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Decomposing change in energy use in the Japanese economy:

A double calibration approach

Makoto TAMURA* and Shinichiro OKUSHIMA

Graduate School of Arts and Sciences,
The University of Tokyo

Contents

Introduction

- Decomposition methods are necessary if we want to understand the contribution of various explanatory factors to structural change.
- There is still room for progress, however.
- The main purpose here is to suggest a new approach to the decomposition.
  - It can separate structural change due to price substitution from that due to other effects by capturing the interdependence among economic sectors.
- The method is applied to an empirical case, post-oil crisis in Japan.

Background -Structural Decomposition Analysis-

- Conventional decomposition method
- SDA is the analysis of economic change by means of a set of comparative static change in key parameters in an input-output table
  - It overcomes the static features of the IO analysis and enables us to examine structural changes.
    - Skolka(1989), etc
- Applicable to the analysis of material flows
  - Rose and Chen(1991), Casler and Rose (1998), etc

Table1. Input-output table

	1	..	n	F	X	m
1						m_1
:		**A**		**F**	**X**	:
n						m_n

X : output vector
A : input coefficient matrix
F : final demand vector
m: material flow (from other source)

$$\mathbf{X} = \mathbf{AX} + \mathbf{F}$$

$$\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{F} = \mathbf{LF}$$

$\mathbf{L} = \left(\mathbf{I} - \mathbf{A}\right)^{-1}$: Leontief inverse

$\Delta\mathbf{X} = \mathbf{X}^t - \mathbf{X}^{t-1}$

$$\Delta\mathbf{X} = \Delta\mathbf{L}\mathbf{F} + \mathbf{L}\Delta\mathbf{F}$$

Leontief inverse effect + final demand effect

The problems of SDA

- It is not formally derived
  - It employs *ad hoc* specifications of estimating equations
    - Non-uniqueness, Index number problem
  - “a rigorous grounding in economic theory is lacking for SDA”
    - Rose and Casler (1996)
- Difficulty in capturing the price substitution effects

$$\Delta\mathbf{X} = \Delta\mathbf{L}\mathbf{F} + \mathbf{L}\Delta\mathbf{F}$$

$$\Delta\mathbf{X} = \left[\left(\mathbf{I}-\mathbf{A}^{t}\right)^{-1} - \left(\mathbf{I}-\mathbf{A}^{t-1}\right)^{-1}\right]\mathbf{F}^{t-1} + \left(\mathbf{I}-\mathbf{A}^{t}\right)^{-1}\left(\mathbf{F}^{t}-\mathbf{F}^{t-1}\right)$$

←Laspeyres

$$= \left[\left(\mathbf{I}-\mathbf{A}^{t}\right)^{-1} - \left(\mathbf{I}-\mathbf{A}^{t-1}\right)^{-1}\right]\mathbf{F}^{t} + \left(\mathbf{I}-\mathbf{A}^{t-1}\right)^{-1}\left(\mathbf{F}^{t}-\mathbf{F}^{t-1}\right)$$

←Paasche

↓ Marshall-Edgeworth

$$= \left[\left(\mathbf{I}-\mathbf{A}^{t}\right)^{-1} - \left(\mathbf{I}-\mathbf{A}^{t-1}\right)^{-1}\right]\mathbf{F}^{t-1} + \left(\mathbf{I}-\mathbf{A}^{t-1}\right)^{-1}\left(\mathbf{F}^{t}-\mathbf{F}^{t-1}\right) + \left[\left(\mathbf{I}-\mathbf{A}^{t}\right)^{-1} - \left(\mathbf{I}-\mathbf{A}^{t-1}\right)^{-1}\right]\left(\mathbf{F}^{t}-\mathbf{F}^{t-1}\right)$$

DCDA

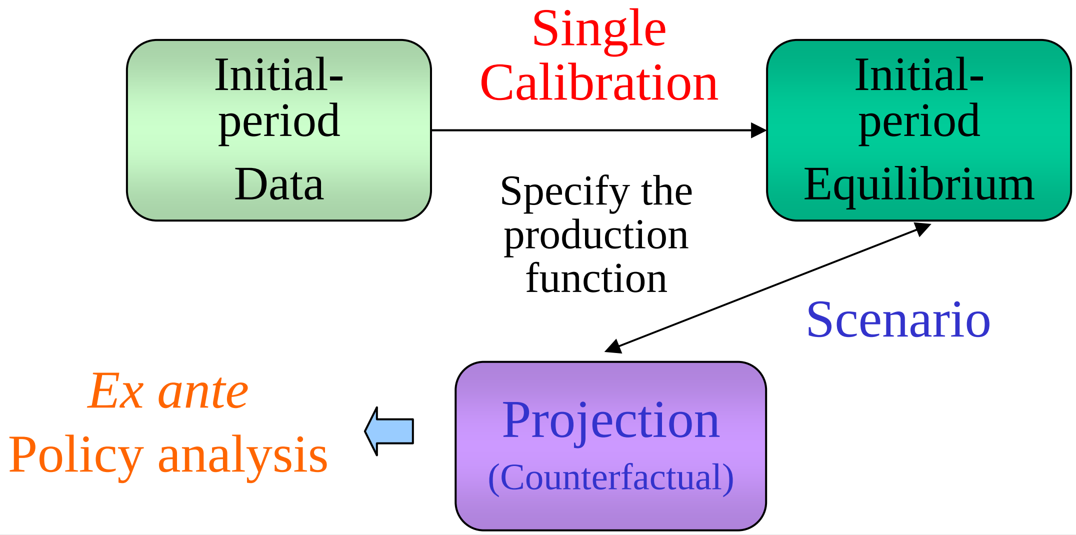
- Double Calibration Decomposition Analysis (DCDA)

- An elementary way of evaluating structural change
  - Price substitution effect and technological change
  - Captures the interdependence among economic sectors
- Provides some theoretical underpinnings to Structural Decomposition Analysis in Input-Output framework (IO-SDA)
- Data availability or efficiency
  - only two period datasets
  - a practical alternative to econometrics

The Methodology -single calibration-

- Calibration is a technique to specify the parameters, which is normally applied to *ex ante* policy analysis

- Single calibration
  - Specify the economic structure by single-period data set
  - *Ex ante* projections by changing the policy parameters
    - Mansur and Whalley(1984), Shoven and Whalley(1992)



The methodology -DCDA-

- DCDA is the application of the double calibration technique to *ex post* decomposition analysis
- Double calibration
  - Isolate the several factors of observed outcomes by two-period data set
    - Dawkins et al. (2001), Abrego and Whalley(2002),
- DCDA enables us to distinguish the individual causes from a series of simultaneous shocks in consistent with general equilibrium framework
  - Change in Factor inputs (CFI)

    = Price Substitution (PS)

    + Technological Change in DCDA (TC^{DC})

The model

- Two-tier CES function
  - Competitive market
  - Profit maximization

- Aggregate E and aggregate M are weakly separable
- $\sigma = 0$ and σ_E , σ_M =1 for simplicity

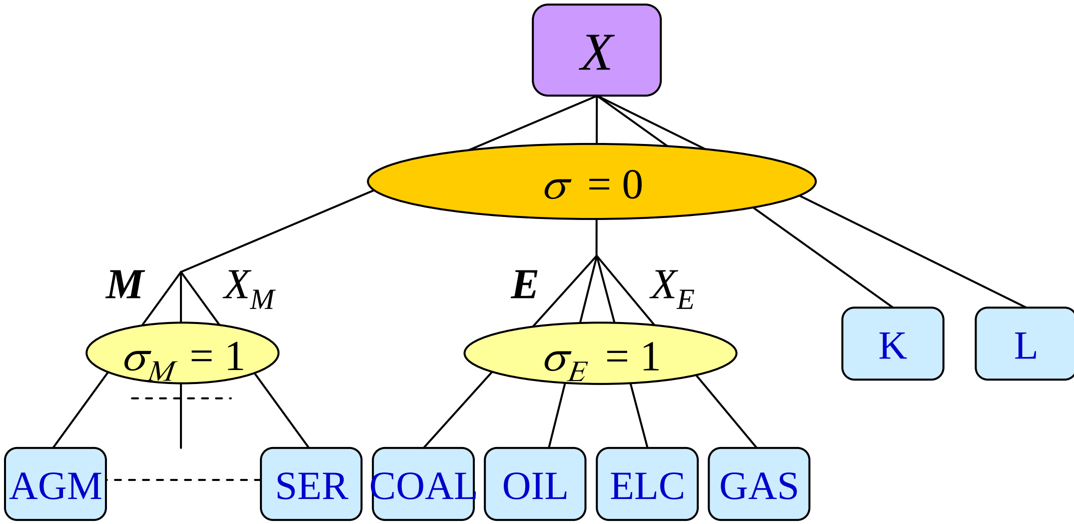


Figure 1. The Model

The Methodology -Initial Period (t-1)-

$$a_{ij}^{t-1} = A_{Ij}^{t-1} = \lambda_{Ij}^{t-1} \beta_j^{\sigma-1} \left(\alpha_{Ij} \frac{p_j^{t-1}}{p_{I(j)}^{t-1}} \right)^{\sigma} \quad , I = K, L; i = k, l.$$

$$a_{ij}^{t-1} = \frac{X_{I(j)}^{t-1}}{X_j^{t-1}} \cdot \frac{x_{ij}^{t-1}}{X_{I(j)}^{t-1}} = \overbrace{\lambda_{Ij}^{t-1} \beta_j^{\sigma-1} \left(\alpha_{Ij} \frac{p_j^{t-1}}{p_{I(j)}^{t-1}} \right)^{\sigma}}^{\text{Top tier (KLEM)}} \cdot \overbrace{\lambda_{I(ij)}^{t-1} \beta_{I(j)}^{\sigma_I - 1} \left(\alpha_{I(ij)} \frac{p_{I(j)}^{t-1}}{p_i^{t-1}} \right)^{\sigma_I}}^{\text{Bottom tier (Sub model)}}, I = E, M; i = e, m.$$

a_{ij}^{t-1} A_{Ij}^{t-1} : factor input of i and I by the sector j
x_{ij}^{t-1} : input of i by sector j $X_{I(j)}^{t-1}$: input of I by the sector j
X_j^{t-1} : output of sector j
→From the data set

σ σ_I : elasticity of substitution →Exogenously given
λ_{Ij}^{t-1} $\lambda_{I(ij)}^{t-1}$: TC parameter in t-1 p_j^{t-1} $p_{I(j)}^{t-1}$: price of j and I →Set at unity
α_{Ij} $\alpha_{I(ij)}$: share parameter ($\sum_I \alpha_{Ij} = 1$ $\sum_i \alpha_{I(ij)} = 1$)
β_j $\beta_{I(j)}$: scale parameter
→Determined to reproduce the actual economic structure in t-1

- The parameters (α, β) are determined to reproduce the actual economic structure in the initial period (t-1)
- In t-1, this is similar to conventional single calibration

The Methodology -Terminal Period (t)-

- Another data period is used to specify unknown parameters.

Same as the counterfactual point

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

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

x_{ij}^t : input of i by sector j $X_{I(j)}^t$: input of I by the sector j
X_j^t : output of sector j in t
p_i^t : price of i

→From the data set

$p_{I(j)}^t$: aggregate price of I in t →Calculated by the initial period calibration

$\lambda_{ij}^t\ \lambda_{I(ij)}^t$: TC parameter in t →Endogenously determined

- TC parameters (λ_{ij}^t) are endogenously determined to replicate the economic structure in t

The Methodology -Counterfactual point-

- In decomposition analysis, it is important to make counterfactual points and indicate what the counterfactual points actually mean.
  - Change in factor inputs (CFI) can be decomposed:

$$a_{ij}^{t} - a_{ij}^{t-1} = \left(a_{ij}^{t} - \boxed{a_{ij}^{c}}\right) + \left(\boxed{a_{ij}^{c}} - a_{ij}^{t-1}\right)$$

$$\mathrm{CFI} = \mathrm{TC}^{\mathrm{DC}} + \mathrm{PS}$$

  - Counterfactual points:

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

Prices in the terminal period

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

- Prices are obtained from data set in the terminal period (*t*)
- The other parameters are the same as the initial period (*t*-1)
  - Incorporate the effect of relative price change between periods

Concept of the method

- Decompose CFI

- PS (Price substitution effects)
  - Price change effect
    - Elasticity of substitution σ
    - Change in relative prices
  - Change in factor inputs along the production function
- TC^{DC} (Technological Change in DCDA)
  - The parts of input that cannot be explained by PS
    - $\lambda^t > 1$: Factor-augmenting TC
    - $\lambda^t < 1$: Factor-diminishing TC
  - Shifts in the production function

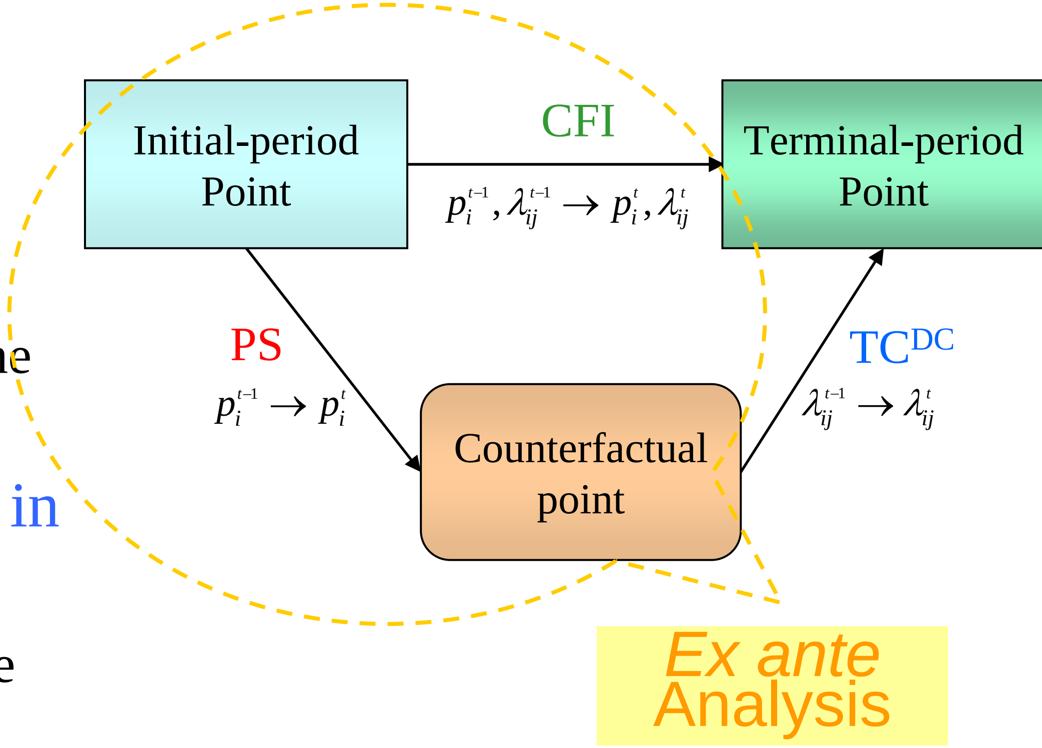


Figure 2. Concept of the DCDA

Data

- Data from 1970 to 1995 are used

- Nominal outputs (factor inputs)
  - 1970-75-80 and 1985-90-95 Linked Input-Output Tables (Management and Coordination Agency)
- Real outputs (factor inputs)
  - Deflating nominal outputs by the following price indices.
  - Price indices
    - Domestic Wholesale Price Index (Bank of Japan)
    - Deflators on Outputs of National Accounts (Economic Planning Agency).
    - Capital and labor prices: Ito and Murota (1984).

Classifications

- 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
- ELC: Electricity
- GAS: Gas

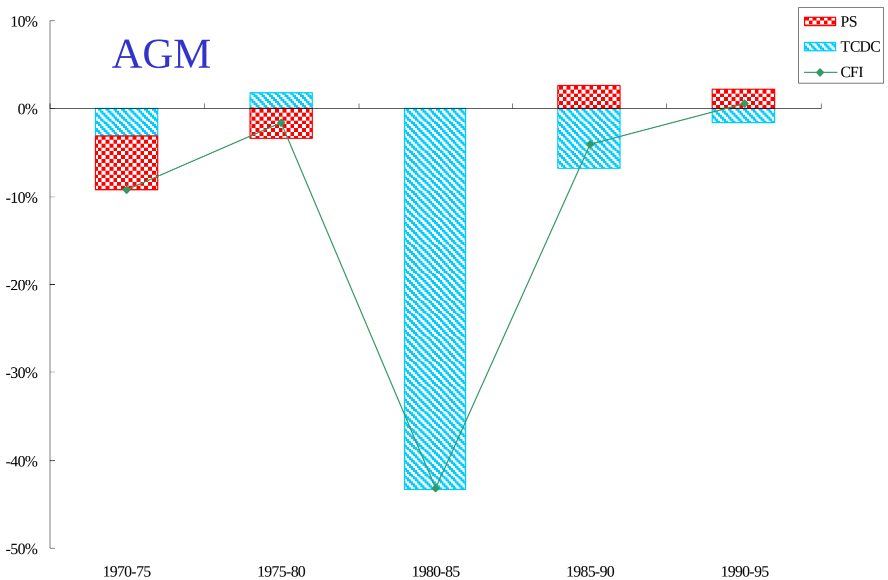
Change in energy use

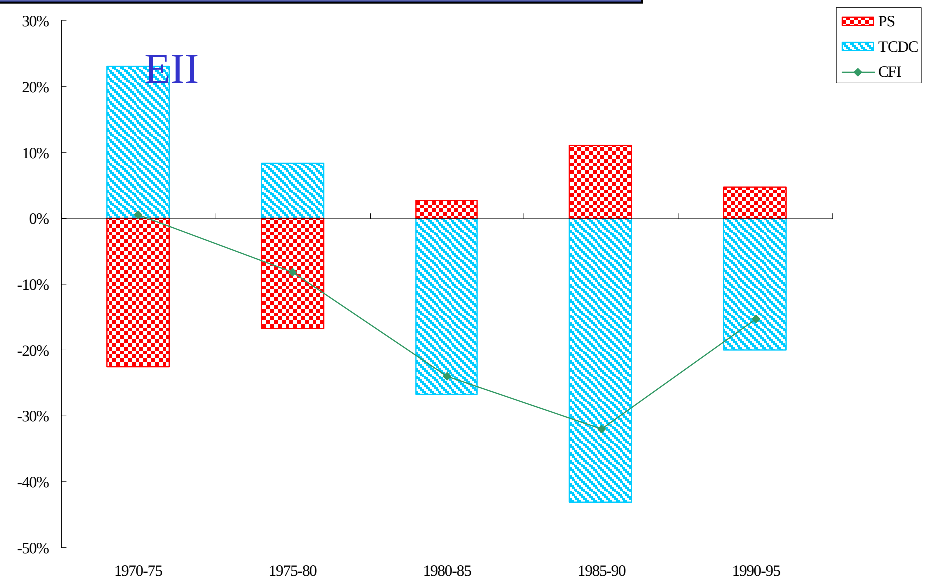
Table 2. Decomposition of changes in energy inputs in the Japanese economy

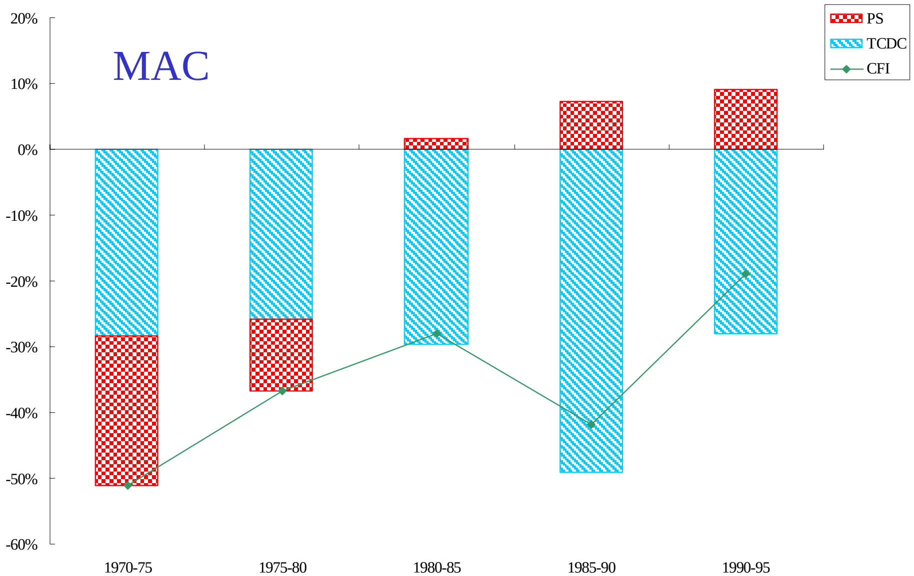
Input		Sector														
		AGM			EII			MAC			OMF			SER		
		CFI	TC^{DC}	PS	CFI	TC^{DC}	PS	CFI	TC^{DC}	PS	CFI	TC^{DC}	PS	CFI	TC^{DC}	PS
COAL	1970-75	-59.5%	-86.9%	27.4%	29.6%	24.6%	5.0%	-70.1%	-74.9%	4.8%	-43.6%	-49.5%	5.9%	-5.2%	-20.7%	15.5%
	1975-80	-23.6%	-64.1%	40.5%	-31.7%	-52.9%	21.1%	-19.2%	-48.7%	29.5%	-14.1%	-47.4%	33.2%	-0.3%	-33.9%	33.6%
	1980-85	-68.5%	-59.2%	-9.3%	-36.1%	-29.3%	-6.9%	-60.1%	-52.2%	-7.9%	-36.8%	-29.2%	-7.6%	-32.7%	-24.9%	-7.7%
	1985-90	32.2%	56.6%	-24.4%	-25.4%	-7.2%	-18.2%	-3.6%	17.4%	-21.0%	-22.5%	-1.4%	-21.1%	-19.3%	2.5%	-21.8%
	1990-95	-62.7%	-67.9%	5.1%	-41.2%	-49.0%	7.8%	-39.4%	-51.5%	12.2%	-52.8%	-64.5%	11.7%	6.3%	-2.9%	9.1%
OIL	1970-75	-9.2%	-3.1%	-6.1%	0.6%	23.1%	-22.6%	-51.0%	-28.3%	-22.8%	-6.6%	15.3%	-21.9%	-22.0%	-7.1%	-14.8%
	1975-80	-1.5%	1.8%	-3.3%	-8.2%	8.4%	-16.7%	-36.8%	-25.9%	-10.9%	7.6%	16.0%	-8.3%	-23.2%	-15.1%	-8.1%
	1980-85	-43.2%	-43.3%	0.1%	-23.9%	-26.7%	2.8%	-28.0%	-29.7%	1.7%	-38.8%	-40.8%	1.9%	-15.2%	-17.0%	1.8%
	1985-90	-4.1%	-6.7%	2.7%	-32.0%	-43.0%	11.0%	-41.8%	-49.1%	7.2%	-31.1%	-38.2%	7.1%	-22.9%	-29.1%	6.2%
	1990-95	0.6%	-1.7%	2.3%	-15.2%	-20.0%	4.8%	-19.0%	-28.0%	9.1%	2.1%	-6.5%	8.6%	1.2%	-4.9%	6.2%
ELC	1970-75	7.5%	-29.7%	37.2%	12.9%	-0.3%	13.2%	-17.9%	-30.8%	12.9%	20.9%	6.8%	14.1%	21.0%	-3.5%	24.5%
	1975-80	23.3%	14.9%	8.4%	-9.1%	-2.5%	-6.6%	-16.4%	-16.3%	-0.1%	19.2%	16.4%	2.8%	1.3%	-1.8%	3.1%
	1980-85	-24.5%	-21.0%	-3.4%	-7.7%	-6.8%	-0.8%	37.0%	38.9%	-1.9%	-6.3%	-4.7%	-1.7%	-2.9%	-1.1%	-1.8%
	1985-90	25.8%	31.6%	-5.7%	0.5%	-1.4%	1.9%	-24.0%	-22.5%	-1.6%	-6.1%	-4.4%	-1.7%	8.3%	10.8%	-2.5%
	1990-95	14.0%	22.2%	-8.2%	-7.8%	-1.9%	-5.9%	-0.3%	1.8%	-2.0%	9.4%	11.9%	-2.4%	7.7%	12.4%	-4.6%
GAS	1970-75	14.3%	-29.8%	44.1%	2.8%	-16.0%	18.8%	-36.3%	-54.8%	18.5%	-13.2%	-33.0%	19.8%	49.1%	18.4%	30.7%
	1975-80	30.6%	5.6%	25.0%	34.0%	26.2%	7.8%	-13.4%	-28.6%	15.2%	62.0%	43.4%	18.5%	15.4%	-3.4%	18.9%
	1980-85	-24.7%	-23.6%	-1.1%	-51.0%	-52.6%	1.5%	-42.8%	-43.2%	0.5%	84.7%	84.0%	0.7%	-17.8%	-18.4%	0.6%
	1985-90	-40.2%	-45.2%	5.0%	88.3%	74.7%	13.6%	-41.9%	-51.5%	9.7%	19.0%	9.5%	9.6%	-15.5%	-24.1%	8.6%
	1990-95	23.8%	31.6%	-7.8%	17.5%	23.0%	-5.5%	19.5%	21.2%	-1.6%	35.8%	37.8%	-2.1%	57.2%	61.5%	-4.3%

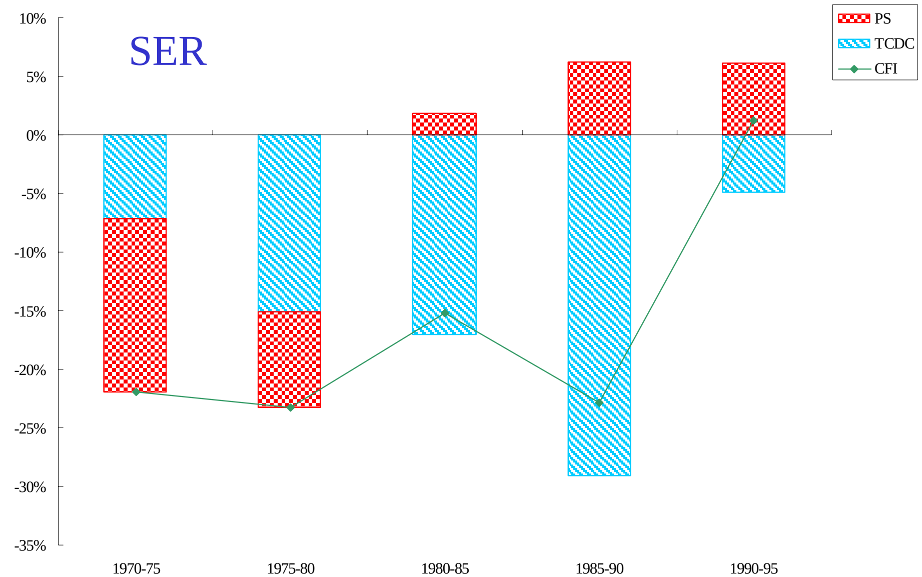
Note: (1) The values are percentage changes.
(2) Classifications are as follows.
AGM: Agriculture, forestry, fishery, and mining; EII: Energy intensive industry (paper and pulp, chemical, ceramics, and iron and steel); MAC: Machinery; OMF: Other manufacturing; SER: Services and others (including Construction); COAL: Coal and coal products; OIL: Oil and oil products; ELC: Electricity; GAS: Gas.

Change in OIL use









Results -Change in energy use-

- PS for OIL
  - Negative in the 1970s
    - The rise in OIL prices decreased factor inputs of OIL
  - Positive after the 1980s
    - reflecting the fall in the price of OIL
- TC^{DC} for OIL in EII and OMF
  - Positive in the 1970s
    - Price substitution effects were expected to induce a larger decrease in the factor inputs of OIL, whereas the inputs of OIL did not decrease to the extent that was expected
  - Negative after the 1980s
- COAL and other energy
  - Good contrast of OIL (especially) in the 1970s
    - Temporal fuel conversion from OIL

Decomposing Change in CO_2 emissions

- Decompose the changes in CO_2 in the Japanese economy during the period 1970-1995 using the previous results
  - A kind of Structural Decomposition Analysis
  - Deal with factor input matrix and final demand

$$\Delta \mathbf{m} = \mathbf{B}\Delta\mathbf{X} = \mathbf{B}\left(\Delta\mathbf{L}\mathbf{F} + \mathbf{L}\Delta\mathbf{F}\right) + \varepsilon$$

$\mathbf{m}$: CO_2 emission vector [t-C], $\mathbf{B}$: CO_2 emission intensity matrix [t-C/Yen]
$\mathbf{X}$: output vector [Yen]
$\mathbf{L} = \left(\mathbf{I} - \mathbf{A}\right)^{-1}$: Leontief inverse, $\mathbf{I}$: identity matrix
$\mathbf{A}$: factor input matrix (input coefficient matrix)
$\mathbf{F}$: final demand vector, ε : interaction term

$$\Delta \mathbf{m} = \text{Leontief inverse effect} + \text{final demand effect} + \varepsilon$$

Decomposition of CO_2 emissions

- Leontief inverse effect =>KLEM effects

$$\Delta \mathbf{A} = \Delta \mathbf{A}_K^{\mathrm{CFI}} + \Delta \mathbf{A}_L^{\mathrm{CFI}} + \Delta \mathbf{A}_E^{\mathrm{TC^{DC}}} + \Delta \mathbf{A}_E^{\mathrm{PS}} + \Delta \mathbf{A}_M^{\mathrm{TC^{DC}}} + \Delta \mathbf{A}_M^{\mathrm{PS}}$$

$\Delta \mathbf{A}_I^{\mathrm{CFI}}$: CFI matrix,

$\Delta \mathbf{A}_I^{\mathrm{TC^{DC}}}$: $\mathrm{TC^{DC}}$ matrix

$\Delta \mathbf{A}_I^{\mathrm{PS}}$: PS matrix

$$\Delta \mathbf{L} = \mathbf{L}^t \Delta \mathbf{A} \mathbf{L}^{t-1} = \mathbf{L}^t \Delta \mathbf{A}_1 \mathbf{L}^{t-1} + \ldots + \mathbf{L}^t \Delta \mathbf{A}_n \mathbf{L}^{t-1}$$

$$\Delta \mathbf{m} = \left(\mathbf{B}\mathbf{L}^t \Delta \mathbf{A}_1 \mathbf{L}^{t-1}\right)\mathbf{F}^{t-1} + \ldots + \left(\mathbf{B}\mathbf{L}^t \Delta \mathbf{A}_n \mathbf{L}^{t-1}\right)\mathbf{F}^{t-1}$$

$+$ final demand effect $+ \ \varepsilon$

- Final demand effect
  - Level effect and mix effect

$$\Delta \mathbf{F} = \left(\mathbf{F}^t - \mathbf{F}^t \frac{\sum_i \mathbf{F}_i^{t-1}}{\sum_i \mathbf{F}_i^t} \right) + \left(\mathbf{F}^t \frac{\sum_i \mathbf{F}_i^{t-1}}{\sum_i \mathbf{F}_i^t} - \mathbf{F}^{t-1} \right)$$

CO_2 emissions in Japan

- Japan is the fourth CO_2 emitting county in the world
  - USA, China , Russia
  - 58% increase between 1970-1995
- Decompose the change in CO_2 emissions using the method

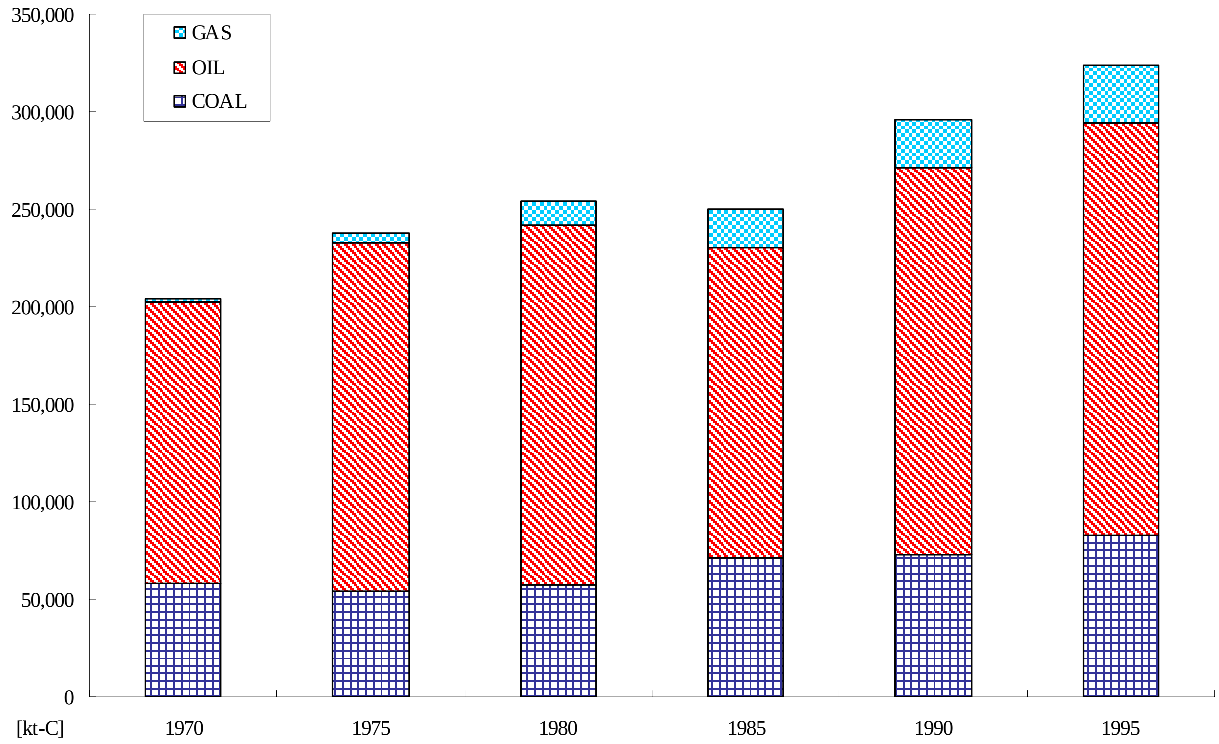


Figure 3. CO_2 emissions from energy use in Japan, 1970-1995

Source) IEA(1999)

Results -changes in CO_2 emissions-

Total [kt-C]	1970-75	1975-80	1980-85	1985-90	1990-95
Final demand effects					
Final demand level	38,905	16,491	-4,676	48,808	30,786
Final demand mix	-2,822	-123	-276	-60	-2,138
KLEM effects					
Capital CFI	5,596	1,606	-572	6,185	12,964
Labor CFI	-4,858	-1,749	439	-4,480	-4,513
Energy PS	-312	-253	-36	229	170
Material PS	692	-12	-124	749	1,088
Energy TC^{DC}	2,147	-349	560	-2,682	-1,237
Material TC^{DC}	-5,258	401	591	-1,807	-6,669
Interaction effects	-672	110	225	-1,231	-2,578
Total	33,419	16,123	-3,870	45,712	27,872

Table 3. Decomposition of changes in CO_2 emissions

Decomposing CO_2 emissions –KLEM effects –

- Final demand effects
  - mainly positive
  - Level effects
- KLEM effects
  - Energy PS
    - negative=> positive
    - energy price affects energy inputs
    - Fuel conversion
  - Energy TC^{DC}
    - Positive => negative
  - Capital CFI
    - positive

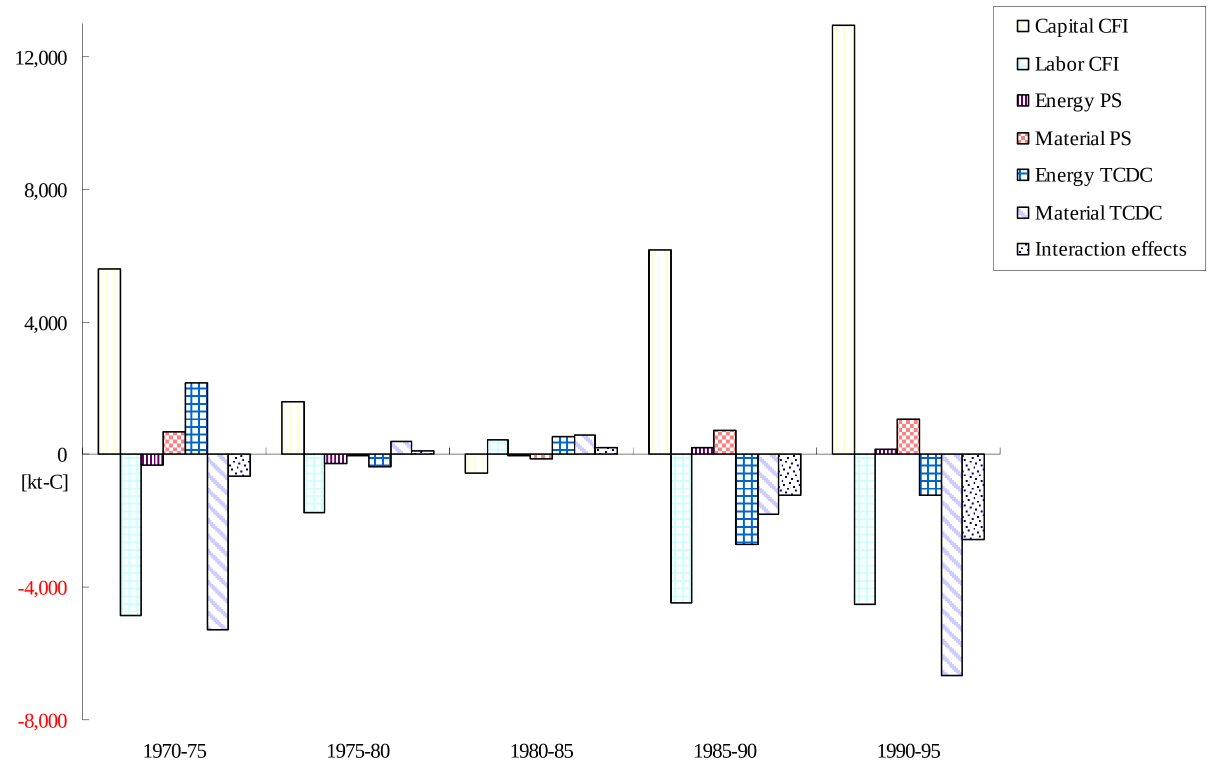


Figure 4. Decomposition of changes in CO_2 emissions
(the values are same as Table3, but only KLEM effects)

Conclusion

- We suggest a new decompositional methodology.
- We apply it to the decomposition of change in energy use and CO_2 emissions in Japan.
- It is based on calibration technique.
  - Double calibration is applied to *ex post* analysis.
  - It gives some micro-theoretical foundation to conventional methods.
  - This method serves as an elementary but powerful tool for empirical studies.
  - Using deterministic procedure is regarded as both advantage and limitation.
- The method could be more fruitful if used complementarily with other conventional ones.

Thank you.

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