization of production process and waste heat recovery such as coke dry quenching (CDQ) in the iron and steel industry, and new suspension preheater (NSP) kilns in the ceramic industry were developed. However, although the coal-diminishing technological change was expected to induce a larger decrease in the factor inputs of COAL they did not decrease to the extent that was expected. The CFIs did not decrease as much as suggested by the TCs, possibly because of an offsetting effect whereby COAL was demanded as an alternative to OIL, especially during the 1970s. Hence, the PSs for COAL make a good contrast with those for OIL.

For GAS, the CFIs and PSs are positive in most cases. The industries had continuously expanded the use of GAS, which has a price advantage, after the oil crises, as also inferred from Figure 2. Moreover, the CFIs for GAS in 1990-95 are positive in all sectors even when the corresponding PSs are all negative. This implies that the factor inputs of GAS had increased in that period, notwithstanding the disadvantage in relative prices; that is the price substitution from GAS to other types of energy. This is because the increase in CFIs for GAS that could not be explained by the price substitution had occurred in 1990-95, then the TCs for GAS are largely positive in all sectors.

The trends in ELC depend on the sectors. Interestingly, the CFI and TC in MAC are positive in 1980-85 while those in the other sectors are negative. This reflects the growth in sectors such as the processing assembly and precision machinery industries, which use large amounts of electricity, in the Japanese economy after the second oil crisis. In turn, electricity-augmenting technological change had occurred in AGM and SER, as the CFIs and TCs in those sectors turn positive after 1985. This is evidenced by the well-known electrification of the service industry.

When arranging the result in this section, the PSs for OIL are negative in all sectors while those for the other types of energy are mostly positive in the 1970s. On the contrary, in the 1980s, the PSs for OIL turn to positive while the PSs for COAL change to negative. The MCDA has the advantage of quantitatively capturing such interrelationship caused by price substitution effects, in consistent with the production theory in microeconomics. In addition, the TCs for OIL are largely negative from the 1980s; this means that oil-diminishing technological change had mainly occurred in the 1980s rather than in the 1970s. The TCs for COAL are mostly negative over the

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[6] It is noteworthy that some of these technologies would reduce not only the use of OIL but also those of the other types of energy (especially, COAL).

periods, and those for GAS are substantially positive in recent years. These results show that technological change is important for the change in energy use. Another strength of the MCDA is that it can evaluate such technological change in types of energy, sectors, or periods, respectively.

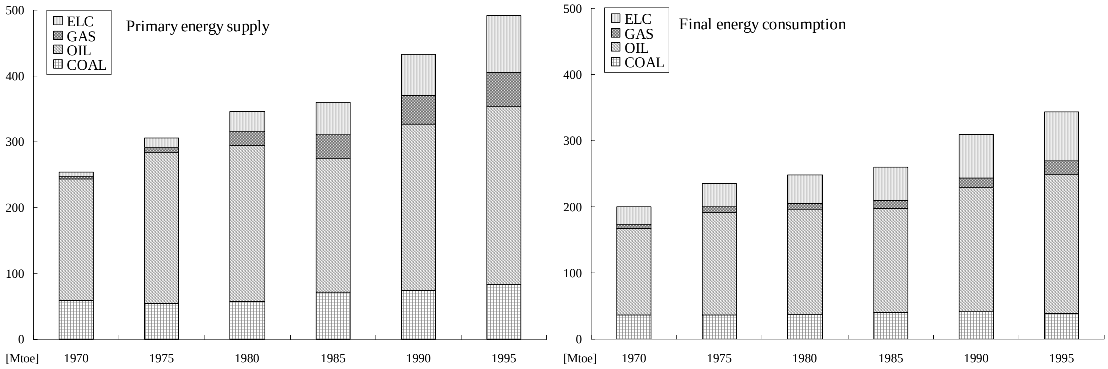

***Figure 2*. Primary energy supply and final energy consumption in Japan, 1970-95**

Source: IEA (1999)

***Table I*. Decomposition of changes in energy inputs in the Japanese economy**

Input		Sector														
		AGM			EII			MAC			OMF			SER		
		CFI	TC	PS	CFI	TC	PS	CFI	TC	PS	CFI	TC	PS	CFI	TC	PS
COAL	1970–75	-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%
	1975–80	-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%
	1980–85	-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%
	1985–90	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%
	1990–95	-62.7%	-67.4%	4.7%	-41.2%	-48.8%	7.6%	-39.4%	-51.6%	12.2%	-52.8%	-64.3%	11.5%	6.3%	-2.2%	8.5%
OIL	1970–75	-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%
	1975–80	-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%
	1980–85	-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%
	1985–90	-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%
	1990–95	0.6%	-1.2%	1.8%	-15.2%	-19.9%	4.6%	-19.0%	-28.1%	9.2%	2.1%	-6.3%	8.5%	1.2%	-4.3%	5.5%
GAS	1970–75	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%
	1975–80	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%
	1980–85	-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%
	1985–90	-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%
	1990–95	23.8%	32.0%	-8.2%	17.5%	23.1%	-5.6%	19.5%	21.1%	-1.6%	35.8%	38.0%	-2.2%	57.2%	62.1%	-4.8%
ELC	1970–75	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%
	1975–80	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%
	1980–85	-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%
	1985–90	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%
	1990–95	14.0%	22.6%	-8.6%	-7.8%	-1.8%	-6.0%	-0.3%	1.7%	-1.9%	9.4%	12.0%	-2.6%	7.7%	12.9%	-5.2%

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.

4. Decomposing the Change in CO_2 Emissions

4.1 METHODOLOGY

This section decomposes the change in carbon dioxide (CO_2) emission in the Japanese economy during the period 1970-95. This analysis would be regarded as an extension of Structural Decomposition Analysis (SDA) in the meaning that it deals with the decomposition of both a factor input matrix (input coefficient matrix) and a final demand vector (Rose and Casler 1996; Rose 1999). One of the advantages is that it can allow the evaluation in volume considering both direct and indirect effects.[7] This paper practices the decomposition of a factor input matrix (input coefficient matrix) based on the MCDA methodology, by utilizing the results of the analysis in Section 3. From a historical point of view, many applications of SDA have been used in environmentally relevant physical flows (see, Hoekstra and van den Bergh 2002). While there are some studies on energy intensity or energy use in Japan (e.g., Han and Lakshmanan 1994; Kagawa and Inamura 2001), little SDA literature has been in the context of CO_2 emissions. Furthermore, there are no studies concerning the decomposition analysis for the Japanese economy using the full-fledged KLEM model that includes all factor inputs (capital, labor, energy, and material). The KLEM model gives a circumstantial account of the interdependent relationship in the economy.

The formulation of the analysis is based on Casler and Rose (1998). The CO_2 emission is expressed as:

$$\mathbf{\Pi}_{TOT} = \mathbf{C}\left(\mathbf{I}-\mathbf{A}\right)^{-1}\mathbf{Y}, \tag{11}$$

where $\mathbf{\Pi}_{TOT}$ is the CO_2 emission vector[t-C], $\mathbf{C}$ is the CO_2 emission coefficient matrix[t-C/Yen], $\mathbf{I}$ is an identity matrix, $\mathbf{A}$ is the factor input matrix (input coefficient matrix), $\left(\mathbf{I}-\mathbf{A}\right)^{-1}\left(\equiv \bar{\mathbf{\Pi}}\right)$ is the Leontief inverse matrix, and $\mathbf{Y}$ is the final demand vector. The emission intensity matrix is defined as $\mathbf{\Pi} \equiv \mathbf{C}\left(\mathbf{I}-\mathbf{A}\right)^{-1}$.

The change in carbon dioxide emission over periods is given by:

$$\Delta\mathbf{\Pi}_{TOT} = \Delta\mathbf{\Pi}\mathbf{Y} + \mathbf{\Pi}\Delta\mathbf{Y} + \varepsilon, \tag{12}$$

where Δ is the derivative between periods and ε is an interaction term. Each source of the change represents a comparative static result, while controlling the other factors constant. From Equation (12), the change in CO_2 emissions is decomposed into three major components: a Leontief inverse effect (KLEM effects) due to changes in the factor input matrix (input coefficient matrix),

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[7] Another decomposition technique is Index Number Analysis (INA) or Index Decomposition (ID). Although ID requires less data than SDA, it cannot distinguish direct effects from indirect effects. See Ang and Zhang (2000) for more detail.

a final demand effect attributable to changes in a final demand vector, and an interaction effect (see, e.g., Casler and Rose 1998; Hoekstra and van den Bergh 2002).

The Leontief inverse effect is further subdivided into the various types of KLEM effects. The change in emission intensity matrix can be approximately written as $\Delta\mathbf{\Pi} \cong \mathbf{\Pi}^{t-1}\Delta\mathbf{A}\overline{\mathbf{\Pi}}^{t-1}$ (see, Casler and Rose 1998; Rose 1999); hence the change in CO_2 emissions due to the Leontief inverse effect (KLEM effects) is given by:

$$\Delta\mathbf{\Pi}_{TOT,KLEM} \cong \left(\mathbf{\Pi}^{t-1}\Delta\mathbf{A}\overline{\mathbf{\Pi}}^{t-1}\right)\mathbf{Y}. \tag{13}$$

The MCDA can divide the change in the factor input matrix (the *ij*th element is $a_{ij}^{t} - a_{ij}^{t-1}$) into the matrices reflecting the various effects by extending the individual elements obtained from the result in Section 3 into the corresponding matrices with zeros elsewhere:

$$\Delta\mathbf{A} = \Delta\mathbf{A}_{K}^{\mathrm{TC}} + \Delta\mathbf{A}_{K}^{\mathrm{PS}} + \Delta\mathbf{A}_{L}^{\mathrm{TC}} + \Delta\mathbf{A}_{L}^{\mathrm{PS}} + \Delta\mathbf{A}_{E}^{\mathrm{TC}} + \Delta\mathbf{A}_{E}^{\mathrm{PS}} + \Delta\mathbf{A}_{M}^{\mathrm{TC}} + \Delta\mathbf{A}_{M}^{\mathrm{PS}}, \tag{14}$$

where $\Delta\mathbf{A}_{I}^{\mathrm{TC}}$ (*I* = *K*, *L*, *E*, *M*) represents the technological change (TC), and $\Delta\mathbf{A}_{I}^{\mathrm{PS}}$ (*I* = *K*, *L*, *E*, *M*) does the price substitution (PS), as has been explained in the previous section. Here, $\Delta\mathbf{A}_{K}^{\mathrm{PS}}$ and $\Delta\mathbf{A}_{L}^{\mathrm{PS}}$ no exist because the elasticity of substitution in the top tier is zero. The KLEM effects for the changes in CO_2 emissions are given by inserting Equation (14) into Equation (13), and decomposed into the effects derived from price substitution and technological change.

In addition, Equation (15) decomposes the changes in a final demand vector into its ‘level’ and ‘mix’ components:

$$\Delta\mathbf{Y} = \left(\mathbf{Y}^{t} - \mathbf{Y}^{t}\frac{\sum_{i}\mathbf{Y}_{i}^{t-1}}{\sum_{i}\mathbf{Y}_{i}^{t}}\right) + \left(\mathbf{Y}^{t}\frac{\sum_{i}\mathbf{Y}_{i}^{t-1}}{\sum_{i}\mathbf{Y}_{i}^{t}} - \mathbf{Y}^{t-1}\right). \tag{15}$$

The first term of the right side of the equation is referred to as the final demand level effect, which represents the effect of total level change in final demand. The second term is referred to as the final demand mix effect, which represents the effect of changes in the mix of final demand while controlling the total level of final demand.

4.2 EMPIRICAL RESULTS

Japan is the fourth largest CO_2 emitting country in the world, after the United States, China, and Russia. Figure 3 depicts that the CO_2 emission in the Japanese economy, which is obtained by multiplying the energy consumption by their respective emission coefficients (IEA 1999), increased in total by 119[Mt-C] (204 to 323[Mt-C]): a 58% increase between 1970 and 1995.

The data sources and classifications in this section are the same as earlier. The CO_2 emission is calculated by multiplying the CO_2 emission coefficient matrix by the standard monetary I-O transactions. The energy inputs that lead to CO_2 emission are COAL, OIL, and GAS while the use of ELC does not directly generate CO_2. Following Rose and Chen (1991), a Leontief inverse closed with respect to capital and labor is used for the decomposition of a Leontief inverse effect (KLEM effects), while a regular open inverse and a full final demand vector are used for the decomposition of a final demand effect. This is because the part related to input coefficients and that related to final demand are separable (see Rose and Casler 1996).

Table II shows the decomposition of the change in CO_2 emission between 1970 and 1995. In each column, the sum of the entries equals to the total, excluding minor rounding errors. As for a final demand effect, the final demand level effect is the major contributor to the CO_2 emission increase. It represents the expansion of the economy. This result is usually observed in the continuously growing economy, and is consistent with the results of empirical studies on energy use in the Japanese economy (e.g., Kagawa and Inamura 2001).[8] Furthermore, the final demand mix effect has a positive impact on the increase in the period. This indicates that the change in the mix of final demand also contributes to the increase. As a result, the final demand effect is the primary cause of the CO_2 emission increase in Japan during 1970-95.

Next, some of the KLEM effects serve as negative sources to the increase in emissions. In particular, the negative contribution of the labor TC stands out. This is due to the increase in labor productivity. On the contrary, the capital TC contributes substantially to the increase in CO_2 emission. This reflects the continuously increasing trend in capital intensity in the Japanese economy. These results can be inferred by other empirical results on structural change in the Japanese economy (see, e.g., Tokutsu 1998). With regard to materials, the PSs and TCs for all types of energy have positive effects on the emission in the period.

As seen in Table II, the energy PS for OIL is negative while those for COAL and GAS are positive. This reflects the price substitution from OIL to the other types of energy following the oil crises. Notably, the influence on CO_2 emission stemming from the price substitution effect is mutually canceled out. Accordingly, as in Table II, the energy PSs have positive influence on the emission overall. The MCDA enables to produce this kind of information by considering the interrelationship between inputs that is caused by the price substitution effect.

The energy TCs for COAL and OIL are negative, and the former has the large negative impact on the emission. This is implied by the result in Section 3, which shows that the energy TCs for COAL are mainly negative regardless of the period or industry, in addition to the fact that COAL is the most carbon intensive. In contrast, the energy TC for GAS is positive, reflecting that the

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[8] If one avoids the level effect of final demand or the effect of economic growth that does not cause any structural changes, see Skolka (1989), which suggests a method for removing it.

TCs for GAS are largely positive in recent period as seen in Section 3. On the whole, the energy TCs contributes to the downward impact on emissions. This analysis shows that the energy TC played a key part in cutting off CO_2 emission.

This section decomposes the change in carbon dioxide emission in Japan between 1970 and 1995. Among the effects, the final demand level effect and capital TC are the major contributors to the emission increase. The energy PS for OIL is a negative cause of emission, however, the negative effect is offset by the corresponding positive effects of the other energy PSs. Consequently, the energy PS is totally a positive contributor to the increase. On the other hand, the labor and energy TCs are the primary negative sources and then mitigate the increase in CO_2 emission. This result shows that technological change is of much importance in the context of reducing carbon dioxide emission.

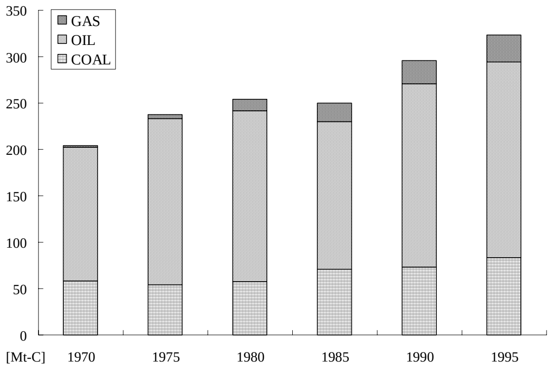

***Figure 3*. CO_2 emission in Japan, 1970-95**

***Table II*. Decomposition of changes in CO_2 emission, 1970-95 (millions of tons)**

	COAL	**OIL**	**GAS**	**TOTAL**
KLEM effects				
Capital TC	33.1	83.2	16.4	132.8
Labor TC	–8.6	–23.4	–5.6	–37.5
Energy TC	–17.0	–8.2	9.2	–16.1
Energy PS	3.0	–4.8	4.9	3.1
Material TC	9.3	36.9	7.4	53.5
Material PS	6.8	9.9	2.4	19.0
Final demand effects				
Final demand level	33.7	87.9	23.6	145.2
Final demand mix	5.9	13.1	2.7	21.7
Interaction effects	–41.1	–128.2	–33.0	–202.4
Total	25.0	66.4	27.9	119.2

5. Conclusions

This paper develops a new decomposition methodology, the Multiple Calibration Decomposition Analysis (MCDA). It is an *ex post* decomposition analysis of structural change between periods, enabling the distinction between price substitution and technological change to be made for each sector in consistent with the production theory. The MCDA serves as an elementary but powerful tool for empirical studies. In the paper, the approach is applied to the evaluation of changes in energy use and carbon dioxide emissions in the Japanese economy since the 1970s.

The empirical result in Section 3 sheds light on how the factor inputs of energy were affected by relative price change between energy inputs or technological change through the experience of the two oil crises. It shows that the price substitution from OIL to the other types of energy had occurred in the 1970s; on the contrary, the opposite had in the 1980s. In spite of such an adverse effect, the factor inputs of OIL had fallen off in all sectors in the 1980s. It is because that oil-diminishing technological change had occurred, primarily in the 1980s. As for COAL, technological change has continuously been a diminishing source on the factor inputs. The factor inputs of GAS a lot increased in 1990-95 despite the negative price substitution effect in all sectors; gas-augmenting technological change had taken place in that period. Thus, the analysis by the MCDA depicts that technological change played a significant role for change in energy use in Japan.

Section 4 decomposes the change in carbon dioxide emission in the Japanese economy during 1970-95 using the result in the previous section. The CO_2 emission from energy use in Japan increased by 58% in that period. The analysis shows that the final demand level effect, which reflects the expansion of the economy, is the primary cause to the increase in CO_2 emission. This indicates that economic growth is an overwhelming driver behind the CO_2 emission hike. On the other hand, technological change for labor or energy mitigates such increase. As for price substitution effects, energy PS for OIL is a negative contributor to the emission increase, which reflects the price substitution from OIL to the other types of energy after the oil crises; nevertheless, the overall influence ascribed to energy PS had increased the CO_2 emission. This is because the negative effect of OIL is offset by the corresponding positive price substitution effects of the other types of energy, namely, COAL and GAS. The results show that technological change, rather than price substitution, mitigated the increase in carbon dioxide emission in Japan. In that context, technological change is essential for reducing carbon dioxide emission.

Before closing, it is necessary to make clear the assumptions upon which our methodology depends. The first is that the MCDA assumes that the economy is in equilibrium in each period. The MCDA compares two periods of the economy as two equilibria, although the economy is, in fact, constantly changing. Many researchers suggest that this assumption should be regarded as a weakness prevailing in economic methods. However, as Hicks (1963) argues, the error resulting from this assumption will generally be within some permissible range, if the two periods compared are separated by a substantial time span.

The second assumption is that the MCDA has defects similar to applied general equilibrium analysis. That is, it employs a deterministic procedure and the reliability of empirical results depends on the empirical validity of elasticity parameters. Despite the importance of elasticity parameters, there are still few estimates of elasticities in the literature (see, e.g., Shoven and Whalley 1984, 1992). The method could be more fruitful if used complementarily with econometric methods.

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