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EVALUATION OF JAPANESE AUTOMOBILE INDUSTRIAL METABOLISM

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Abstract

The Japanese automobile sector's energy and resource intensity were analyzed for the year 1960 to 1990. Its industrial metabolism was investigated not only in terms of the output-related flow in the form of emissions, but also in terms of the input-related resource flow and efficiency. Loop closing initiatives for material conversion and resource recovery were considered in view of recyclable waste (scrap) production. Results revealed that changes in the structural composition of the manufacturing and the final demand sectors influenced the industrial sectors' production operations and the associated environmental impacts. Despite eco-efficiency, expanding automobile demand caused continued rise in the total material consumption. Nevertheless, there was an evident decoupling from energy and material use resulting to reduced carbon dioxide emission and improved resource efficiency notably in the last period.

KEYWORDS: *automobile industry, industrial metabolism, input-output analysis, carbon dioxide emission, energy and material intensity*

1. Introduction

With the unraveling of the impact of human activity on the environment, the consequences of our interference with the ecosystem became apparent. Anthropogenic material flows often exceed nature's capacity and the current rate of resource consumption is beyond sustainable level. Thus there is a compelling need for the radical change in the current product and resource practices, as well as for the restructuring of environmental systems management.

An integrative approach to analyze mechanisms of material flow and transformation, i.e. the 'metabolism' of the economy, will greatly improve product policy and methods to move toward sustainability. The path to sustainable growth is one that considers the integrated economic, social and environmental requirements of both the present and future societal systems (WCED 1987; Meadows, et.al., 1992).

Industrial metabolism is the study of mass flows and transformation in the economy through a small or large, regional or national boundary system. It is akin to the living metabolism in the living

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organisms and uses a holistic approach to understand the dynamics, efficiency and opportunities within the system (Ayres and Simones, 1994; Klostermann and Tukker, 1998).

Reduction of the man-induced material and resource flow required to serve economic functions is under way. Up to what degree, lay the foundation for global assessment. This concept is known as dematerialization, primarily defined as the absolute or relative reduction in the quantity of materials and energy used to produce a product. There is an enormous environmental benefit that can be derived from the therapy of dematerialization. Lower material consumption means less resource depletion rate, reduce amount of wastes, limit human exposure to harmful effects of emissions and overall environmental conservation. Beyond decoupling economic activities from environmental degradation, dematerialization aspires to 'close the loop' by modeling feedbacks into the economic process. As a result, besides additional revenues through value-added reuse and recycling, better advantage can be attained through image gains (Wernick, et.al., 1996; NBL, 1997; Moll and Femia, 1997).

In the industry level, innovative technologies and initiatives are encouraged to improve production operations for an environmentally sound performance. Individual firm faced with the challenge of 'eco-efficient product', employs various environmental tools such as material flow analysis, eco-design, life-cycle management, etc. (Klostermann and Tukker, 1998; Saur, et.al., 1998; Morioka, 1999).

The Japanese automobile manufacturing sector, a leading industry since 1976 (JAMA, 1997), was studied since it represents a mature sector with diverse linkages to other sectors in its whole life cycle, in effect reflecting a very dynamic economic network. The analysis of its industrial metabolism would, therefore, provide important insights on Japans' industrialization and post-industrialization processes. Such studies could also address resource and environmental policy formulation and models, that can be adopted locally or emulated by rapidly developing industrial economies, especially in the neighboring Asian countries.

2. Methodology

Input-output (IO) technique, which relates the interdependence of the different sectors of the economy, was used in the analysis to describe the interrelationships among the three factors driving globalization: energy, economy and environment. It is an established method used to evaluate the direct and indirect inputs in combination with other economic data. The environmental applications of input-output analysis were focused mainly on energy consumption and emissions: Tiwaree and Imura (1994) for Asian countries; Morioka and Yoshida (1995) for Japan and UK; Born, (1996) and Moll and Femia (1997) both for Germany.

This study attempts to extend the same principle to assess resource productivity by considering only the direct material input data during the production process. The concept of hidden flows and foreign components in the total material requirement per output (TMR/GDP) introduced in WRI report (1997) was disregarded in the calculation due to data limitation. Nonetheless, the model captures the induced material and energy flow due to the interdependence among industrial sectors. Knowing the status quo and trends of resource flow metabolism is indispensable to effectively set the substitution and dematerialization measures.

The standard open input-output model :

$$X_j + AX_{ij} = Y_j \qquad \text{or} \qquad X_j = (I - A)^{-1}\, Y_j \tag{1}$$

where:

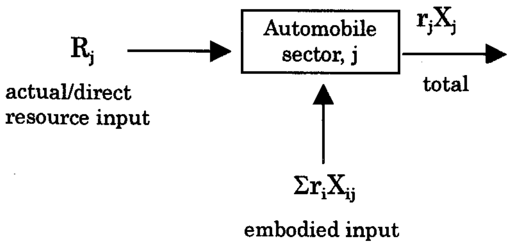
- X_j - vector of production output of industrial sectors
- A - matrix of input coefficients
- X_{ij} - intermediate sectors transaction matrix
- Y_j - vector of total final demand
- I - unit matrix

The IO energy or material balance for the *j*th sector, e.g., automobile sector, can be expressed as :

$$R_j + \Sigma r_i X_{ij} = r_j X_j \tag{2}$$

where:

- R_j - external direct resource input to sector *j*
- r_i - embodied resource intensity per unit of production, X_j



In matrix notation, equation 2 becomes:

$$R + rX = r\grave{X} \tag{3}$$

where **R** is the row vector of resource input, $\grave{X}$ is the diagonalized vector of industries output flow and **X** is the nxn transaction matrix. Rearranging gives the resource intensity, r, or the productivity coefficient. (Pearson 1989). The term $\grave{X}$ represents the direct component of the intensity, the rest is the embodied or indirect repercussion.

$$r = R(\grave{X} - X)^{-1} \tag{4}$$

Resource intensity is a measure of the extent of material or energy use (productivity) regardless of the total volume of the production activity. It is the amount of resource input necessary to manufacture a unit product expressed either in physical or monetary term for example: ton/unit product or ton/unit price of product.

Applying **r** back to equation (1) yields the resource intensity matrix due to final demand.

$$r^{*}B^{*}Y \tag{5}$$

where $B = (I - A)^{-1}$, Leontief inverse coefficient matrix .

Final demand **Y**, was then decomposed into household expenditures H, government expenditures G, capital formation CF and net stocks S, to examine the inducement share of the final demand sectors in the total resource efficiency of the automobile sector. The effect of fixed capital formation was further fractionated into public and private sectors, using the input-output fixed capital formation supplementary data matrix.

Figure 1 below summarizes the flow of analyses.

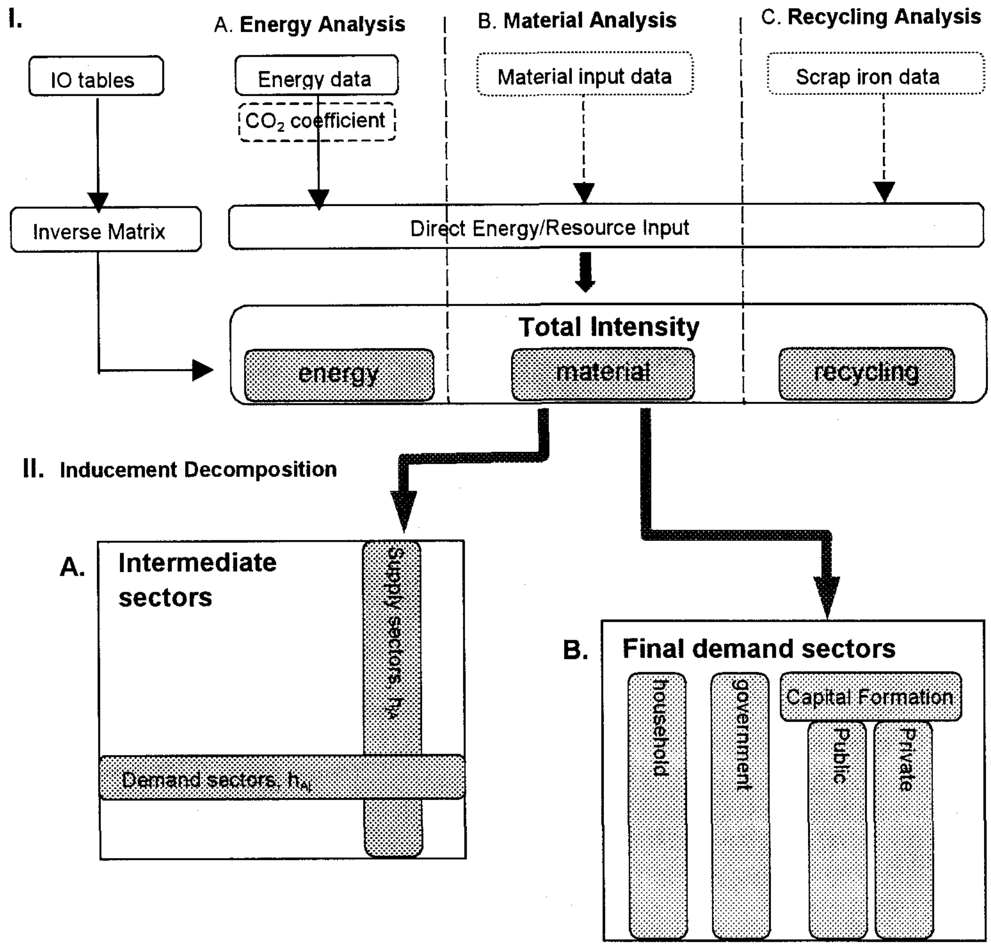


Fig. 1 *Flow chart of analyses*

The energy and emission analysis was centered mainly on the automobile industry. Being the largest manufacturing enterprise in the world, it therefore has the potential to bring forth significant environmental impacts. Since automobile is 75% steel, steel was chosen as the representative input and recycled material in this study. Among the different types of steel products, hot-rolled accounts for 2/3 of the total steel production demanded by most industries for their operation processes.

Contribution of the various manufacturing sectors on the automobile(A) sector's hot-rolled steel (h) requirement was scrutinized in detail from intermediate(j) sectors' transaction matrix **rBY** of equation 5 above. Each of the row element, $\mathbf{h}_{Aj}$ in this matrix (II.A of figure 1) represents the induced demand for hot-rolled by each one of the other industrial sectors. Similarly, each of the column element, $\mathbf{h}_{jA}$

corresponds to the induced hot-rolled input to the different firms associated with the goods/services demand of the automobile industry. Sectors excluding the automobile itself, were then ranked according to their influence as supply or demand (input and output) sector relative to motor vehicle sector. The calculation fulfilled the basic equation of input-output balance in the system.

Japan IO tables for the year 1960 to 1990, with 112 x 112 matrix aggregation together with the corresponding energy and commodity matrices plus steel scrap production data were employed. The environmental performance of the automobile industry production, consumption and recycling patterns were investigated in terms of (1) greenhouse effects expressed as carbon emission intensity obtained from the energy requirement, (2) resource utilization or material productivity exemplified by hot rolled steel, and (3) pre-consumer recycling that characterizes the manufacturing processes wastes measured by the recyclable scrap production.

3. Results

3.1 Total Carbon Dioxide Emission

The environmental impact associated with a unit output from each of the industrial sector of the Japanese economy was evaluated in terms of direct and indirect carbon dioxide emission intensity. Energy use generate proportional carbon emissions to the atmosphere leading to greenhouse effects. Fuel consumption gives rise not only to the release of carbon dioxide related with direct energy use, but also indirect discharges associated with the production of fuel, as well as direct and accrued

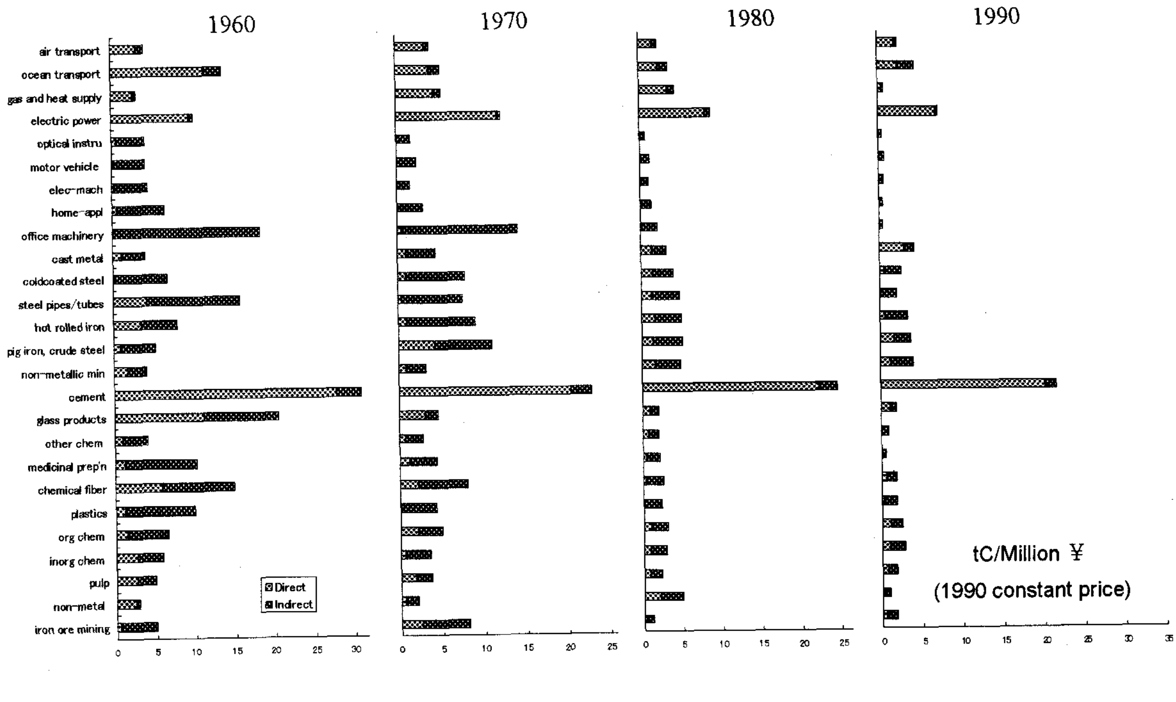


Fig. 2 *Industrial sectors' total carbon emission intensity*

consumption from other sectors through inter-industrial linkages. All these factors comprise the direct and induced or embodied environmental load (EEL). This is also referred to as 'ecological rucksack' after the German word for backpack, and used to describe hidden flows (Morioka, 1995; WRI, 1997)

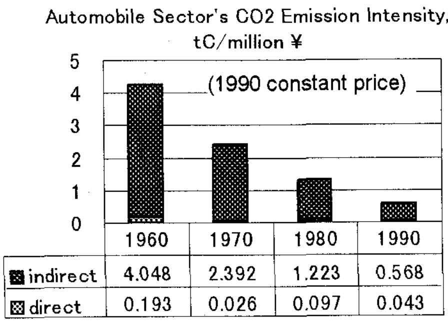
Figure 2 presents the direct and embodied CO_2 emission from the top ranking energy-dependent sectors, from 1960 to 1990. The general reduction trend in both direct and cumulative quantities of the sectoral emission is a good indicator of the delinking of the production process from the energy input requirements, resulting to increase energy use or efficiency and reduce discharges. This situation can be accounted to the compliance of the industries on energy and emission regulations in Japan issued since 1970 (Quality of Environment, 1994; JAMA, 1997)

The magnitude of the indirect emission of each sector when compared to the counterpart direct emission was generally more pronounced (e.g. machinery, appliance and instrument sectors), except for some heavy industries like cement, electric power, air and ocean transport. This implies that products produced from a relatively thought "clean" industry have more substantial environmental impacts due to the production of the needed components or supplies (indirect effect), than from the assembly or manufacture of the product itself (direct effect). Such is a phenomenon of the hidden or latent emission, which make up the environmental rucksack. Goods and services produced from activities with high direct emission intensity are consumed in other activities for raw materials and other purposes.

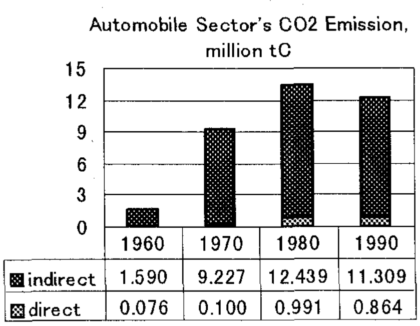
3.1.1 Automobile Industry CO_2 Emission

Ranking the sectors from the highest (1) to the lowest (112) according to the amount of emissions, the motor vehicle industry placed way below the top 10. Although this industry is often regarded as an energy-intensive sector, total and direct CO_2 emissions turned out to be lower than those of the other heavy- and metal industries. Figure 3 shows decreasing trend of emission intensity with time, i.e., tons carbon emission per unit output (monetary basis). This indicates favorable performance during the manufacturing process of automobile in terms of energy efficiency. Reduced emission intensity resulted from lower energy consumption, regardless of the volume or level of production activity.

While it is generally held that the total amount of energy required to manufacture automobile is far less than that associated with the use-phase, the energy consumed is still substantial, hence, emission. According to Kobayashi (1996), manufacturing process demand for energy is only around 15% of its



	1960	1970	1980	1990
indirect	4.048	2.392	1.223	0.568
direct	0.193	0.026	0.097	0.043



	1960	1970	1980	1990
indirect	1.590	9.227	12.439	11.309
direct	0.076	0.100	0.991	0.864

Fig. 3 *Automobile sector's CO_2 emission*

life cycle total energy requirement, considering each stage from raw material extraction, manufacturing, use until final disposal. The total absolute volume of emission during the manufacturing stage continued to ascend until 1980, followed by a great 10% slack during the 1990. The value may seem rather large and misleading compared to the actual reduction in real situation. Nonetheless, this value implies the possible contribution of the automobile manufacturing sector to the overall energy and CO_2 reduction effort of the industry, and the country at large, to combat global energy-related greenhouse effects. Japan during the Kyoto summit advocates to stabilize CO_2 emission on a per capita basis by the year 2010 to about 6% decrement from the 1990 level.

Despite the greater demand for goods and services due to population and production growth, majority of the Japanese manufacturing sectors demonstrated increased production level with decreased energy use, leading to "decarbonized" production processes. The result is consistent with OECD's report of decreasing energy intensity in most developed countries with Japan having the lowest rate per GDP or per capita (OECD, 1991). Economic activities were, therefore, regarded as eco-efficient, attributable to innovative energy saving measures and more stringent environmental regulations.

3.1.2 Inducement by Final Demand Sectors

The automobile industry having large influence in the production chain, has high environmental impacts during its production and operation processes (Shuckert, 1996).

Energy use for manufacturing automobile comprise 10% of the total energy requirement of Japan's industrial sectors (OECD ESB, 1991). Since energy consumption entails greenhouse gases particularly CO_2, it is therefore interesting to know how much, to whom and by whom can emission be accounted for in the production of a unit automobile.

Figure 4a presents the trends of demand for motor vehicle by the different final demand sectors. The household, private fixed capital and export sectors indicated a continuous increase in demand as a result of growing population and social or business activities, with export having the fastest rate of demand increase. The corresponding CO_2 emission inducement is shown in figure 4b. Except for the household sector, there was a decoupling of production

Fig. 4a. Final Demand Inducement on Motor Vehicle Production

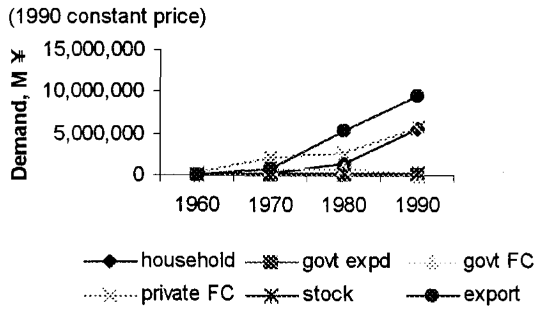
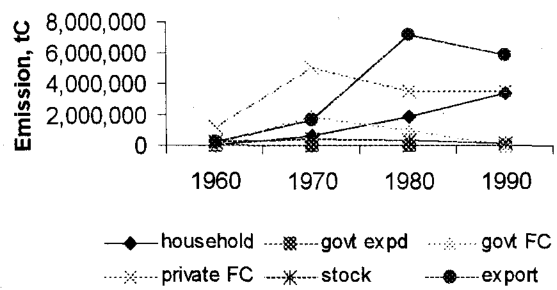


Fig. 4b. Final Demand Inducement on Motor Vehicle CO2 Emission



activity from energy requirement and therefore emission, from the year 1980. Nevertheless, the rate of increase of household-induced emissions was slower than that of the final demand. To some extent, energy use efficiency was achieved. The figures disclose an improvement in the automobile industry's consumption of energy resource and the subsequent reduction in CO_2 discharge.

The proportion of inducement by each of the mentioned demand sectors is presented in figure 5. The figure vividly shows the distribution as well as the shift of structural demand from one sector to another. Household's share (hsld) increased with time, together with export (until 1980). A surprising trend was that of the private fixed capital (pvt FC). Its share decreased from 65% to 52% and down to 25% in 1960, 1970 and 1980 respectively. This trend, however, can be quite deceptive as the data only represents the share of the aggregate emission and should not be mistaken as the actual volume or intensity. For the private investment, the influence was the highest in 1970, and decreased from then on (refer back to fig. 4). This trend is favorable as they imply efficiency in energy use.

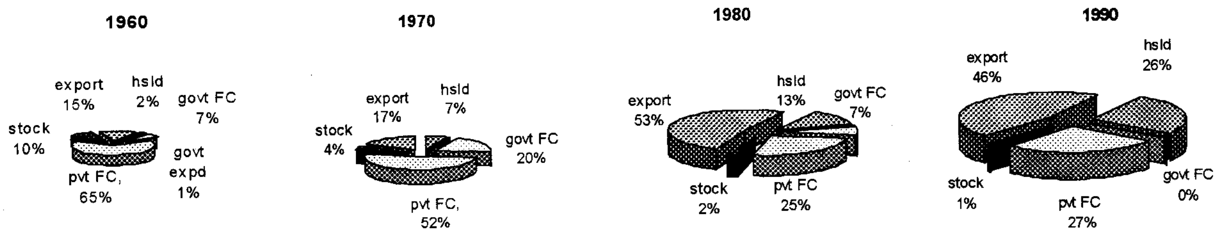
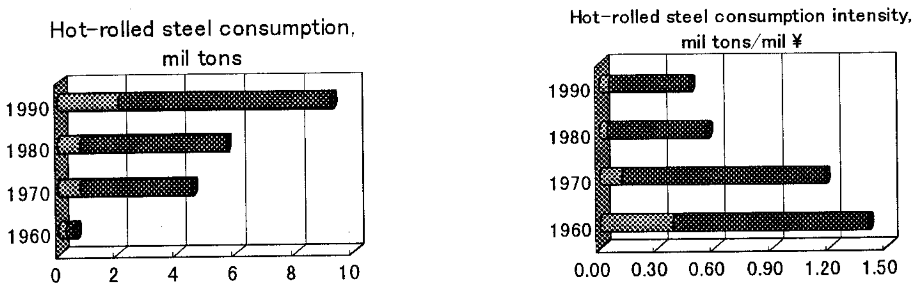


Fig.5 *Final demand sectors' inducement share in automobile CO_2 emission*

3.2 Resource Productivity

Material Input Requirement

According to the International Iron and Steel Institute, Japan remains the world's leader in steel production hitting 110 million tons, 22% more than that of US in 1990. In terms of consumption, however, Japan is also the highest with 100 million tons, compared to US which consumed 17% more



	1960	1970	1980	1990
indirect	0.30	3.78	4.94	7.21
direct	0.25	0.73	0.75	2.05

	1960	1970	1980	1990
indirect	1.01344	1.05399	0.51773	0.41276
direct	0.38141	0.11486	0.04140	0.05187

Fig. 6 *Automobile sector's hot-rolled steel requirement*

than their production capacity in the same year. (World Resources 1996-97).

The evaluation of consumption patterns is indispensable in reference to dematerialization policy i.e., minimized material input per good/service. As steels are used by various industrial sectors, consideration of inter-industrial steel flow transaction is essential. Automobile sector is one of the principal consumers of hotrolled steel products, next to construction sector. In 1997, the automobile industry accounted for 18% of the total domestic demand for steel products mainly hotrolled, coldrolled and cast steels (JISF, 1998).

Figure 6 shows motor vehicle's hotrolled steel requirement and efficiency. Reduction trend of hot-rolled consumption intensity means improved resource productivity attributable to the process innovations and product design of automobile industry as well as to the compliance with the regulations that require the utilization of lighter weight materials.

As expected, consumption expanded with time. In spite of improved material productivity starting 1980 (by more than half of the last two decades level), increased final demand offset the reduction rate causing great amount of cumulated material consumption. Japan's drastic increase in the total material consumption since 1970 until the bursting bubble economy, was due to the successful takeoff toward export-oriented economic development, exemplified by the automobile industry.

3.2.1 Inducement by intermediate sectors

Table 1 shows the top ranking intermediate sectors which have direct and indirect interactions with the automobile industry in terms of material (hot-rolled steel) flow in the entire system. Input sectors were dominated by heavy equipment sectors while heavy metals dominated the output side. Most of the supply sectors' inducement decreased when compared with the value in the previous decade. This is in contrast with the demand sectors' increased inducement which contributed to the overall swelling demand of the industry for hotrolled steel, as mentioned in the preceeding section.

3.2.2 Inducement by final demand

Figure 7 exhibits the final demand sectors' inducement in automobile hot rolled steel consumption, both in proportion and amount. It was observed that household and export sectors exhibited an increased trend of share to the total automobile steel consumption. The opposite trend was observed for the private fixed capital

Table 1. Intermediate sectors' influence on automobile sector's hot-rolled steel demand

Industrial sectors	Supply	Demand
coal mining	○	↓ ◆
natural gas	○	◆
non-metallic mining	○	◇
non-metal ores	↓ ○	◇
wood products	↓ ◎	◇
furniture	↓ ◎	↓ ◇
non-metallic mineral	↓ ◎	↓ ◆
hot rolled iron	◎	◆
steel pipes and tubes	◎	◆
cold finish/coated steel	↓ ◎	◆
cast metal	↓ ◎	↓ ◆
other basic metal scrap	○	◆
metal products for construction	↓ ◎	↓ ◆
other metal products	↓ ◎	◆
metal work machinery	↓ ◎	◆
prime mover and boiler	↓ ●	◆
office machinery	↓ ◎	◇
home-use electrical equipment	↓ ●	↓ ◆
heavy electrical machinery	↓ ●	↓ ◆
steel ships	↓ ◎	↓ ◆
railway	↓ ◎	↓ ◆
aircraft	↓ ◎	◇
two-wheel motors	↓ ●	◇
watch and clock	↓ ◎	◇
precision instrument	↓ ◎	↓ ◆
other industrial products	↓ ●	◆
infrastructure	◎	◆
motor vehicle repair	↓ ●	↓ ◇
unclassified	○	↓ ◆

legend: (value in tons)
○ <0
◎ 0 - 1000
● >1000
◇ <1000
◆ >1000
↓ decreased value from 1980 to 1990

share of 2/3 to only 1/3 from 1960 to 1990. This implies a shift in the structural demand effect from private investment to household and export. This can be accounted to the improvements in domestic automobile production, mainly used as capital goods by the private sectors, which led to personal use and export boom in the last two decades.

Referring to the same figure, the actual volume of hot rolled steel induced by these demand factors revealed the same increased trend due to household and export. Fixed capital demand inducement,

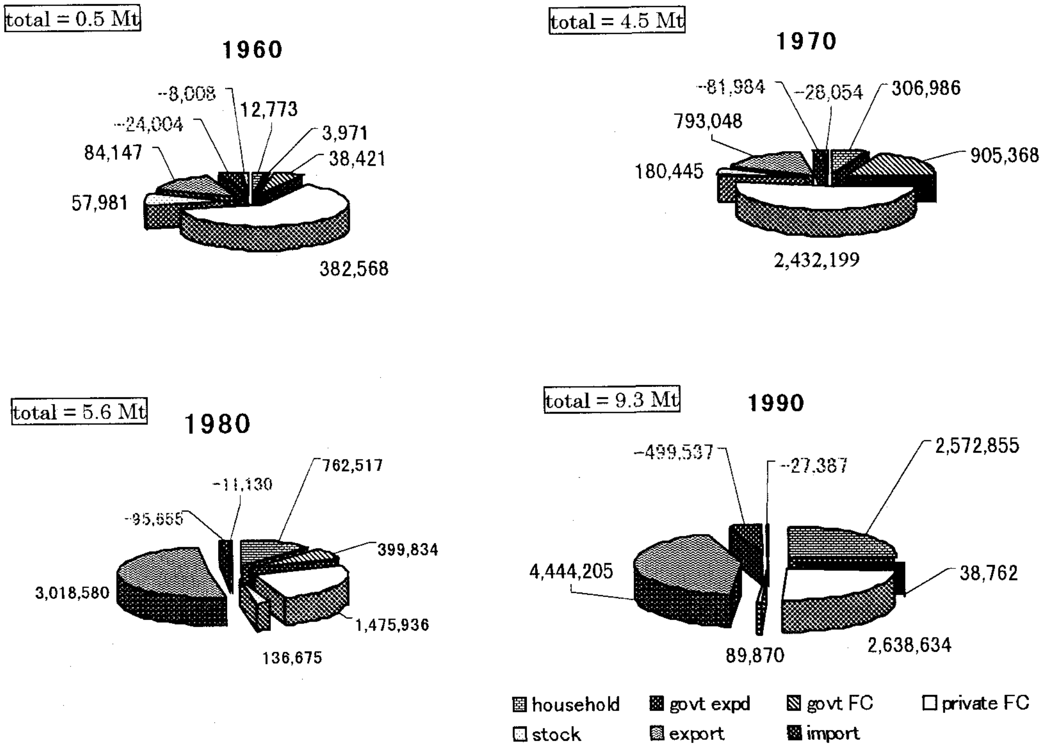


Fig. 7 *Final demand sectors' inducement on automobile sector's hotrolled steel consumption (1990 constant price)*

however, was high in 1970, decreased by half in 1980 and then increased again in the last year, this time only 8% higher than 1970 level. For all the period considered, private fixed capital demand had greater influence than the household. On the other hand, when compared with export, its effect was greater in the first two periods, then fell by almost half in the succeeding periods. The overall trend showed a steady increase in total hotrolled requirement due to private and export demand for automobile. Thus despite eco-efficiency, an increase in total material consumption - due to expansion of the business car use, such as inland express delivery services; and increased mobility needs as dictated by the society - was apparent.

3.2.3 Inducement by Fixed Capital Demand

Vehicles have supported the high mobility need in daily life and business activities of the country. Moreover, drastic technical innovation and spreading social investment such as roads, tunnels and bridges enhanced the development of quality land transport system corresponding to the post-industrialized society.

Figures 8 and 9 show the detailed distribution of industrial sectors share in automobile hotrolled steel consumption which comprised the private and public fixed capital formation demand, respectively. As shown in figure 8, service industry demanded much mobility year by year; i.e., 38%, 52% and 67% in 1970, 1980 and 1990, respectively, as combined wholesale/retailer and service sectors share. Construction also gave large contribution: 21, 14 and 8%. Transport itself increased both share and amount which denotes growth of the transport sector as a service industry, so called " the third party logistics".

Similar to the above-mentioned trend, the government or public investment inducement was also dominated by the service sectors which contributed a high 80% share in 1990. The other notable sectors include the building and equipment sector (only for 1970), communication, electric, water and

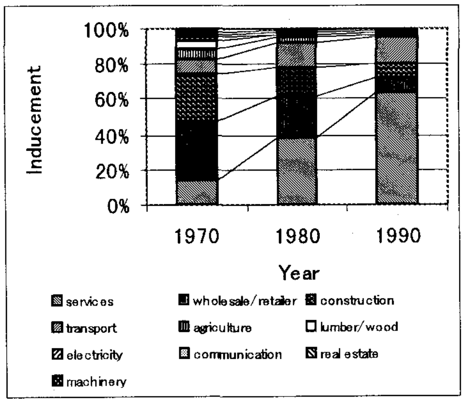


Fig.8 *Private fixed capital formation demand inducement bv industrial sectors*

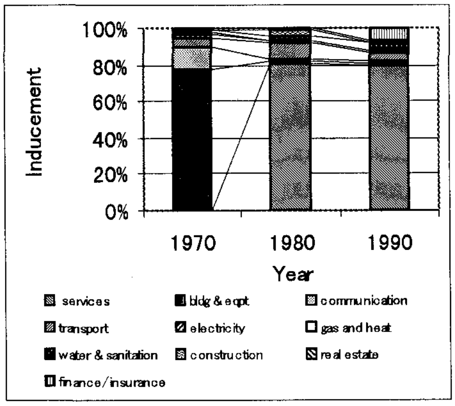


Fig. 9 *Public fixed capital formation demand inducement by industrial sectors*

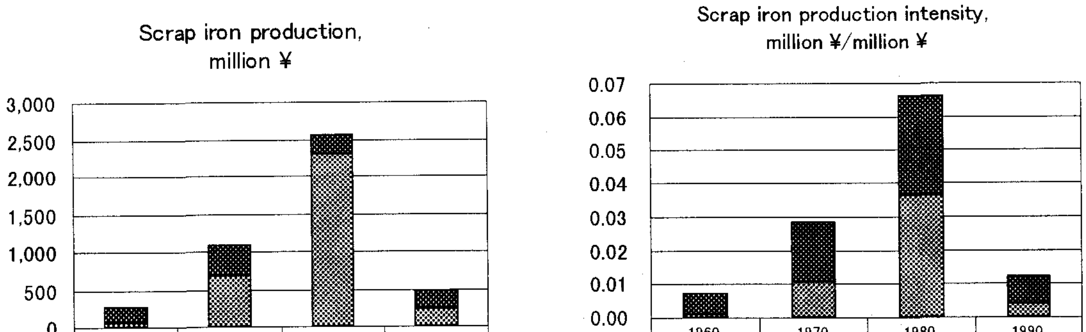
transport sector. The contribution trend can be explained by the structural shift in the Japanese economy from the heavy and traditional industries towards the service industry.

3.3 Recycling

Partially as a response to the dematerialization effort and space use problems for landfill, many environmental policies strongly encourage recycling and reuse of products . Producers have much greater responsibility for the waste or output-related flows in the production process. Thus, "pre-consumer recycling" which characterizes the wastes during the manufacture of the product (Ramirez, 1996), was considered by analyzing scrap iron, the best example of recyclable waste generated by automobile manufacturers.

Scrap iron production

Automobile industry is the top supplier of scrap, providing about 30% of the total annual supply (MITI, 1997) to the scrap sector, mainly for electric furnace steel processing. Highest volume was incurred in 1980, the same year during Japan's first world record in automobile production (JAMA, 1997). Although this automobile production level was exceeded in the last period during the bubble economy, the scrap iron output was notably reduced. Referring to the volume output and intensity in figure 10, there was a drastic decline in 1990. The first three period recorded high material or resource recovery, an indication of improved recycling activity. Nevertheless, minimum waste generation is preferable as exhibited in 1990, attributable to improved product design and material-based eco-efficiency efforts of the industry.



	1960	1970	1980	1990
indirect	213	417	251	226
direct	59	675	2,292	240

	1960	1970	1980	1990
indirect	0.0061	0.0177	0.0299	0.0083
direct	0.0009	0.0106	0.0361	0.0038

Fig. 10 *Automobile sector's scrap production (1990 constant price)*

4. Conclusions

Material balance principle applied to track energy and material flows through supplier-supplied sectors and manufacturer-consumer groups provided the framework for environmentally sound metabolism analysis. Embodied energy and material intensities brought about indirectly by the different economic sectors were found to be greater than their direct components. The relationship implied the importance of industrial or trans-sectors linkages in the ecological rucksack of an economic activity.

Energy and carbon emission intensities due to final demand repercussions revealed a general reduction pattern, but expanded economic activities and growing population offset the continued rise in the total resource consumption.

Material productivity analysis showed dematerialization despite the increased demand by the private and export sectors for automobile, most notably in the last two period. The increased demand was due to the improvement in automobile domestic production and industrialization needs. Production efficiency was also confirmed from the scrap output generation.

Future work will include set of standard indicators and dematerialization rate to assess the degree of environmental sustainability of production systems. Completely closing the loop is another area to focus on in environmentally sound metabolic performance studies.

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