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Impacts of Growth of a Service Economy on CO_2 Emissions: Japan's Case

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Abstract The structural transition to a service economy has clearly contributed to decreasing direct (or territorial) greenhouse gas emissions. Nevertheless, the role of this structural transition on direct greenhouse gas emissions is not well understood quantitatively. This study applied the additive decomposition method and decomposed the change in CO_2 emissions from domestic industries into five components: changes in the overall scale of the economy, changes in the industrial composition of the various economic sectors, energy intensity changes, changes in import composition, and changes in the import scale. The decomposition results show that during the 15-year period from 1990 to 2005, structural change effects under the domestic technology assumption (which include industrial composition effects, import scale effects, and import composition effects) totaled −35 Mt CO_2, or 3 % of total CO_2 emissions in 1990. It is concluded that the CO_2 reduction due to the transition to a service economy was not negligible during 1990–2005 and that the structural transition to a service economy was much more important than the material dependence of service industries.

JEL Classification O14 · O44 · Q56

1 Introduction

Increased environmental loads can be understood as arising from a variety of economic factors. For example, the environmental Kuznets curve describes an inverted-U relationship between economic growth (including structural changes) and environmental pollution (Grossman and Krueger 1991, 1995, 1996; Carson 2010 for a literature overview). In particular, this article sheds light on the relationship between structural changes and environmental load in a specific country. As in Levinson (2009),

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I will focus on influences on CO_2 emissions. In this study, I consider not only the economic scale, but also another factor that exhibits significant influence: changes in industrial composition. In Japan, the percentage of domestic Japanese production attributable to secondary industries (manufacturing), which exhibit high rates of CO_2 emissions per unit production (i.e., large direct emissions coefficients), fell drastically, from 49 % in 1990 to just 39 % in 2005. In contrast, the percentage of domestic Japanese production attributable to tertiary industries (service industries), which exhibit low coefficients of direct CO_2 emissions, rose significantly, from 48 % in 1990 to 60 % in 2005.[1] This also implies that Japan's transition toward a service-oriented economy has contributed in reducing CO_2 emissions, but the extent to which this has slowed the pace of global warming remains unclear.

Important studies on the relationship between the transition to a service economy and CO_2 emissions include those of Suh (2006) and Nansai et al. (2009). Suh (2006) demonstrated that household consumption of services, excluding electric utilities and transportation services, accounts for 37.6 % of total industrial GHG emissions in the United States. Nansai et al. (2009) analyzed the factors governing life-cycle CO_2 emissions in Japanese service industries between the years 1990 and 2000 and concluded that increased inputs of energy and resources (including materials and components) led to significantly increased CO_2 emissions.

However, the studies of Suh (2006) and Nansai et al. (2009) did not quantify the transition to a service economy in terms of the increasing industrial composition attributable to service industries and also did not analyze the impact of the transition to a service economy on production-based CO_2 emissions.[2] In addition, their studies did not argue that the transition to a service economy spurs an increase in imports of CO_2-intensive commodities and that consequently this structural change contributes to global warming. Therefore, in the present study, I apply the Shapley–Sun additive decomposition method (Shapley 1953; Sun 1998) and decompose the change in production-based CO_2 emissions from domestic industries into five components: that due to changes in the overall scale of the economy, that due to changes in the industrial composition of the various economic sectors, that due to energy intensity (i.e., technical) changes, which measures CO_2 emissions per unit of domestic production, that due to changes in the import composition of the various commodities, and that due to changes in the import scale. Using this index decomposition method, I will analyze the impact of Japan's transition to a service economy on Japanese CO_2 emissions between 1990 and 2005, and finally argue the environmental benefits of its structural transition.

The rest of this paper is organized as follows: Sect. 2 presents the decomposition method, Sect. 3 describes the data source, Sect. 4 presents a case study of Japan, and Sect. 5 concludes the paper.

[1] I estimated the industrial composition rates using the linked input–output tables during 1990–2005 (see Ministry of Internal Affairs and Communication of Japan, 2010, for the linked input–output tables).

[2] Production-based CO_2 emissions represent CO_2 emissions from the production activities of domestic industries.

2 Methodology

2.1 Estimating CO_2 Emissions Originating from Industrial Activities

Let $e^t_{k,i}$ denote the energy consumption (Gigajoules: GJ) of fuel type k ($k = 1, 2, \ldots, M$) associated with 1 unit (¥1 million) of production in industry sector i ($i = 1, 2, \ldots, N$) during year t. Here, N is the number of industry sectors and M is the number of types of fuel. Also, let c_k denote the CO_2 emissions (t CO_2) generated directly from the consumption of 1 GJ worth of fuel type k in the specific industry sector. Then the quantity of CO_2 emitted in conjunction with unit production in industry sector i in year t can be expressed in the form $c_k \times e^t_{k,i}$ (t CO_2/million yen).

If θ^t_i denotes the industrial composition showing the fraction of output of industry sector i of total production across all industries, and X^t_d denotes total industrial output summed over all industry sectors, the total amount of domestic production contributed by industry sector i in year t is then represented as $\theta^t_i \times X^t_d$ (million yen).

Multiplying the CO_2 emission coefficient of industry sector i, $c_k \times e^t_{k,i}$, by the domestic output of industry sector i, $\theta^t_i \times X^t_d$, yields $c_k e^t_{k,i} \theta^t_i X^t_d$ as an estimate of CO_2 emissions arising from the use of fuel type k in industry sector i. Summing these estimates over all industry sectors and all fuel types, we obtain the following estimate of total domestic production-based emissions Q^t_d (t CO_2):

$$Q^t_d = \sum_{i=1}^{N} \sum_{k=1}^{M} c_k e^t_{k,i} \theta^t_i X^t_d \tag{1}$$

2.2 Changes in CO_2 Emissions: Factor Decomposition

We now use the Shapley–Sun decomposition method to analyze changes in the quantity of CO_2 emissions originating from industrial activities (i.e., the quantity Q^t_d) into three sources: technical effects, industrial composition effects, and economic scale effects (Levinson 2009). (For details on the decomposition method, see Ang 2004; Ang et al. 2003; Wood and Lenzen 2006 and see e.g., Ma and Stern 2008; Kagawa et al. 2012 for the energy decomposition analysis.)

Let ΔQ_d denote the change from year t to year $t + 1$ in CO_2 emissions originating from industrial activities, expressed as follows:

$$\begin{aligned} \Delta Q_d &= Q^{t+1}_d - Q^t_d \\ &= \sum_{i=1}^{N} \sum_{k=1}^{M} c_k e^{t+1}_{k,i} \theta^{t+1}_i X^{t+1}_d - \sum_{i=1}^{N} \sum_{k=1}^{M} c_k e^t_{k,i} \theta^t_i X^t_d \\ &= \mathbf{c} \cdot \mathbf{E}^{t+1} \cdot \boldsymbol{\theta}^{t+1} \cdot X^{t+1}_d - \mathbf{c} \cdot \mathbf{E}^t \cdot \boldsymbol{\theta}^t \cdot X^t_d \end{aligned} \tag{2}$$

Here, c is a $(1 \times M)$ row vector whose kth element, c_k, is the emission coefficient of fuel type k; $\mathbf{E}$ is an $(M \times N)$ matrix whose (k, i) element, $e_{k,i}$, is the energy consumption (i.e., energy intensity) for fuel type k used to produce one unit of output in industry sector i; and $\boldsymbol{\theta}$ is an $(N \times 1)$ column vector whose ith element, θ_i, is the industrial composition of industry sector i. The superscripts t and $t+1$ indicate the year.

The changes in $\mathbf{E} = (e_{k,i})$, $\boldsymbol{\theta} = (\theta_i)$, and X can be expressed as follows:

$$\Delta \mathbf{E} = \mathbf{E}^{t+1} - \mathbf{E}^{t} \tag{3}$$

$$\Delta \boldsymbol{\theta} = \boldsymbol{\theta}^{t+1} - \boldsymbol{\theta}^{t} \tag{4}$$

$$\Delta X_d = X_d^{t+1} - X_d^{t} \tag{5}$$

Using Eqs. (3), (4), and (5), Eq. (2) can be transformed as follows:

$$\begin{aligned}
\Delta Q_d &= \mathbf{c} \cdot \mathbf{E}^{t+1} \cdot \boldsymbol{\theta}^{t+1} \cdot X_d^{t+1} - \mathbf{c} \cdot \mathbf{E}^{t} \cdot \boldsymbol{\theta}^{t} \cdot X_d^{t} \\
&= \mathbf{c} \cdot \left(\mathbf{E}^{t} + \Delta \mathbf{E}\right) \cdot \left(\boldsymbol{\theta}^{t} + \Delta \boldsymbol{\theta}\right) \cdot \left(X_d^{t} + \Delta X_d\right) - \mathbf{c} \cdot \mathbf{E}^{t} \cdot \boldsymbol{\theta}^{t} \cdot X_d^{t+1} \\
&= \mathbf{c} \Delta \mathbf{E} \boldsymbol{\theta}^{t} X_d^{t+1} + \mathbf{c} \mathbf{E}^{t} \Delta \boldsymbol{\theta} X_d^{t} + \mathbf{c} \mathbf{E}^{t} \boldsymbol{\theta}^{t} \Delta X_d + \mathbf{c} \Delta \mathbf{E} \Delta \boldsymbol{\theta} X_d^{t} \\
&\quad + \mathbf{c} \mathbf{E}^{t} \Delta \boldsymbol{\theta} \Delta X_d + \mathbf{c} \Delta \mathbf{E} \boldsymbol{\theta}^{t} \Delta X_d + \mathbf{c} \Delta \mathbf{E} \Delta \boldsymbol{\theta} \Delta X_d
\end{aligned} \tag{6}$$

The first term on the right-hand side of Eq. (6) represents the influence on emissions of changes in the energy intensity in the industrial sector. The second and third terms represent the influence on emissions of changes in the industrial composition of the industrial sector and the total industrial output, respectively. The simplified additive decomposition method (e.g., Park 1992) ignores second-order interaction terms (such as the fourth, fifth, and sixth terms on the right-hand side of Eq. (6)) and third-order interaction terms (such as the seventh term). As a result, the sum of the contributions of the first three terms on the right-hand side will not be equal to total change in emissions ΔQ_d. The important question is how to treat the influence of the interaction terms (Sun 1998).

In the present study, following Sun (1998), I consider the second-order interaction terms and the third-order interaction term, and employ the following additive decomposition formulation:

$$\begin{aligned}
\Delta Q_d = & \underbrace{\mathbf{c} \Delta \mathbf{E} \boldsymbol{\theta}^{t} X_d^{t} + \frac{1}{2}\left(\mathbf{c} \Delta \mathbf{E} \Delta \boldsymbol{\theta} X_d^{t} + \mathbf{c} \Delta \mathbf{E} \boldsymbol{\theta}^{t} \Delta X_d\right) + \frac{1}{3} \mathbf{c} \Delta \mathbf{E} \Delta \boldsymbol{\theta} \Delta X_d}_{\text{Technical effect: } \Delta Q_d^{\text{Tech}}} \\
& + \underbrace{\mathbf{c} \mathbf{E}^{t} \Delta \boldsymbol{\theta} X_d^{t} + \frac{1}{2}\left(\mathbf{c} \Delta \mathbf{E} \Delta \boldsymbol{\theta} X_d^{t} + \mathbf{c} \mathbf{E}^{t} \Delta \boldsymbol{\theta} \Delta X_d\right) + \frac{1}{3} \mathbf{c} \Delta \mathbf{E} \Delta \boldsymbol{\theta} \Delta X_d}_{\text{Industrial composition effect: } \Delta Q_d^{\text{Comp}}} \\
& + \underbrace{\mathbf{c} \mathbf{E}^{t} \boldsymbol{\theta}^{t} \Delta X_d + \frac{1}{2}\left(\mathbf{c} \Delta \mathbf{E} \boldsymbol{\theta}^{t} \Delta X_d + \mathbf{c} \mathbf{E}^{t} \Delta \boldsymbol{\theta} \Delta X_d\right) + \frac{1}{3} \mathbf{c} \Delta \mathbf{E} \Delta \boldsymbol{\theta} \Delta X_d}_{\text{Economic scale effect: } \Delta Q_d^{\text{Scale}}}
\end{aligned} \tag{7}$$

We refer to the first, second, and third terms on the right-hand side of Eq. (7) respectively as the technical effect, the industrial composition effect, and the economic scale effect, which we denote by ΔQ_d^{Tech}, ΔQ_d^{Comp}, and $\Delta Q_d^{\text{Scale}}$. The effect expressed by Eq. (7) is the *total* effect, representing the sum of the effects across all industries; thus, for example, it is not possible to isolate from Eq. (7) the industrial composition effect in the service industry or the technical effect in the manufacturing industry. For this reason, we will further decompose Eq. (7) into the effect in each industry.

We will classify our N industry sectors into four industry groups:

(1) primary industries,
(2) secondary industries,
(3) electricity, gas, and water supply industries, and
(4) tertiary industries (service industries).

For industry sector i belonging to the group of primary industries (i.e., $i \in$ primary industry), we define $\mathbf{S}_a$ to be the $(N \times N)$ diagonal matrix with ith diagonal element equal to 1 and all other elements equal to 0. Here, the subscript a indicates primary industries (i.e., agriculture, forestry, and fishery industries). The technical effect (i.e., that from changes in the energy intensity) in industry sectors belonging to the group of primary industries and the effect from changes in industrial composition in industry sectors belonging to the primary industries can be quantified using Eqs. (8) and (9) below:

$$\Delta Q_{d,a}^{\text{Tech}} = \mathbf{c}\Delta\mathbf{E}\mathbf{S}_a\boldsymbol{\theta}^t X_d^t + \frac{1}{2}\left(\mathbf{c}\Delta\mathbf{E}\mathbf{S}_a\Delta\boldsymbol{\theta} X_d^t + \mathbf{c}\Delta\mathbf{E}\mathbf{S}_a\boldsymbol{\theta}^t\Delta X_d\right) + \frac{1}{3}\mathbf{c}\Delta\mathbf{E}\mathbf{S}_a\Delta\boldsymbol{\theta}\Delta X_d \tag{8}$$

$$\Delta Q_{d,a}^{\text{Comp}} = \mathbf{c}\mathbf{E}^t\mathbf{S}_a\Delta\boldsymbol{\theta} X_d^t + \frac{1}{2}\left(\mathbf{c}\Delta\mathbf{E}\mathbf{S}_a\Delta\boldsymbol{\theta} X_d^t + \mathbf{c}\mathbf{E}^t\mathbf{S}_a\Delta\boldsymbol{\theta}\Delta X_d\right) + \frac{1}{3}\mathbf{c}\Delta\mathbf{E}\mathbf{S}_a\Delta\boldsymbol{\theta}\Delta X_d \tag{9}$$

Similarly, the technical effects and industrial composition effects in secondary industries, electricity, gas, and water supply industries, and tertiary industries can be estimated as in Eqs. (10) through (15) below:

$$\Delta Q_{d,m}^{\text{Tech}} = \mathbf{c}\Delta\mathbf{E}\mathbf{S}_m\boldsymbol{\theta}^t X_d^t + \frac{1}{2}\left(\mathbf{c}\Delta\mathbf{E}\mathbf{S}_m\Delta\boldsymbol{\theta} X_d^t + \mathbf{c}\Delta\mathbf{E}\mathbf{S}_m\boldsymbol{\theta}^t\Delta X_d\right) + \frac{1}{3}\mathbf{c}\Delta\mathbf{E}\mathbf{S}_m\Delta\boldsymbol{\theta}\Delta X_d \tag{10}$$

$$\Delta Q_{d,m}^{\text{Comp}} = \mathbf{c}\mathbf{E}^t\mathbf{S}_m\Delta\boldsymbol{\theta} X_d^t + \frac{1}{2}\left(\mathbf{c}\Delta\mathbf{E}\mathbf{S}_m\Delta\boldsymbol{\theta} X_d^t + \mathbf{c}\mathbf{E}^t\mathbf{S}_m\Delta\boldsymbol{\theta}\Delta X_d\right) + \frac{1}{3}\mathbf{c}\Delta\mathbf{E}\mathbf{S}_m\Delta\boldsymbol{\theta}\Delta X_d \tag{11}$$

$$\Delta Q_{d,g}^{\text{Tech}} = \mathbf{c}\Delta\mathbf{E}\mathbf{S}_g\boldsymbol{\theta}^t X_d^t + \frac{1}{2}\left(\mathbf{c}\Delta\mathbf{E}\mathbf{S}_g\Delta\boldsymbol{\theta} X_d^t + \mathbf{c}\Delta\mathbf{E}\mathbf{S}_g\boldsymbol{\theta}^t\Delta X_d\right) + \frac{1}{3}\mathbf{c}\Delta\mathbf{E}\mathbf{S}_g\Delta\boldsymbol{\theta}\Delta X_d \tag{12}$$

$$\Delta Q_{d,g}^{\text{Comp}} = \mathbf{c}\mathbf{E}^t \mathbf{S}_g \Delta\boldsymbol{\theta} X_d^t + \frac{1}{2}\left(\mathbf{c}\Delta\mathbf{E}\mathbf{S}_g \Delta\boldsymbol{\theta} X_d^t + \mathbf{c}\mathbf{E}^t \mathbf{S}_g \Delta\boldsymbol{\theta} \Delta X_d\right) + \frac{1}{3}\mathbf{c}\Delta\mathbf{E}\mathbf{S}_g \Delta\boldsymbol{\theta} \Delta X_d \quad (13)$$

$$\Delta Q_{d,s}^{\text{Tech}} = \mathbf{c}\Delta\mathbf{E}\mathbf{S}_s \boldsymbol{\theta}^t X_d^t + \frac{1}{2}\left(\mathbf{c}\Delta\mathbf{E}\mathbf{S}_s \Delta\boldsymbol{\theta} X_d^t + \mathbf{c}\Delta\mathbf{E}\mathbf{S}_s \boldsymbol{\theta}^t \Delta X_d\right) + \frac{1}{3}\mathbf{c}\Delta\mathbf{E}\mathbf{S}_s \Delta\boldsymbol{\theta} \Delta X_d \quad (14)$$

$$\Delta Q_{d,s}^{\text{Comp}} = \mathbf{c}\mathbf{E}^t \mathbf{S}_s \Delta\boldsymbol{\theta} X_d^t + \frac{1}{2}\left(\mathbf{c}\Delta\mathbf{E}\mathbf{S}_s \Delta\boldsymbol{\theta} X_d^t + \mathbf{c}\mathbf{E}^t \mathbf{S}_s \Delta\boldsymbol{\theta} \Delta X_d\right) + \frac{1}{3}\mathbf{c}\Delta\mathbf{E}\mathbf{S}_s \Delta\boldsymbol{\theta} \Delta X_d \quad (15)$$

Here, $\mathbf{S}_m$, $\mathbf{S}_g$, and $\mathbf{S}_s$, where the subscripts m, g, and s, respectively, denote secondary industries, electricity, gas, and water supply industries, and tertiary industries, are $(N \times N)$ diagonal matrices whose ith diagonal element is 1 for all i in the corresponding industry group and all other elements are zero.

3 Data

I used CO_2 emissions data obtained from industrial tables contained in the Embodied Energy and Emission Intensity Data for Japan Using Input–Output Tables: 3EID data book released by the Center for Global Environmental Research at the National Institute for Environmental Studies of Japan (2012). In addition, I used the 1990–1995–2000–2005 linked environmental input–output tables (396 industry sectors) (Nansai et al. 2007, 2009).

Using the 3EID data book allows energy intensity data for joules of 32 types of raw fuel directly consumed by producing one unit of output in each of 396 industry sectors in the years 1990, 1995, 2000, and 2005 (see Table 1 for the 32 raw fuel types). From this database, we can obtain values of $e_{k,i}^t$. In addition, from the same database, we can obtain data on the quantity c_k (Table 1).

From the 1990–1995–2000–2005 linked input–output tables (which are evaluated in terms of 2005 producer prices), we can obtain not only data on the total production in each industry sector in each year, but also data on the quantity X_d^t. This, in turn, allows us to easily compute θ_i, which measures the industrial composition of industry sector i. For details on the categorization of industry sectors, see Table 2.

4 Results

4.1 Macro-level Decomposition Results

According to the 1990–1995–2000–2005 linked input–output tables, Japan's total industrial output was ¥841 trillion in 1990, ¥886 trillion in 1995, ¥922 trillion in 2000,

Table 1 The classification of fuel types

	Fuel type	CO_2 emission intensity	Unit
1	Coking coal	0.092	t CO_2/GJ
2	Steam coal, lignite and anthracite	0.089	t CO_2/GJ
3	Coke	0.108	t CO_2/GJ
4	Blast furnace coke	0.108	t CO_2/GJ
5	Coke oven gas (COG)	0.040	t CO_2/GJ
6	BFG (Consumption)	0.108	t CO_2/GJ
7	BFG (Generation)	0.108	t CO_2/GJ
8	LOG (Consumption)	0.108	t CO_2/GJ
9	LOG (Generation)	0.108	t CO_2/GJ
10	Crude oil	0.069	t CO_2/GJ
11	Fuel oil A	0.071	t CO_2/GJ
12	Fuel oils B and C	0.071	t CO_2/GJ
13	Kerosene	0.068	t CO_2/GJ
14	Diesel oil	0.069	t CO_2/GJ
15	Gasoline	0.067	t CO_2/GJ
16	Jet fuel	0.067	t CO_2/GJ
17	Naphtha	0.065	t CO_2/GJ
18	Petroleum-based hydrocarbon gas	0.046	t CO_2/GJ
19	Hydrocarbon oil	0.077	t CO_2/GJ
20	Petroleum coke	0.093	t CO_2/GJ
21	Liquefied petroleum gas (LPG)	0.060	t CO_2/GJ
22	Natural gas, LNG	0.051	t CO_2/GJ
23	Mains gas	0.052	t CO_2/GJ
24	Black liquor	0.094	t CO_2/GJ
25	Waste wood	0.077	t CO_2/GJ
26	Waste tires	0.080	t CO_2/GJ
27	Municipal waste	0.031	t CO_2/GJ
28	Industrial waste	0.049	t CO_2/GJ
29	Recycled plastic of packages origins	0.065	t CO_2/GJ
30	Nuclear power generation	–	
31	Hydro and other power generations	–	
32	Limestone	0.0105	t CO_2/GJ

Source: Embodied Energy and Emission Intensity Data for Japan Using Input–Output. Tables (3EID) data book released by the Center for Global Environmental Research at the National Institute for Environmental Studies of Japan (2012). The 3EID data are described with the unit of TOE (Tons of Oil Equivalent).

and ¥962 trillion in 2005. Meanwhile, CO_2 emissions originating from industrial activity were 1.04 billion t CO_2 in 1990, 1.10 billion t CO_2 in 1995, 1.13 billion t CO_2 in 2000, and 1.17 billion t CO_2 in 2005. The increase in CO_2 emissions can be attributed to the growth in total industrial output. However, the CO_2 intensity, which can be defined by dividing CO_2 emissions originating from each year's industrial activity by

Table 2 The categorization of industrial sectors

1	Rice
2	Wheat, barley and the like
3	Potatoes and sweet potatoes
4	Pulses
5	Vegetables
6	Fruits
7	Sugar crops
8	Crops for beverages
9	Other edible crops
10	Crops for feed and forage
11	Seeds and seedlings
12	Flowers and plants
13	Other inedible crops
14	Dairy cattle farming
15	Hen eggs
16	Fowl sand broilers
17	Hogs
18	Beef cattle
19	Other livestock
20	Veterinary service
21	Agricultural services (except veterinary service)
22	Silviculture
23	Logs
24	Special forest products (inc. hunting)
25	Marine fisheries
26	Marine culture
27	Inland water fisheries and culture
28	Metallic ores
29	Materials for ceramics
30	Gravel and quarrying
31	Crushed stones
32	Other non-metal lie ores
33	Coal mining, crude petroleum and natural gas
34	Slaughtering and meat processing
35	Processed meat products
36	Bottled or canned meat products
37	Dairy farm products
38	Frozen fish and shellfish
39	Salted, dried or smoked seafood
40	Bottled or canned seafood
41	Fish paste
42	Other processed seafood
43	Grain milling
44	Flour and other grain milled products
45	Noodles
46	Bread
47	Confectionery
48	Bottled or canned vegetables and fruits
49	Preserved agricultural foodstuffs (other than bottled or canned)
50	Sugar
51	Starch
52	Dextrose, syrup and isomerized sugar
53	Vegetable oils and meal
54	Animal oils and fats
55	Condiments and seasonings
56	Prepared frozen foods
57	Retort foods
58	Dishes, sushi and lunch boxes
59	School lunch (public)**
60	School lunch (private)*
61	Other foods
62	Refined sake
63	Beer
64	Whiskey and brandy
65	Other liquors
66	Tea and roasted coffee
67	Soft drinks
68	Manufactured ice
69	Animal feed
70	Organic fertilizers, n.e.c.
71	Tobacco
72	Fiber yarns
73	Cotton and staple fiber fabrics (inc. fabrics of synthetic spun fibers)
74	Silk and artificial silk fabrics (inc. fabrics of synthetic filament fibers)
75	Woolen fabrics, hemp fabrics and other fabrics
76	Knitting fabrics
77	Yarn and fabric dyeing and finishing (processing on commission only)
78	Ropes and nets
79	Carpets and floor mats
80	Fabricated textiles for medical use
81	Other fabricated textile products
82	Woven fabric apparel
83	Knitted apparel

Table 2 (*Continued*)

84	Other wearing apparel and clothing accessories	127	Soap, synthetic detergents and surface active agents
85	Bedding	128	Cosmetics, toilet preparations and dentifrices
86	Other ready-made textile products	129	Paint and varnishes
87	Timber	130	Printing ink
88	Plywood	131	Photographic sensitive materials
89	Wooden chips	132	Agricultural chemicals
90	Other wooden products	133	Gelatin and adhesives
91	Wooden furniture and fixtures	134	Other final chemical products
92	Wooden fixtures	135	Petroleum refinery products (inc. greases)
93	Metallic furniture and fixture	136	Coal products
94	Pulp	137	Paving materials
95	Paper	138	Plastic products
96	Paperboard	139	Tires and inner tubes
97	Corrugated cardboard	140	Rubber footwear
98	Coated paper and building (construction) paper	141	Plastic footwear
99	Corrugated card board boxes	142	Other rubber products
100	Other paper containers	143	Leather footwear
101	Paper textile for medical use	144	Leather and fur skins
102	Other pulp, paper and processed paper products	145	Miscellaneous leather products
103	Printing, plate making and book binding	146	Sheet glass and safety glass
104	Chemical fertilizer	147	Glass fiber and glass fiber products, n.e.c.
105	Industrial soda chemicals	148	Other glass products
106	Inorganic pigment	149	Cement
107	Compressed gas and liquefied gas	150	Ready mixed concrete
108	Salt	151	Cement products
109	Other industrial inorganic chemicals	152	Pottery, china and earthenware
110	Petrochemical basic products	153	Clay refractories
111	Petrochemical aromatic products (except synthetic resin)	154	Other structural clay products
112	Aliphatic intermediates	155	Carbon and graphite products
113	Cyclic intermediates	156	Abrasive
114	Synthetic rubber	157	Miscellaneous ceramic, stone and clay products
115	Methane derivatives	158	Pig iron
116	Oil and fat industrial chemicals	159	Ferro alloys
117	Plasticizers	160	Crude steel (converters)
118	Synthetic dyes	161	Crude steel (electric furnaces)
119	Other industrial organic chemicals	162	Scrap iron
120	Thermo-setting resins	163	Hot rolled steel
121	Thermoplastics resins	164	Steel pipes and tubes
122	High function resins	165	Cold-finished steel
123	Other resins	166	Coated steel
124	Rayon and acetate	167	Cast and forged steel
125	Synthetic fibers	168	Cast iron pipes and tubes
126	Medicaments	169	Cast and forged materials (iron)

Table 2 (*Continued*)

170	Iron and steel shearing and slitting
171	Other iron or steel products
172	Copper
173	Lead and zinc (inc. regenerated lead)
174	Aluminum (inc. regenerated aluminum)
175	Other non-ferrous metals
176	Non-ferrous metal scrap
177	Electric wires and cables
178	Optical fiber cables
179	Rolled and drawn copper and copper alloys
180	Rolled and drawn aluminum
181	Non-ferrous metal castings and forgings
182	Nuclear fuels
183	Other non-ferrous metal products
184	Metal products for construction
185	Metal products for architecture
186	Gas and oil appliances and heating and cooking apparatus
187	Bolts, nuts, rivets and springs
188	Metal containers, fabricated plate and sheet metal
189	Plumber's supplies, powder metallurgy products and tools
190	Other metal products
191	Boilers
192	Turbines
193	Engines
194	Conveyors
195	Refrigerators and air conditioning apparatus
196	Pumps and compressors
197	Machinists' precision tools
198	Other general industrial machinery and equipment
199	Machinery and equipment for construction and mining
200	Chemical machinery
201	Industrial robots
202	Metal machine tools
203	Metal processing machinery
204	Machinery for agricultural use
205	Textile machinery
206	Food processing machinery and equipment
207	Semiconductor making equipment
208	Other special machinery for industrial use
209	Metal molds
210	Bearings
211	Other general machines and parts
212	Copy machine
213	Other office machines
214	Machinery for service industry
215	Rotating electrical equipment
216	Transformers and reactors
217	Relay switches and switchboards
218	Wiring devices and supplies
219	Electrical equipment for internal combustion engines
220	Other electrical devices and parts
221	Applied electronic equipment
222	Electric measuring instruments
223	Electric bulbs
224	Electric lighting fixtures and apparatus
225	Batteries
226	Other electrical devices and parts
227	Household air-conditioners
228	Household electric appliances (except air-conditioners)
229	Video recording and playback equipment
230	Electric audio equipment
231	Radio and television sets
232	Wired communication equipment
233	Cellular phones
234	Radio communication equipment (except cellular phones)
235	Other communication equipment
236	Personal computers
237	Electronic computing equipment (except personal computers)
238	Electronic computing equipment (accessory equipment)
239	Semiconductor devices
240	Integrated circuits
241	Electron tubes
242	Liquid crystal element
243	Magnetic tapes and disks
244	Other electronic components
245	Passenger motor cars
246	Trucks, buses and other cars
247	Two-wheel motor vehicles
248	Motor vehicle bodies

Table 2 (*Continued*)

249	Internal combustion engines for motor vehicles and parts
250	Motor vehicle parts and accessories
251	Steel ships
252	Ships (except steel ships)
253	Internal combustion engines for vessels
254	Repair of ships
255	Rolling stock
256	Repair of rolling stock
257	Aircrafts
258	Repair of aircrafts
259	Bicycles
260	Other transport equipment
261	Camera
262	Other photographic and optical instruments
263	Watches and clocks
264	Professional and scientific instruments
265	Analytical instruments, testing machine, measuring instruments
266	Medical instruments
267	Toys and games
268	Sporting and athletic goods
269	Musical instruments
270	Audio and video records, other information recording media
271	Stationery
272	Jewelry and adornments
273	"Tatami" (straw matting) and straw products
274	Ordnance
275	Miscellaneous manufacturing products
276	Residential construction (wooden)
277	Residential construction (non-wooden)
278	Non-residential construction (wooden)
279	Non-residential construction (non-wooden)
280	Repair of construction
281	Public construction of roads
282	Public construction of rivers, drainages and others
283	Agricultural public construction
284	Railway construction
285	Electric power facilities construction
286	Telecommunication facilities construction
287	Other civil engineering and construction
288	Electricity
289	On-site power generation
290	Gas supply
291	Steam and hot water supply
292	Water supply
293	Industrial water supply
294	Sewage disposal**
295	Waste management services (public)**
296	Waste management services (private)
297	Wholesale trade
298	Retail trade
299	Financial service
300	Life insurance
301	Non-life insurance
302	Real estate agencies and managers
303	Real estate rental service
304	House rent
305	Railway transport (passengers)
306	Railway transport (freight)
307	Bus transport service
308	Hired car and taxi transport
309	Road freight transport (except Self-transport by private cars)
310	Ocean transport
311	Coastal and inland water transport
312	Harbor transport service
313	Air transport
314	Consigned freight forwarding
315	Storage facility service
316	Packing service
317	Facility service for road transport
318	Port and water traffic control**
319	Services relating to water transport
320	Airport and air traffic control (public)**
321	Airport and air traffic control (industrial)
322	Services relating to air transport
323	Travel agency and other services relating to transport
324	Postal service
325	Fixed telecommunication
326	Mobile telecommunication
327	Other services relating to communication
328	Public broadcasting
329	Private broadcasting
330	Cable broadcasting
331	Information services

Table 2 (*Continued*)

332	Internet based services
333	Image information production and distribution industry
334	Newspaper
335	Publication
336	News syndicates and private detective agencies
337	Public administration (central)**
338	Public administration (local)**
339	School education (public)**
340	School education (private)*
341	Social education (public)**
342	Social education (private, non-profit)*
343	Other educational and training institutions (public)**
344	Other educational and training institutions (profit-making)
345	Research institutes for natural science (pubic)**
346	Research institutes for cultural and social science (public)**
347	Research institutes for natural sciences (private, non-profit)*
348	Research institutes for cultural and social science (private, non-profit)*
349	Research institutes for natural sciences (profit-making)
350	Research institutes for cultural and social science (profit-making)
351	Research and development (intra-enterprise)
352	Medical service (public)
353	Medical service (non-profit foundations, etc.)
354	Medical service (medical corporations, etc.)
355	Health and hygiene (public)**
356	Health and hygiene (profit-making)
357	Social insurance (public)**
358	Social insurance (private, non-profit)*
359	Social welfare (public)**
360	Social welfare (private, non-profit)*
361	Social welfare (profit-making)
362	Nursing care (In-home)
363	Nursing care (In-facility)
364	Private non-profit institutions serving enterprises
365	Private non-profit institutions serving households, n.e.c.*
366	Advertising services
367	Goods rental and leasing (except car rental)
368	Car rental and leasing
369	Repair of motor vehicles
370	Repair of machine
371	Building maintenance services
372	Judicial, financial and accounting services
373	Civil engineering and construction services
374	Worker dispatching services
375	Other business services
376	Movie theaters
377	Performances (except otherwise classified), theatrical companies
378	Amusement and recreation facilities
379	Stadiums and companies of bicycle, horse, motorcar and motorboat races
380	Sport facility service, public gardens and amusement parks
381	Other amusement and recreation services
382	General eating and drinking places (except coffee shops)
383	Coffee shops
384	Eating and drinking places for pleasures
385	Hotels
386	Cleaning
387	Barber shops
388	Beauty shops
389	Public baths
390	Other cleaning, barber shops, beauty shops and public baths
391	Photographic studios
392	Ceremonial occasions
393	Miscellaneous repairs, n.e.c.
394	Supplementary tutorial schools, instruction services for arts, culture and technical skills
395	Other personal services
396	Office supplies

Note: "Primary industry" includes sectors from #1 to #27. "Secondary industry" includes sectors from #28 to #287. "Tertiary industry" includes sectors from #297 to #396. "Electricity industry" includes sectors from #288 to #296.

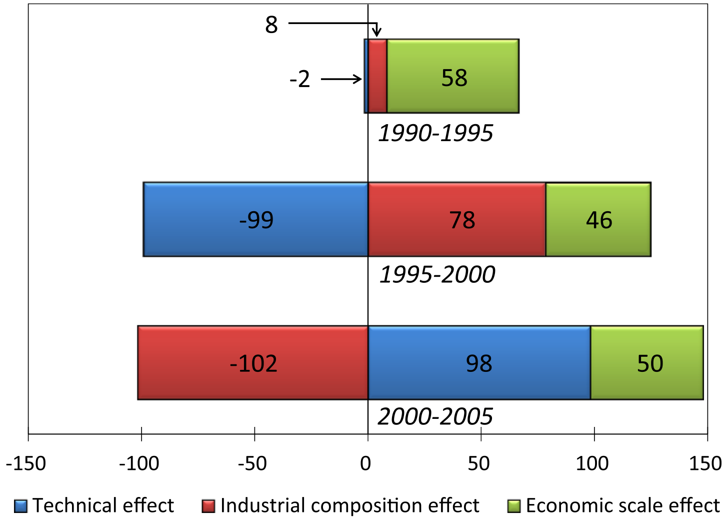

Fig. 1 CO_2 decomposition result using the Shapley–Sun decomposition method (units: Mt CO_2)

total industrial output, was 1.24 t CO_2/million yen in 1990, 1.25 t CO_2/million yen in 1995, 1.22 t CO_2/million yen in 2000, and 1.22 t CO_2/million yen in 2005. Thus, Japan's CO_2 intensity has been gradually improving, indicating that factors such as technological progress and the transition to cleaner fuels have contributed to reducing CO_2 emissions.

Figure 1 shows the results of decompositions, using Eq. (7), of the changes in Japanese CO_2 emissions originating from industrial activity over the 15-year period from 1990 to 2005, as decomposed into three factors: technical effects, industrial composition effects, and economic scale effects. Between 1990 and 1995, the change in CO_2 emissions was +64 Mt CO_2; from the figure, we see that this number breaks down into −2 Mt CO_2 arising from technical effects, +8 Mt CO_2 arising from industrial composition effects, and +58 Mt CO_2 arising from economic scale effects. Next, between 1995 and 2000, the change in CO_2 emissions was +25 Mt CO_2; this number breaks down into −99 million t CO_2 arising from technical effects, +78 Mt CO_2 arising from industrial composition effects, and +46 Mt CO_2 arising from economic scale effects. Finally, between 2000 and 2005, the change in CO_2 emissions was +46 Mt CO_2; this number breaks down into +98 Mt CO_2 arising from technical effects, −102 Mt CO_2 arising from industrial composition effects, and +50 Mt CO_2 arising from economic scale effects.

Thus, we see that, during the 10-year period from 1990 to 2000, economic scale effects and industrial composition effects both contributed to increasing CO_2 emissions, while technical effects contributed to reducing CO_2 emissions. However, this trend reversed itself in the years between 2000 and 2005, during which technical effects contributed significantly to increasing CO_2 emissions, whereas industrial composition effects contributed significantly to reducing CO_2 emissions.

Because the results presented in Fig. 1 are aggregate totals over all industry sectors, they do not allow us to identify the particular industry sectors in which technical

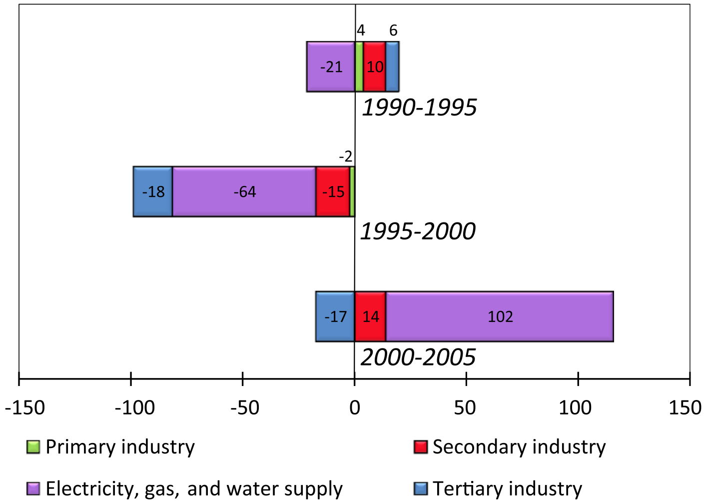

Fig. 2 Technical effects for the four industry groups (units: Mt CO_2)

effects and industrial composition effects influenced CO_2 emissions. To investigate these questions, we use Eqs. (8) through (15) to analyze technical effects and industrial composition effects in each of our four industry groups: primary industries, secondary industries, electricity, gas, and water supply industries, and tertiary industries.

4.2 Technical Effects for the Four Industry Groups

Within each industry, the technical effect measures the impact on CO_2 emissions of changes in the industrial energy intensity. A negative technical effect for an industry signifies that the industry has successfully reduced energy consumption or shifted its use of energy in a way that reduces CO_2 emissions. Figure 2 shows technical effects for the four industry groups considered in this study. As shown, electricity, gas, and water supply industries exhibited a negative technical effect throughout the 10-year period from 1990 to 2000 but crossed over to a large positive technical effect (+102 Mt CO_2) during the interval between 2000 and 2005.

Thus, we see that, in the past 15 years, the technical effects in electricity, gas, and water supply industries have varied widely. In particular, one factor contributing to the increase in emissions during the 5-year period from 2000 to 2005 was the high technical effect of +62 Mt CO_2 observed for the commercial electric power sector. The primary cause of this phenomenon in the commercial electric power sector is the fact that, although the energy intensity for crude oil decreased during this period, the energy intensity for coal, lignite, and anthracite increased, and an energy shift to these fuels, which exhibit relatively higher concentrations of CO_2 emissions, has occurred.

Figure 2 also reveals that technical effects in tertiary industries led to a significant decrease in CO_2 emissions between the years 2000 and 2005. Considering the tech-

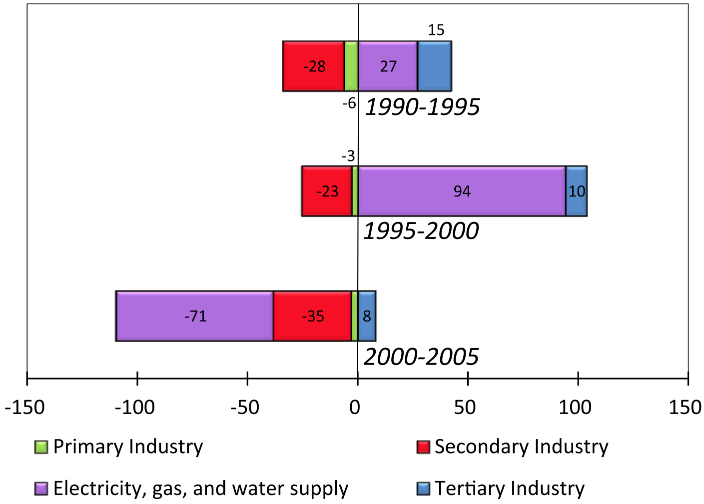

Fig. 3 Industrial composition effects for the four industry groups (units: Mt CO_2)

nical effects in specific sectors, we see that the technical effect in the ocean cargo transport industry was −8 Mt CO_2 and that in the road cargo transport industry was −7 Mt CO_2. Improved fuel efficiency in both these sectors significantly reduced the quantity of heavy oil needed to power ships and the quantity of light oil needed to power trucks, accounting for 88 % of the technical effects observed in tertiary industries.

4.3 Industrial Composition Effects for the Four Industry Groups

Within each industry, the industrial composition effect measures the impact of changes in the fraction of the overall industry accounted for by the various sectors. A negative value for this effect indicates that an industry sector contributed to reducing CO_2 emissions by decreasing the industrial composition. Figure 3 displays industrial composition effects for the four industry groups. As indicated in the figure, both primary and secondary industries exhibited negative industrial composition effects throughout the 15-year period from 1990 to 2005, whereas tertiary industries exhibited an overall positive effect throughout this period.

The total industrial composition effect for primary, secondary, and tertiary industries was −18.8 Mt CO_2 between 1990 and 1995, −15.8 Mt CO_2 between 1995 and 2000, and −30.4 Mt CO_2 between 2000 and 2005. These observations indicate that, throughout this 15-year period, the market for primary and secondary industries contracted, whereas the market for tertiary industries expanded (indicating the transition to a service economy); these changes consequently reduced CO_2 emissions by 65 Mt CO_2.

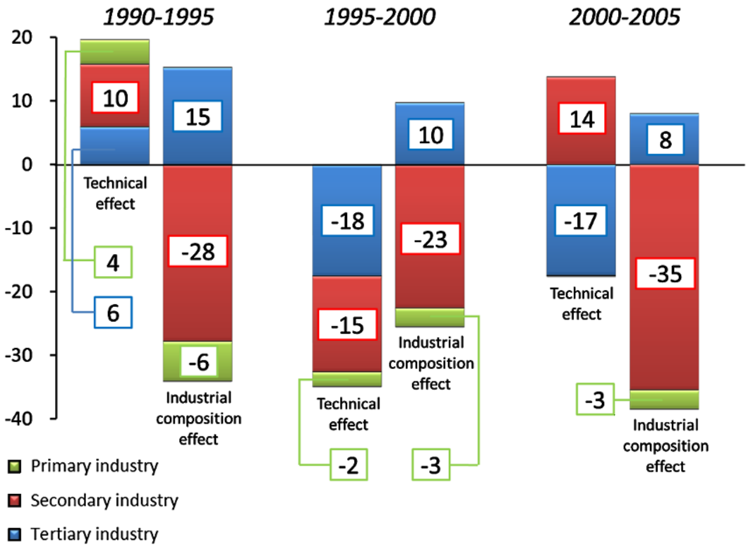

Fig. 4 Overall effects for three industry groups (units: Mt CO_2)

4.4 Role of the Service Economy and International Trade on CO_2 Emissions

Figure 4 compares the total technical effect for primary, secondary, and tertiary industries to the total industrial composition effect for these three industry groups.[3] Considering the overall effect (that is, the sum of the technical effect and the industrial composition effect), we see that, in the years between 1990 and 1995, technical effects and industrial composition effects together accounted for an increase in CO_2 emissions of 880 kt CO_2 (the sum of the technical effect and the industrial composition effect for 1990–1995 shown in Fig. 4). On the other hand, between 1995 and 2000, technical effects and industrial composition effects led to a decrease in CO_2 emissions of 50.7 Mt CO_2, and between 2000 and 2005 these effects led to a further decrease of 34.2 Mt CO_2. Thus, the overall decrease was particularly significant between 1995 and 2000; from the figure, we can see that this is largely attributable to the relatively large technical effects exhibited by tertiary industries during this interval.

The 1990–1995 overall effect of +880 kt CO_2 corresponds to 0.1 % of total emissions in 1990, which is the base year of the Kyoto Protocol. Whereas the industrial composition effect during this period was a large negative effect due to the transition to a service economy, the technical effect contributed significantly to increased CO_2 emissions. Between 1995 and 2000, the overall effect was −50.7 Mt CO_2, corresponding to 4.6 % of total emissions in 1995; between 2000 and 2005, the overall effect was −34.2 Mt CO_2, or a 3 % decrease compared to total emissions in 2000.

[3] Figures 2 and 3 show that the technical effects and industrial composition effects of electricity, gas, and water supply industries were large during the study period. In this section, I would like to discuss how the structural changes affected the CO_2 emissions when excluding these effects of electricity, gas, and water supply industries.

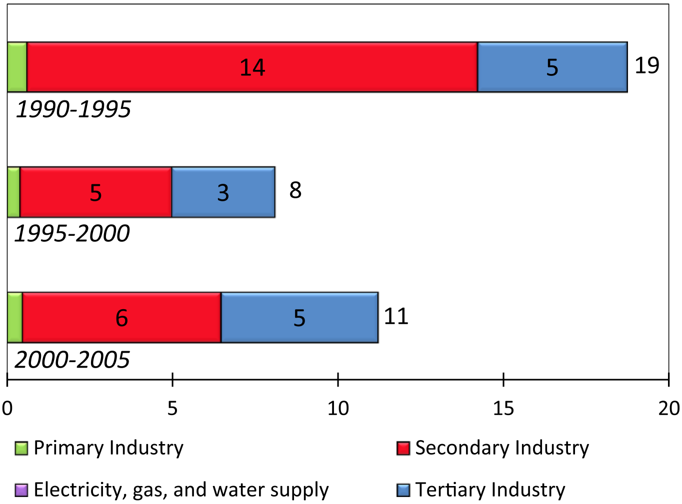

Fig. 5 Import scale effects for three industry groups (units: Mt CO_2)

Nansai et al. (2009) analyzed the domestic CO_2 emissions associated with the energy and material goods absorbed by services through the supply chain during the decade 1990–2000. They found that the CO_2 emissions contributed by way of the material goods absorbed by service industries rose from 68 Mt CO_2 in 1990 to 87 Mt CO_2 in 2000. As a result, the material dependence of service industries increased by 19 Mt CO_2 during 1990–2000. On the other hand, this study found that the CO_2 reduction due to the transition of a service economy was 35 Mt CO_2.[4] This reveals that the structural transition to a service economy was much more important than the material dependence of service industries.

Over the past 15 years, the declining share of domestic output by Japan's manufacturing industries has contributed to the mitigation of global warming, but the corresponding increase in the share of manufactured goods imported from overseas has increased CO_2 emissions in foreign countries. This leads to the question of whether it is possible that the net impact has been to *exacerbate* the phenomenon of global warming. To address this question, we considered the impact on CO_2 emissions of the changing share of imports; we decomposed import-based CO_2 emissions into three sources, as formulated in the Appendix.[5] Figures 5 and 6 present the results of this decomposition analysis. As shown in Fig. 5, over the past 15 years, the absolute quantity of imports from foreign countries to Japan rose and at the same time domestic CO_2 emissions rose by the equivalent of 38 Mt CO_2 (the total import scale effect). In contrast, as shown in Fig. 6, changes in the import composition decreased domes-

[4]The CO_2 reduction effect due to the transition to a service economy during 1990–2000 was estimated by summing total industrial composition effects during 1990–1995 and 1995–2000 (see Fig. 4).

[5]The import-based CO_2 emissions represent CO_2 emitted by producing imported goods and services overseas.

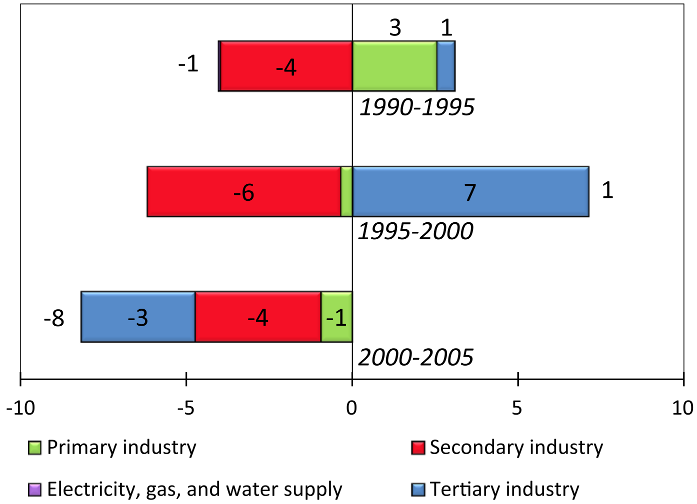

Fig. 6 Import composition effects for three industry groups (units: Mt CO_2)

tic CO_2 emissions by 8 Mt CO_2. These results demonstrate that Japan's increasing dependence on imports during the past 15 years has accelerated global warming.

In this study, we have employed the domestic technology assumption to estimate import-based CO_2 emissions by multiplying Japanese import volumes by Japanese CO_2 emission coefficients for each of 396 industries. For this reason, we might have underestimated CO_2 emissions due to imports from developing countries with relatively high emission coefficients. As the Japanese economy transitions from agricultural and manufacturing industries to service-based industries, it depends increasingly on imports of agricultural products and manufactured goods; on the basis of the domestic technology assumption, these imports changes (especially, the increase in the import scale of manufacturing products) and the previous industrial composition changes (i.e., the transition to a service economy) have consequently brought about a reduction in production-based CO_2 emissions of 35 Mt CO_2, or approximately 3 % of total emissions in 1990.

However, this reduction effect may be considerably overestimated due to differences in CO_2 emission intensities between Japan and other countries. Based on the World Input–Output Database (40 countries and 35 industrial sectors),[6] the Japanese industrial CO_2 intensities are approximately half those of China (one of the more CO_2-intensive countries) *on average*. Although the Chinese CO_2 emission intensities from the World Input–Output Database cannot be easily used for our study due to the highly aggregated sectoral classifications, it is clear that if we simply assume all the Japanese CO_2 intensities for a particular year (1990, 1995, 2000, and 2005) to be double their actual values, both the import scale effect and the import composition effect would be also double, accounting for 76 Mt CO_2 and -16 Mt CO_2, respectively. As a result, this assumption leads to the findings that the imports change

[6]The WIOD is downloadable from the website: http://www.wiod.org/ (Dietzenbacher et al. 2013).

effect, including their scale and composition effects, is 60 Mt CO_2 and the reduction effect due to the industrial composition changes over the entire 15-year period was offset by the imports change effect (see Sect. 4.3 for the industrial composition effects). Thus, the CO_2 emission leakage of Japan might not be negligible.

Under the terms of the Kyoto Protocol, Japan's target was to reduce *domestic* emissions by 6 % of total emissions in 1990; thus, if we consider only the domestic industrial composition effect (-65 Mt CO_2) discussed in Sect. 4.3, then we must conclude that this structural transition has contributed significantly to Japan's attainment of its emissions-reduction goals under the Kyoto Protocol. Moreover, the CO_2 emissions tax under consideration by Japan's Ministry of the Environment is 289 yen/t CO_2, and, based on this tax rate, the environmental benefit of the transition to a service economy will amount to ¥18.7 billion ($= 289$ yen/t $CO_2 \times 65$ Mt CO_2). Thus, we cannot ignore these structural change effects when considering the mitigation of domestic greenhouse gas emissions. Industrial policies that accelerate Japan's transition to a service economy are an effective means of reducing Japanese domestic CO_2 emissions. However, such policies may result in increased emissions overall, by steering the production of manufactured industrial goods to foreign producers exhibiting high concentrations of CO_2 emissions. The important point is to strive for the dematerialization of society as a whole, thereby reducing CO_2 emissions from manufacturing sectors both in Japan and abroad.

5 Conclusions

In this study, I considered the Japanese economy during three time periods, from 1990 to 1995, from 1995 to 2000, and from 2000 to 2005, and I decomposed changes in CO_2 emissions originating from detailed industrial activities into five contributing factors, technical effects, industrial composition effects, economic scale effects, import scale effects, and import composition effects.

The major findings of this study are as follows.

(1) During the 15-year period from 1990 to 2005, technical effects in the ocean and road cargo transport sectors (including, among other factors, increased fuel efficiency for ships and trucks) helped to ensure an overall technical effect of -29 Mt CO_2 for tertiary industries as a whole, thus contributing significantly to a reduction in CO_2 emissions.

(2) The industrial composition changes during the period from 2000 to 2005 contributed to a decrease in CO_2 emissions, while those changes during the 10-year period from 1990 to 2000 led to an increase in CO_2 emissions. The main reason is that the Japanese economy experienced a significant decarbonization due to structural changes toward a service economy during 2000 to 2005.

(3) During the 15-year period from 1990 to 2005, structural change effects under the domestic technology assumption (which include industrial composition effects, import scale effects, and import composition effects) totaled -35 Mt CO_2, or 3 % of total CO_2 emissions in 1990. These effects were instrumental in allowing Japan to attain its emissions-reduction target under the Kyoto Protocol, which was a 6 % reduction from 1990 emissions levels.

(4) I demonstrated that the domestic environmental benefit arising from the transition to a service economy would amount to ¥18.7 billion.

Competing Interests

The author declares that they have no competing interests.

Author's Contributions

SO proposed the SDA method, conducted data analysis, and provided policy implications.

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Appendix

Using the same decomposition as in Eq. (7), the decomposition formula regarding the CO_2 emissions induced by imports can be obtained as

$$\begin{aligned}\Delta Q_m = &\underbrace{\mathbf{c}\Delta\mathbf{E}\boldsymbol{\pi}^t X_m^t + \frac{1}{2}\left(\mathbf{c}\Delta\mathbf{E}\Delta\boldsymbol{\pi} X_m^t + \mathbf{c}\Delta\mathbf{E}\boldsymbol{\pi}^t \Delta X_m\right) + \frac{1}{3}\mathbf{c}\Delta\mathbf{E}\Delta\boldsymbol{\pi}\Delta X_m}_{\text{Technical effect: } \Delta Q_m^{\text{Tech}}} \\ &+ \underbrace{\mathbf{c}\mathbf{E}^t\Delta\boldsymbol{\pi} X_m^t + \frac{1}{2}\left(\mathbf{c}\Delta\mathbf{E}\Delta\boldsymbol{\pi} X_m^t + \mathbf{c}\mathbf{E}^t\Delta\boldsymbol{\pi}\Delta X_m\right) + \frac{1}{3}\mathbf{c}\Delta\mathbf{E}\Delta\boldsymbol{\pi}\Delta X_m}_{\text{Import composition effect: } \Delta Q_m^{\text{Comp}}} \\ &+ \underbrace{\mathbf{c}\mathbf{E}^t\boldsymbol{\pi}^t\Delta X_m + \frac{1}{2}\left(\mathbf{c}\Delta\mathbf{E}\boldsymbol{\pi}^t\Delta X_m + \mathbf{c}\mathbf{E}^t\Delta\boldsymbol{\pi}\Delta X_m\right) + \frac{1}{3}\mathbf{c}\Delta\mathbf{E}\Delta\boldsymbol{\pi}\Delta X_m}_{\text{Import scale effect: } \Delta Q_m^{\text{Scale}}}\end{aligned}$$

where $\boldsymbol{\pi}$ is an $(N \times 1)$ column vector whose ith element, π_i, is the import composition of imported commodity i, and X_m is the total amount of imports to Japan.

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