Outflow of Resources from Japan focusing on End-of-life Vehicles

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In order to examine the risk to resource security in Japan, this paper quantifies the outflow of base metals (iron, aluminum, copper, lead, and zinc) through export of end-of-life vehicles (ELVs) from Japan from 1988 to 2005 using the Trade Statistics of Japan and vehicles composition data. Estimates were also made for engine-related rare metals (manganese, nickel, chromium, and molybdenum), under statistical restrictions. This analysis shows that 24% of iron, 38% of aluminum, 13% of copper, 53% of lead, 11% of zinc, and 38% of rare metals in ELVs in Japan were not recycled and flowed out of the country, mostly in the form of used vehicle and parts. The destinations of these metals were mainly developing countries with rudimentary recycling technology. These results strongly indicate that many metal resources that could be utilized domestically from automobiles in Japan were instead scattered and lost overseas.   [doi:10.2320/matertrans.MAW200712]

1. Introduction

It is an important political issue for Japan to secure a stable supply of metal resources,[1] because the nation is not blessed with many metal deposits and is consequently largely dependent on imports. On the other hand, Japan manufactures and uses a variety of products, thereby indirectly consuming large quantities of natural resources, as well as generating end-of-life products. Most of these end-of-life products are sent to developing countries, mainly in Asia, as used products and parts and as secondary materials.[2–5] Unlike Japan, developing countries cannot be expected to recover resources from used products as most do not yet have effective recycling technologies in place.[6] In particular, it is technically difficult to collect rare metals mixed with base metals. There is a "resource scattering risk" then that these metals will be lost to human use due to their outflow from Japan. It is therefore necessary to know the physical flows of metal resources that leave Japan in order to evaluate further recovery options. However, it is difficult to determine such amounts because the forms of used products, used parts, and secondary materials are not comprehensively identified and because few statistics have been compiled.

The present paper focuses on base metals (iron, aluminum, copper, lead, and zinc) present in ELVs, which have the biggest physical share of all used products, contain various metal resources, and are traded as an international commodity. In particular, it is explored how much of each metal were exported from Japan to other countries. In addition, because the degree of spread of rare metals in importing countries depends on the countries' technological level, this paper shall try to examine the flows of rare metals (manganese, nickel, chromium, and molybdenum), all of which constitute parts of automotive engines. Section 2 of this paper sets the parameters for evaluation. Section 3 explains the methods for evaluating the amounts of exported metals using the Trade Statistics of Japan and vehicle composition data. Sections 4 and 5 respectively describe the physical outflows of base metals and rare metals.
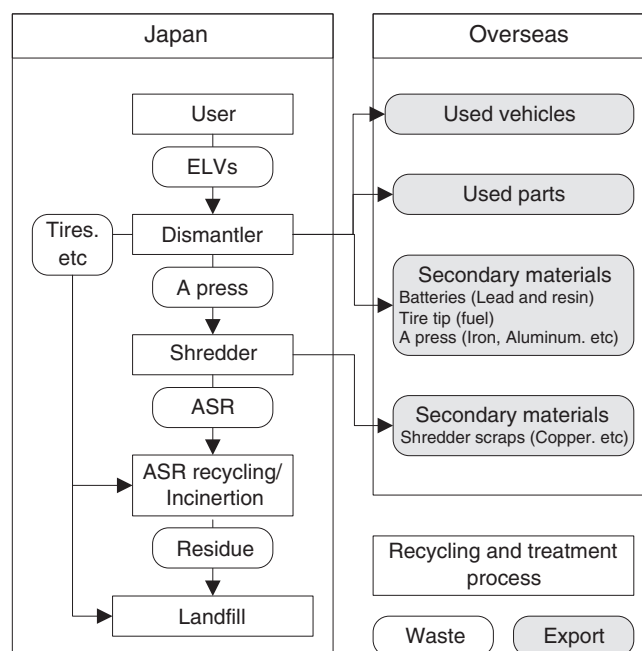

Fig. 1 Recycling flow of ELVs and their export forms.

2. Scope of Evaluation

The flow of domestic recycling of ELVs and the export forms are shown in Fig. 1 below. The recycling of ELVs is comprised of several processes: from export of used vehicles, disassembly, recovery of used parts and metals, press working, through shredding to collecting iron and aluminum scraps, to final disposal by landfill ELVs are exported to overseas as used vehicles, used parts, and secondary materials for recycling in accordance with those processes, in close relation to the domestic recycling process.

In this paper, metals that were indirectly exported in the forms of used vehicles and used parts were considered, in addition to those in scrap materials. The time lag associated

with continued use in foreign countries was noted in calculations of metal available for recycling. To identify export trends, 18 years from 1988 to 2005 were examined using data from the Trade Statistics of Japan.[7] Products traded at very low prices such as tire chips for fuel use and shredded scraps (mixed metal) were excluded, as the Trade Statistics of Japan does not contain data on these products.

3. Evaluation Method

3.1 Overall explanation

The outflows of base metals in ELVs and rare metals in engines exported from Japan between 1988 and 2005 were estimated by multiplying exports of ELVs and engines by the percent composition of each metal. Exports of used vehicles, used parts, secondary materials, engines in used vehicles, and used engines based were estimated utilizing the Trade Statistics of Japan; the method is described in detail in Section 3.2. The composition rates of base metals by vehicle and by part,[8,9] and of base metals and rare metals in scrap engines from an A Press were used[10,11] and the composition data are described in Section 3.3. However, this estimation for rare metals is confined to a test calculation level, as detailed data do not exist.

3.2 Exports of ELVs

For used vehicles (except-special purpose vehicles) and used tires, only data describing the situation after April 2001 were available. Therefore, we needed to estimate exports of other ELVs for earlier periods. The Trade Statistics of Japan impose the following main restrictions:

1) There is no distinction between new and used vehicles.
2) There is no agreement between export items and utilization forms. In one case, shredded parts of ELVs are exported as "parts" but are counted as a "vehicle" in the countries that import the parts.
3) Hand-carried goods are not counted (for example, the statistics do not cover used vehicles that were hand-carried and systematically exported to Russia by Russian sailors. This practice was prohibited in July 2005.)

To address the first point, we used customs data on the export of new and used cars and tires after 2001 (estimation method 1) and specified customs that handled many exports of new and used products. We estimated the prices of new and used products from the same data and then divided the exports of new and used products by the estimated prices. We distributed the exports of used products to each country by the Frater method,[12] used in traffic research. The flow estimated by estimation method 1 is shown in Fig. 2.

To address the second point, we cross-checked items in the Trade Statistics of Japan with reference to existing literature[13,14] and a spoken survey carried out for the industries involved (estimation method 2). When the products were not distinguished between new and used, we used estimation method 1 in parallel.

To address the final point, we based our estimate on the effect of the prohibition on hand-carried exports of used vehicles in July 2005 (estimation method 3). First, from eq. (1), we estimated the number of vehicles affected by the

1. Sampling of new and used export data

$$SQ_{i:1,j} = \sum_{k1} AQ_{i:(1+2),jk1}, \quad SV_{i:1,j} = \sum_{k1} AV_{i:(1+2),jk1}$$

$$SQ_{i:2,j} = \sum_{k2} AQ_{i:(1+2),jk2}, \quad SV_{i:2,j} = \sum_{k1} AV_{i:(1+2),jk2}$$

$$k1: \sum_j \left\{ AQ_{i:2,jk} / \left(AQ_{i:1,jt} + AQ_{i:2,jt} \right) \right\} < 0.01$$

$$k2: \sum_j \left\{ AQ_{i:2,jk} / \left(AQ_{i:1,jt} + AQ_{i:2,jt} \right) \right\} \geq 0.99$$

Where, i: 1,2 (1=new, 2=used), j: country, k: customs ($k1$: mainly new products, $k2$: mainly used products) ,SQ and SV: Sampling data for export quantity and value from trade statistics, AQ and AV: Actual data for export quantity and value in trade statistics (Vehicles: related data in 2002–2005, Parts: tire data in 1988–2005)

2. Estimation of new and used price

$$P_{i:1} = \sum_j \left(SV_{i:1,j} / SQ_{i:1,j} \right)$$

$$P_{i:2} = \sum_j \left(SV_{i:2,j} / SQ_{i:2,j} \right)$$

3. Division into new and used export data

$$\begin{pmatrix} AQ_{i:1} \\ AQ_{i:2} \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ P_{i:1} & P_{i:2} \end{pmatrix}^{-1} \cdot \begin{pmatrix} AQ_{i:(1+2)} \\ AV_{i:(1+2)} \end{pmatrix}$$

— Frater method (4–7) —

4. Setting of first value in Frater method

$$AQ_{ij}^{(0)} = \left(SQ_{i:1,j} / \sum_j SQ_{i:1,j} \right) \cdot AQ_{i:1} + \left(SQ_{i:2,j} / \sum_j SQ_{i:1,j} \right) \cdot AQ_{i:2}$$

$$AQ_i^{(0)} = \sum_j AQ_{ij}^{(0)}, AQ_j^{(0)} = \sum_i AQ_{ij}^{(0)}$$

5. Allocation of used export data to country

$$AQ_{ij}^{(n+1)} = 0.5 \cdot F_i^{(n)} \cdot F_j^{(n)} \left(L_i^{(n)} + L_j^{(n)} \right) \cdot AQ_{ij}^{(n)}$$

$$F_i^{(n)} = AQ_{i:(1+2),j} / AQ_i^{(n)}, \quad F_j^{(n)} = \sum_i AQ_{ij} / AQ_j^{(n)}$$

$$L_i^{(n)} = AQ_i^{(n)} / \sum_j AQ_{ij}^{(n)} \cdot F_j^{(n)}, \quad L_j^{(n)} = AQ_j^{(n)} / \sum_i AQ_{ij}^{(n)} \cdot F_i^{(n)}$$

6. Condition

$$\sum_j AQ_{ij}^{(n)} = AQ_i$$

$$\sum_i AQ_{ij}^{(n)} = AQ_j$$
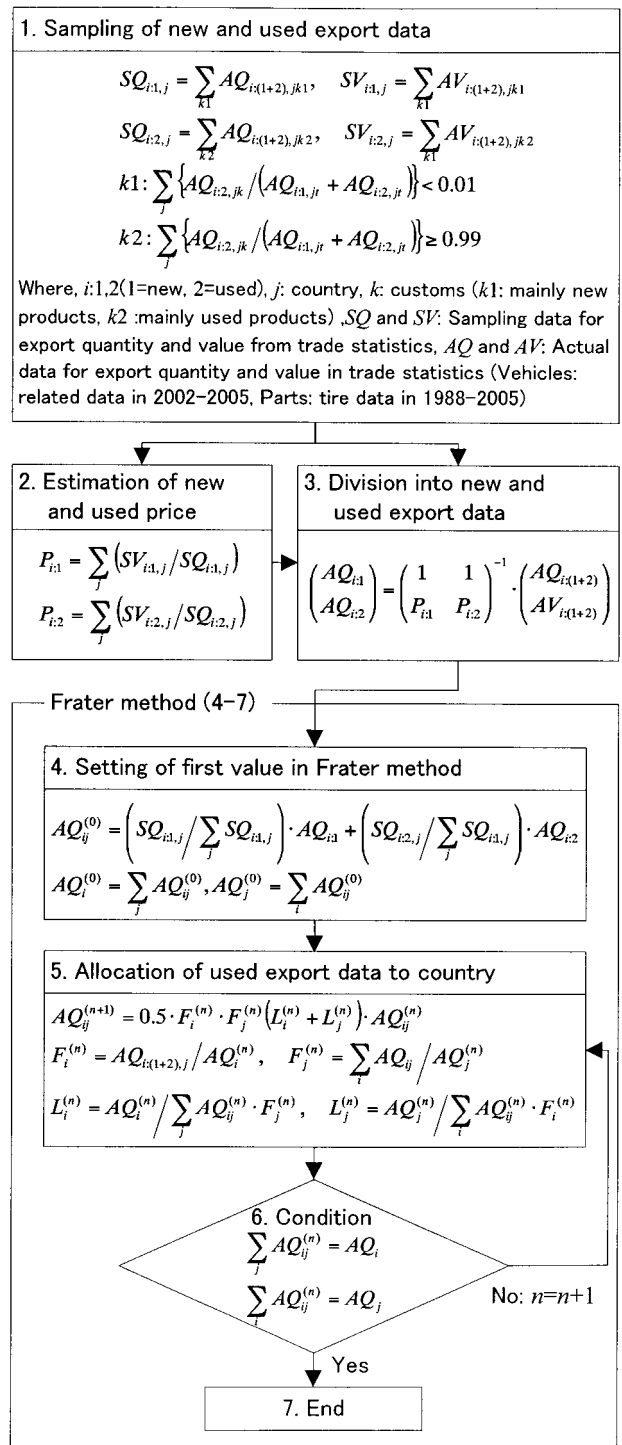
No: $n=n+1$

Yes

7. End

Fig. 2   Calculation flow of the estimation method 1.

prohibition of hand-carried export from July, 2005. We then calculated a baseline number of used vehicles exported by hand-carrying from that number and the amount of wood imported. Personal interviews with customs officials[11] revealed that, the Russian vessels importing the used vehicles were exporting wood to Japan. This procedure was carried out for the entire period from 1988 to 2005. Here, suffix i identifies the item in the Trade Statistics of Japan (Table 1), 2004 and 2005 are the years, 1–6 and 7–12 are the sums from January to June and July to December respectively, and RBE

Table 1 Estimation methods and the corresponding items in the Trade Statistics of Japan.

Form	Estimation method	Corresponding items in the Trade Statistics		
		Contents	No	Code
Used vehicles	Estimation method 1	Passenger car[1]	12	870310000, 870321910, 870321920, 870322900, 870323910, 870323920, 870324900, 870331000, 870332910, 870332920, 870333900, 870390000
		Bus[1]	2	870210900, 870290900
		Truck[1]	11	870410000, 870421910, 870421920, 870422910, 870422920, 870423900, 870431910, 870431920, 870432910, 870432920, 870490000
		Special-purpose vehicles	5	870510000, 870520000, 870530000, 870540000, 870590000
	Estimation method 1 Estimation method 2	Knockdown exports	12	870210100, 870290100, 870321100, 870322100, 870323100, 870324100, 870332100, 870333100, 870421100, 870422100, 870423100, 870431100
		Chasis with engine	3	870600100, 870600900, 870600200,
	Estimation method 3	Hand-carried export[2]		
Used parts	Actual value	Tire[3]	3	401211000, 401212000, 401219000, 401220000
	Estimation method 1	Engine system	6	840732900, 840733900, 840734900, 840820000, 840991100, 840999100
		Brake and steering system	13	681310100, 870831000, 870839000, 870840000, 870850000, 870860000, 870870000, 870880000, 870891000, 870892000, 870893000, 870894000, 870899900
		Body system	16	732010100, 830120000, 830230000, 841430100, 851220000, 851230000, 851240000, 851290000, 851840200, 853910100, 853929100, 870710000, 870790000, 870810000, 870821000, 940120000
		Erectrical system	5	851110100, 851120100, 851130100, 851180100, 851190100
	Estimation method 2	Engine system	1	720449900
Secondary materials	Estimation method 1 Estimation method 2	Battery[3]	1	850710000
	Estimation method 2	A press	1	720449900
		Lead scarp	1	780200000

[1]This paper can obtain actual data for used vehicles from April, 2001 for the change of the item classification in trade statistics.

[2]Used vehicles exported by hand-carrying have been accounted in the trade statistics from July, 2005 by the prohibition of hand-carried export.

[3]As the amounts of tires and batteries exported include those that are to be replaced during use, we need to exclude that amount.

and RNE are the number of vehicles transferred to business export to Russia and the number of vehicles of business export to Russia respectively.

$$RBE_{7-12}^{2005}$$
$$= \sum_i \left\{ RNE_{7-12,i}^{2005} - \left(RNE_{7-12,i}^{2004} \middle/ RNE_{1-6,i}^{2004} \right) RNE_{1-6,i}^{2005} \right\} \quad (1)$$

The relationship between the estimating methods described here and the corresponding items in the Trade Statistics of Japan is shown in Table 1 where the ELVs export is expressed by weight. The number of exported used vehicles is converted to weight using a conversion rate estimation.[11] As the amounts of tires and batteries exported include those that are to be replaced during use, that amount is excluded using replacement rates derived from literature.[15,16]

3.3 Composition data

The compositions of base metals and rare metals are shown in Table 2, respectively. Among used vehicles, the difference between passenger cars and trucks is considered. However, as for bus and special-purpose vehicles, the composition of freight vehicles is substituted. Among the used parts, the differences among engine systems, brake and steering systems, electrical systems, bodies, and tires are considered. The composition of batteries and "A press" are treated in the section on secondary materials. In addition, it is considered that the composition changes according to the product year. This paper estimates the upper and lower limit for the composition of each metal from passenger cars in six product years, as provided by JAMA.[9] The variation rates of each metal are shown in Table 3. This paper does not consider the change of composition of rare metals and A press according to the product year due to poor data availability.

4. Evaluation Results for Base Metals from ELVs

First, Fig. 3 shows the estimation results for ELVs export from Japan between 1988 and 2005. The exported quantities of ELVs from Japan increased by 3.6 times from 7.3×10^5 metric tons to 2.6×10^6 metric tons over this period. Used vehicles rate increased from 44% to 61% while used parts rate decreased from 52% to 38% and the secondary materials rate ranged from 0.12% to 6.8%. Therefore, it is clear that many of ELVs generated in Japan were exported and used as vehicles, used parts and secondary materials globally.

For used vehicles, the export amount was increasing by 4.9 times from 3.2×10^5 metric tons to 1.6×10^6 metric tons. Japan exported used vehicles mainly to Russia, New Zealand,

Table 2 Composition of base and rare metals (unit: mass%).

(a) Base metals (Range)

		Iron	Aluminum	Copper	Lead	Zinc	Others	Total
Used vehicles	Passenger car	69	6.2	1.5	0.64	0.54	22	100
		(65–73)	(3.7–8.6)	(1.1–1.9)	(0.49–0.79)	(0.41–0.68)		
	Truck	70	4.9	0.53	0.71	0.020	24	100
		(66–74)	(3.0–6.8)	(0.40–0.66)	(0.55–0.87)	(0.015–0.025)		
Used parts	Engine system	73	20	0.33	0.19	0	6.1	100
		(63–83)	(12–28)	(0.25–0.40)	(0.15–0.23)	(—)		
	Brake and steering system	86	12	0	0.10	0	1.9	100
		(80–91)	(7.4–17)	(—)	(0.074–0.12)	(—)		
	Body system	74	0	0	0.017	0.93	25	100
		(67–82)	(—)	(—)	(0.013–0.020)	(0.70–1.4)		
	Erectrical system	24	3.9	27	0.39	1.2	43	100
		(11–38)	(3.0–4.8)	(21–33)	(0.29–0.49)	(1.1–1.13)		
	Tire	14	0	0	0	0	86	100
		(10–18)	(—)	(—)	(—)	(—)		
Secondary materials	Battery	0	0	0	55	0	45	100
		(—)	(—)	(—)	(42–68)	(—)		
	A press	73	4.3	1.5	0.30	0.04	21	100
		(—)	(—)	(—)	(—)	(—)		

(b) Rare metals

	Manganese	Nickel	Chromium	Molybdenum	Others	Total
Engine	0.24	0.047	0.38	0.013	99	100
	(—)	(—)	(—)	(—)		

Table 3 Composition by product year and the variation rate.

	Composition by car product year (unit: mass%): X						Variation rate[1]	
	1977	1980	1983	1986	1989	1992	Upper	Lower
Iron Cast iron	3.2	2.8	2.2	1.7	1.7	2.1	1.3	0.69
Hot rolled common steel sheets	15	14	14	12	12	12	1.1	0.87
Cold rolled common steel sheets	38	34	29	26	23	15	1.4	0.57
high tensile strength common steel	0.5	1.4	4.1	7.3	6.4	3.9	1.9	0.13
Galvanized common steel	4.4	7.2	7.8	8.2	13	20	1.6	0.36
Common steel pipes	2.2	2.3	2.3	2.7	2.4	2.0	1.1	0.85
Common bar steel	1.8	2.2	2.0	1.3	1.2	1.4	1.3	0.71
Carbon special steel	6.8	6.1	6.0	6.1	6.0	5.8	1.1	0.92
Alloy special steel	4.6	3.8	3.6	3.4	3.5	3.7	1.2	0.85
Free-cutting special steel	0.70	1.00	1.00	1.4	1.9	2.1	1.5	0.50
Stainless steel	0.90	0.90	0.90	1.0	1.0	1.4	1.2	0.78
Spring special steel	2.0	1.5	1.5	1.5	1.4	1.3	1.2	0.79
Other special steel	1.1	1.4	1.3	1.6	1.3	1.0	1.2	0.77
Aluminum	2.6	3.3	3.5	3.9	4.9	6.0	1.4	0.60
Copper	0.90	0.80	0.90	1.00	1.30	1.00	1.2	0.76
Lead	0.60	0.80	0.60	0.60	0.60	0.50	1.2	0.77
Zinc	0.50	0.30	0.40	0.40	0.40	0.30	1.3	0.75
Non metals	15	17	19	20	19	20		
Total	100	100	100	100	100	100		

[1]Upper variation rate $= X_{upper}/\{(X_{upper} + X_{lower})/2\}$, Lower variation rate $= X_{lower}/\{(X_{upper} + X_{lower})/2\}$

Philippines, United States and United Arab Emirates (UAE). In recent years Russia imported over 30% of the total. UAE did not use these vehicles domestically but re-exported them to surrounding countries such as Pakistan.[17] Therefore it was identified that used vehicles from Japan have been used not only in neighboring and developing countries but also in countries with free trade to used vehicles and income gap such as New Zealand and the United States.

For used parts, the export amount increased by 2.6 times from 3.8×10^5 metric tons to 9.9×10^5 metric tons and the

Table 4 Total outflow amounts of base metals from ELVs export between 1988 and 2005 and the range.

	Units	Iron	Aluminum	Copper	Lead	Zinc
Tins estimation (a)	ton	1.9×10^7	2.7×10^6	2.3×10^5	3.8×10^5	6.8×10^4
The upper limit (b)	ton	2.1×10^7	3.7×10^6	2.8×10^5	4.1×10^5	8.4×10^4
The lower limit (c)	ton	1.8×10^7	1.6×10^6	2.7×10^5	3.5×10^5	5.1×10^4
(b)×100/(a)	%	1.1×10^2	1.4×10^2	1.2×10^2	1.1×10^2	1.2×10^2
(c)×100/(a)	%	92	61	77	91	75

(a) ELVs export from Japan

(b) Used vehicles export from Japan

(c) Used parts export from Japan

(d) Secondary materials export from Japan
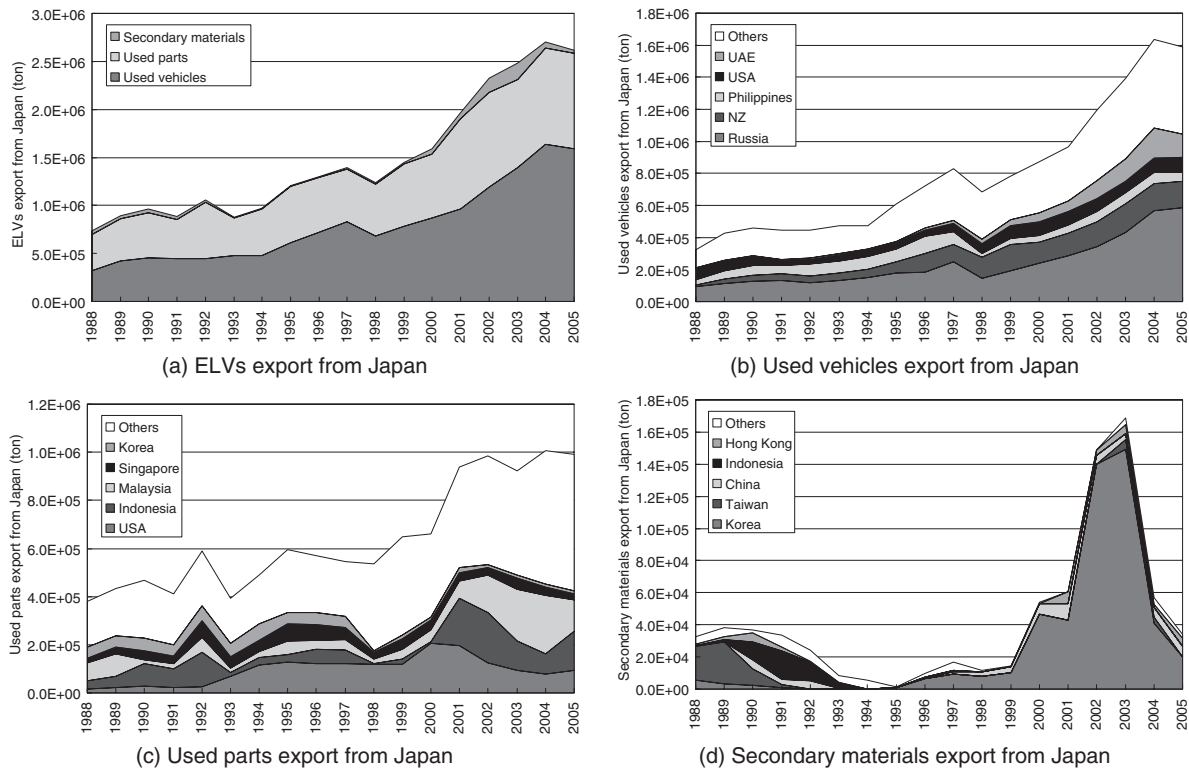
Fig. 3 Export amounts of ELVs from Japan by the destination.

growth rate is lower than for used vehicles. Japan exported many used parts to the United States, Indonesia, Malaysia, Singapore and South Korea. Singapore is a relay country similar to UAE. Used parts were exported to Asian countries largely due to the demand for spare parts for vehicle maintenance.

Considering secondary materials, exports followed a trend different than that for used cars and parts. Quantities ranged from 1.4×10^3 metric tons to 1.7×10^5 metric tons but not monotonically. Japan exported over 95% of secondary materials to Asian countries such as Korea, Taiwan, China, Indonesia and Hong Kong. Therefore, it was found that the trade of secondary materials was strongly controlled by the world market conditions and import regulations in each country. Secondary materials with a low value were generally not exported to outside the region, in order to avoid the high transport costs.

The evaluation results of total metal outflow amounts from the export of ELVs from Japan are shown in Table 4. From ELVs abandoned in Japan during 1988 to 2005, 1.9×10^7 metric tons of iron, 2.7×10^6 metric tons of aluminum, 2.3×10^5 metric tons of copper, 3.8×10^5 metric tons of lead, and 6.8×10^4 metric tons of zinc were exported. For iron and

lead, the error is less than 10%. However, for other metals such as aluminum, copper and zinc, the estimated error is more than 20%. The results for aluminum have low precision with an associated error of almost 40%. The reason for the high uncertainty is that it is difficult to evaluate changes in metals composition according to the model year for all product types.

Figure 4 details the outflow of each base metal with a focus on the type of product and the outflow rate that is divided the amount of outflow for base metal by the amount of base metal in ELVs generated in Japan. The outflow amounts of iron increased by 3.6 times from 5.2×10^5 metric tons to 1.9×10^6 metric tons. Of the total amount of ELV material exported, the proportion of used vehicles increased from 43% to 59% while the proportion of used parts rate decreased from 57% to 40% and the secondary materials rate ranged from 0.1% to 6.9%.

The outflow amounts of aluminum increased by 3.7 times from 6.7×10^4 metric tons to 2.5×10^5 metric tons. Of the total amount of aluminum exported the proportion of used vehicles increased from 27% to 38% while used parts rate was decreasing from 73% to 61% and secondary materials rate was ranging from 0.040% to 2.8%.
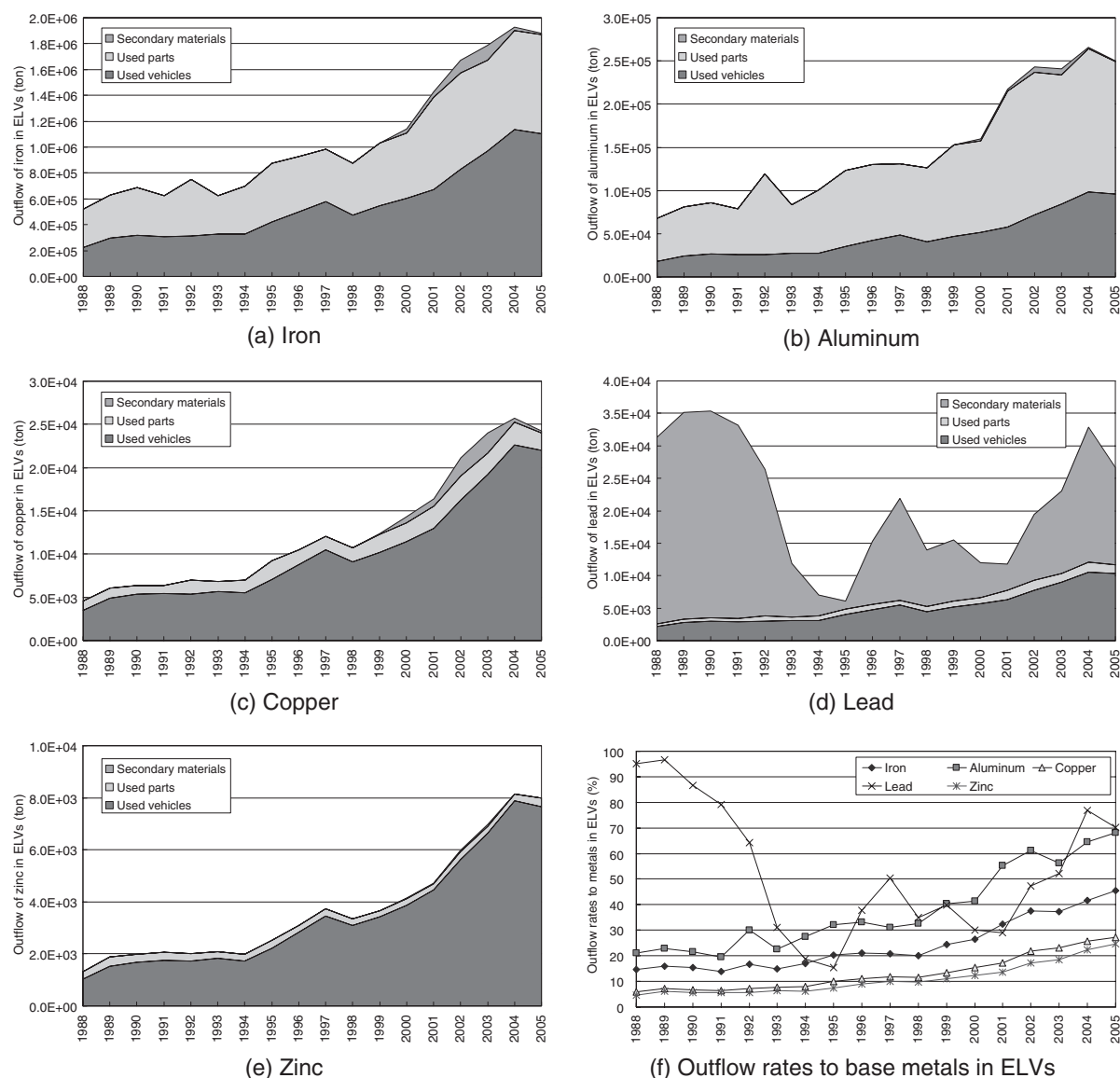
Fig. 4   Outflow amounts of base metals in ELVs from Japan by the export form and the rates.

The outflow amount of copper was increasing by 5.3 times from 4.6×10^3 metric tons to 2.5×10^4 metric tons. For the composition of export form, used vehicles rate was increasing from 76% to 83% while used parts rate was decreasing from 24% to 10% and secondary materials rate was ranging from 0.15% to 9.7%.

The outflow amount of lead was ranging from 7.0×10^3 metric tons to 3.5×10^4 metric tons. For the composition of export form, used vehicles rate was increasing from 6.8% to 38% while used parts and secondary materials were ranging from 1.4% to 13% and from 21% to 92%.

The outflow amount of zinc was increasing by 6.1 times from 1.3×10^3 metric tons to 8.0×10^3 metric tons. For the composition of export form, used vehicles rate was increasing from 79% to 96% while used parts rate was decreasing from 21% to 4% and secondary materials rate was ranged from 0.010% to 0.93%.

Overview, the outflow amounts of all metals except for lead increased annually. More than 98% of these metals were exported in the forms of used vehicles and parts. Depending on the reuse conditions in the importing countries, there is a time lag before the recovery of metals from Japan in the importing countries.

Regarding the outflow rates, the all rates expect for lead were increasing from 15% to 45% for iron, 21% to 68% for aluminum, 6% to 27% for copper, and 5% to 25% for zinc annually. For lead, the rate was ranging from 15% from 95%. Therefore, for the base metals in ELVs from Japan between 1988 and 2005, 24% of iron, 38% of aluminum, 13% of copper, 53% of lead, and 11% of zinc were not recycled in Japan but sent overseas.

Next we consider the destination countries for Japan's ELV exports. Figure 5 shows the total outflow amounts of base metals by importing country between 1988 and 2005, the distances from Japan to the importing countries,[18] and GDP per capita on 2005.[19] The quantities sent to each country of course depend on the share of product types such as used vehicles, used parts, or scrap. For copper and zinc exported mostly in the form of used vehicles, the destinations have the same tendency with used vehicles export obtained in

(a) Iron

(b) Aluminum
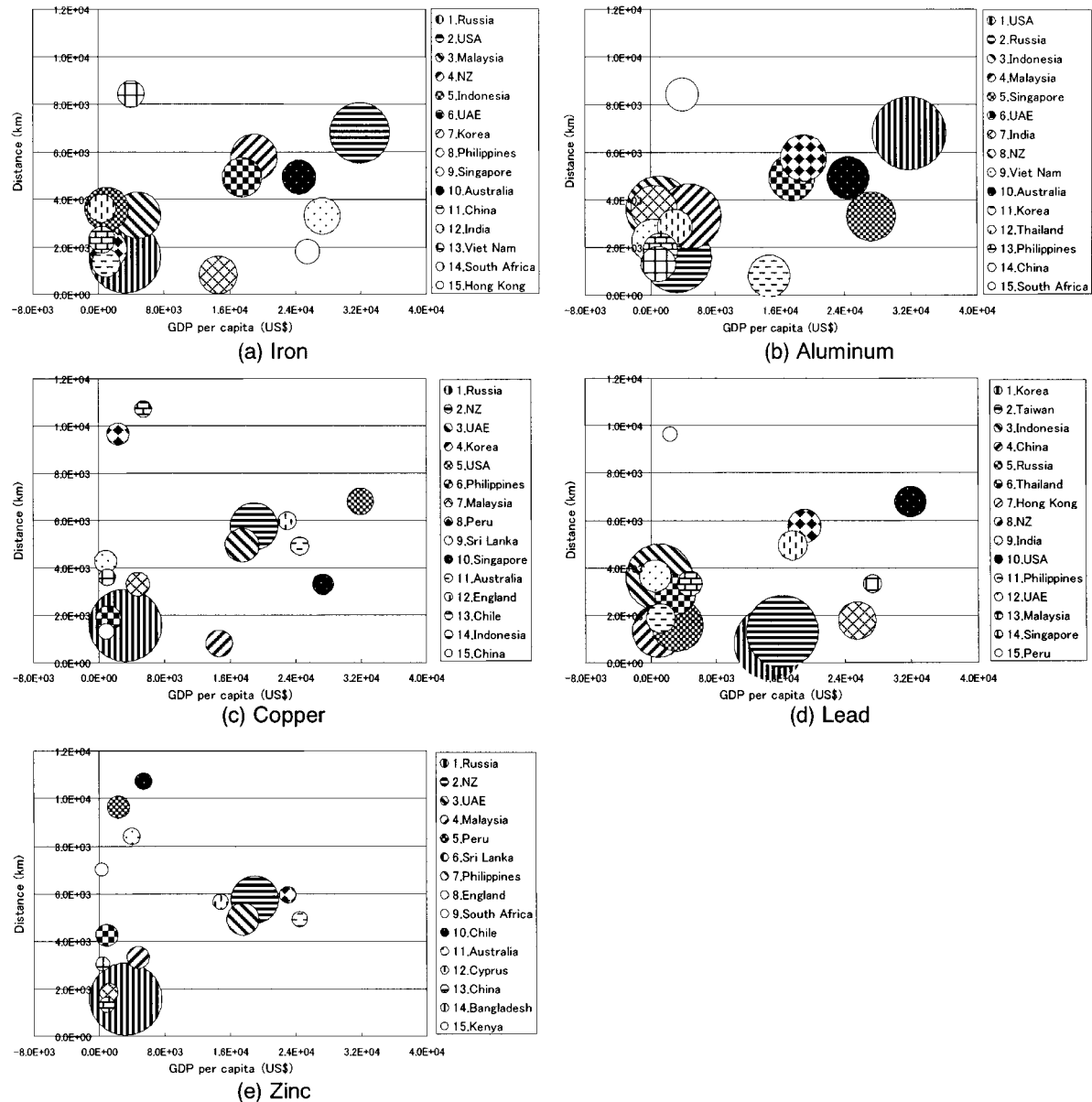

(c) Copper

(d) Lead

(e) Zinc

Fig. 5   Relationship between the outflow amounts of base metals in ELVs from Japan by the destination, distance, and GDP per capita.

Fig. 3. Hence, these metals were exported to not only neighboring and developing countries such as Russia but also to more developed countries such as New Zealand and the United States. For iron and aluminum exported mostly in the forms of used vehicles and parts, the destinations were largely developing countries in Asia. For lead exported mostly in the form of secondary materials, the main destinations again are neighboring countries, such as Korea and Taiwan, Indonesia and Thailand. The share of exported metal to low income countries (with a GDP per capita of less than US$10,000) was 56% of iron, 64% of aluminum, 63% of copper, 45% of lead, and 50% of zinc. Hence, it was become clear that many base metals in ELVs from Japan are exported to countries not yet having adequate recycling technology.

5.   Evaluation Results for Rare Metals from Engines

The amounts and rates of outflow for rare metals through engine export from Japan are shown in Fig. 6. The quantities

of engine related rare metals were estimated by multiplying the composition of engine shown in Table 2 by the amount of ELVs. The outflow rate is calculated by dividing the amount of metal outflow in engines by the total quantity of metal in ELV engines generated in Japan. From engines in ELVs abandoned in Japan during 1988 to 2005, 2.2×10^4 metric tons of manganese, 4.3×10^3 metric tons of nickel, 3.4×10^4 metric tons of chromium, and 1.2×10^3 metric tons of molybdenum were exported. All of these metals experienced growth in exports between 1988 and 2005; the total amount exported in engines increased by 4.8 times during this time. There is no difference in trend of the outflow between each metal because this estimation considers only the engine composition and the export amount in ELVs from Japan. As these results account only for engine related rare metals, these results only account for a fraction of the total amount of rare metals exported. Increasing monotonically over the survey period, the rate of engine related rare metals rose from 15% to 68%. During that period, 38% of engine related rare

(a) Outflow amounts of rare metals in engines

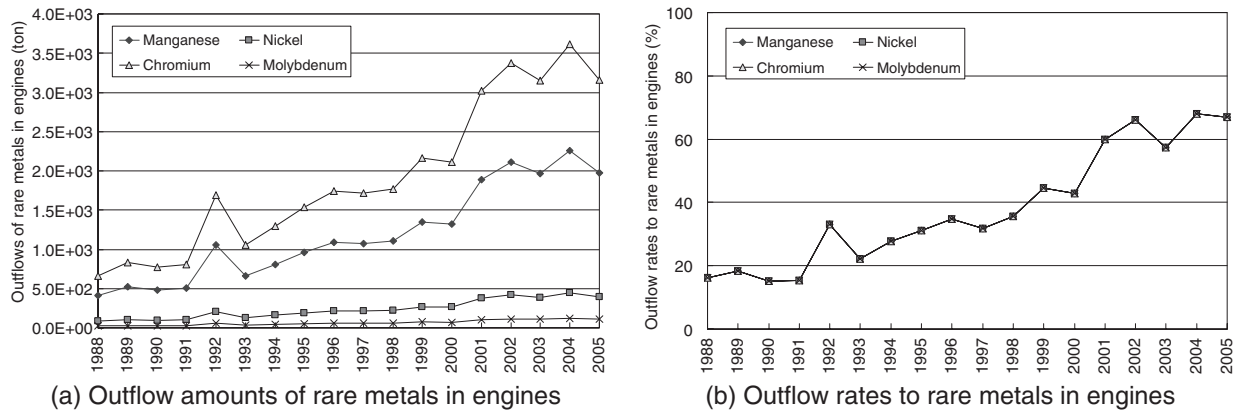(b) Outflow rates to rare metals in engines

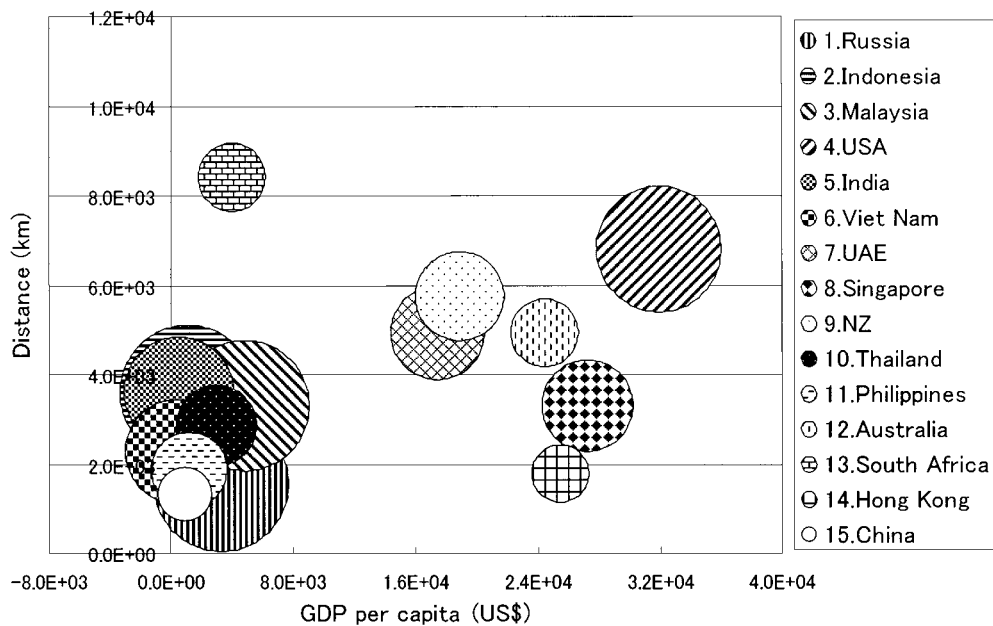Fig. 6 Outflow amounts of rare metals in engines from Japan and the rates.

Fig. 7 Relationship between the outflow amounts of rare metals in engines from Japan by the destination, distance, and GDP per capita.

metals in ELVs from Japan were exported. Therefore, depending on the reuse conditions in the importing countries, some time elapse between the arrival of used vehicles and parts exported from Japan, and the potential recycling of the metal resources they contain. Engines showed a similar trend over time as aluminum in section 4, as aluminum is used extensively in engines.

Figure 7 shows the relations among the total outflow amount of engine related rare metals by importing country between 1988 and 2005, the distance from Japan to the importing country,[18] and GDP per capita on 2005.[19] For engine related rare metals exported mostly in the form of used vehicles and parts, the destinations have a similar tendency as aluminum in that these metals were exported in large amounts to the developing countries in Asia. In many Asian countries, where vehicles have a relatively long lifetime, demand for used engines for replacement is proportionally high. Therefore, the amounts of engine related rare metals in exported to Asia are remarkably high in comparison to base metals in other automotive parts.

6. Conclusion

In order to examine the risk to resource security in Japan, this paper quantified the outflow of base metals (iron, aluminum, copper, lead, and zinc) through the ELVs export from Japan during 1988 to 2005 using the Japanese trade statistics and composition data. Furthermore, estimations of engine related rare metals (manganese, nickel, chromium, and molybdenum) were made.

It was found that Japan has flowed out of the base and rare metals through the ELVs export in large amounts. The total outflow amounts of the base metals during 1988 to 2005 is 1.9×10^7 metric tons of iron, 2.7×10^6 metric tons of aluminum, 2.3×10^5 metric tons of copper, 3.8×10^5 metric tons of lead, and 6.8×10^4 metric tons of zinc. These amounts account for 24% of iron, 38% of aluminum, 13% of copper, 53% of lead, and 11% of zinc in ELVs generated in Japan. For engine related rare metals, 2.2×10^4 metric tons of manganese, 4.3×10^3 metric tons of nickel, 3.4×10^4 metric tons of chromium, and 1.2×10^3 metric tons of

molybdenum were exported. This is equivalent to 38% of engine related rare metals generated in ELVs in Japan. The outflow amounts of the base and rare metals increased annually. These metals were exported to not only neighboring and developing countries but also distant, developed countries. The proportion of each metal exported to developing countries ranged from 45% to 65%.

These results strongly indicate that many metal resources abandoned in Japan are not recycled in Japan and being scattered in foreign countries, mainly developing countries in Asia. When the shift of demand from used parts to used vehicles for the progress of motorization together with future economic growth in Asia is considered, it is assumed that the resource outflow through the used vehicle export to Asian countries will accelerate. On the other hand, the possibility remains that the resources will be collected in these countries, because large amounts will be exported in the forms of used vehicles and parts. It is necessary to set up an international recycling system immediately in order to secure a stable supply of resources under the leadership of Japan having excellent recycling technology.

Acknowledgement

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