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Household Waste Reduction Effect of Sorted Collection of Recyclable Waste in Japan

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Abstract: The purpose of this study is to analyze the household waste reduction effect of sorted collection of recyclable waste in Japan using a panel data analysis, which considers time-series and cross-section data simultaneously. Also, the study shows the effect of the type of sorted items on the quantity of household waste disposed. We used the data attained from 103 cities recorded over three years, and applied the quantity of total waste disposed, the quantity of combustible waste, the quantity of other waste (waste excluding combustible and recyclable waste), and the quantity of combustible plus other waste as objective variables, respectively, in the models. The result suggests that when the number of sorted items is increased marginally, the quantity of household waste decreases by about 0.5%-3.3% or 1.28-4.17 grams per capita per day. In addition, it is shown that sorting out white trays is effective in reducing the quantity of combustible waste. Sorting out paper containers and packages is also effective in reducing the quantity of other waste and combustible plus other waste.

Key words: Household waste, sorted collection, recyclable waste, waste reduction, panel data analysis.

1. Introduction

In Japan, the total quantity of general waste disposed in FY 2009 was 46.3 million tons (metric tons), which is 8.6 million tons less than that in FY 2000 [1]. On the other hand, the recycling rate in FY 2009 increased by 6.2% points from the level in FY 2000.

In order to reduce the quantity of waste disposed, municipalities have introduced various measures. For example, Kyoto City subsidizes purchases of electric waste disposal units for domestic use [2]. Kagoshima City subsidizes recycling activities [3]. As a policy to reduce the quantity of waste disposed by municipalities, charges for household waste collection have been introduced by 60% of local governments in Japan [4]—The effect is shown to be a reduction in the quantity of household waste disposed [5-8]. Although similar effects are also indicated for sorted collection of recyclable waste, research studies are few [5, 7].

Sasao [7] analyzes the effect of sorted collection of recyclable waste in reducing the quantity of household waste by using a multiple regression analysis targeting 583 cities in Japan, which opens all the data related to waste management, out of 663 cities (as of March 1995) [7]. Sasao [7] suggests that a marginal increase in the number of sorted items would reduce waste by 1%-2% of Japan's annual total. However, since multiple regression analysis only evaluates one aspect of the waste reducing effect, factors contributing to reduce waste can be misjudged [8, 9]. Furthermore, it is possible to capture the changes in the number of sorted items, the types of sorted item, and socioeconomic situations in a single city by considering time-series.

The purpose of this study is to analyze the effect of sorted collection of recyclable waste in reducing Japan's household waste considering time-series. As a variation to Sasao's method of analysis [7], not only

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the total quantity, but also the quantity of combustible waste, other waste (the total, minus combustible and recyclable waste), and combustible plus other waste, are used as objective variables. As such, sorted collection of recyclable waste may affect differently on the quantity of waste of each category. For example, since metal waste is considered to be disposed of as unburnable waste when sorted collection is not institutionalized, sorted collection of metal waste will reduce unburnable waste, but will not reduce combustible waste substantially. In this study, we define "sorted collection of recyclable waste" as "the method to collect recyclable without using a system of charges for waste collection simultaneously".

In this study, the pure effect of sorted collection of recyclable waste by household (considered effective to reduce waste—as with charges for waste collection) in reducing waste is analyzed quantitatively by using a panel data analysis. In addition, the effect of the type of sorted item on the quantity of waste disposed is also analyzed.

2. Methodology

2.1 Time-Series and Cross-Section

In this study, time-series and cross-section are considered simultaneously. The time period of this analysis (time-series) is set as follows. This study uses the MOEJ (ministry of the environment, Japan) [1] for the waste data. Although the data after FY 1998 is stored therein, only the total quantity of general waste from business activities and from household exists before FY 2006. Since this study covers household waste, the data from FY 2007 and the proceeding three years are used.

The cross section of this analysis is set as follows. From 786 cities in Japan, cities which introduced sorted collection of recyclable waste are extracted. Since this study considers time-series, as described above, cities that have merged during the analysis period are eliminated from consideration to ensure consistency over time. Furthermore, if sorted collection of plastic waste is not introduced, plastic waste is disposed of as either combustible waste or other waste (including unburnable waste) depending on the cities involved. If these cities are analyzed simultaneously, the effect of sorted collection of plastic waste can be observed differently from that of the actual disposed category. Therefore, cities collecting plastic waste as other waste are excluded, since the number of cities collecting plastic waste as combustible waste is larger. As a result, 103 cities are used in the analysis.

2.2 Method

2.2.1 Panel Data Analysis

In this study, a panel data analysis is used, which considers multiple years and multiple cities simultaneously. In general, a fixed effect model, a random effect model, and a pooling estimate model are used for panel data analysis. From the three models, the best model is selected by statistical tests. An *F*-test is used for the pooling estimate model and the fixed effect model, the Breusch-Pagan test is used for the pooling estimate model and the random effect model, and the Hausman test is used for the fixed effect model and the random effect model.

In this study, Eq. (1) is used to analyze the effect of the number of sorted items on waste disposed. In addition, the type of sorted items, and some socioeconomic factors are included as explanatory variables.

$$W_{it} = C_i + a_1 PD_{it} + a_2 AI_{it} + a_3 AH_{it} + a_4 NC_{it} + \sum_j b_j D_{jit} + \varepsilon_{it} \quad (1)$$

Where, *i*: city, *j*: sorted item, *t*: year, *W*: waste disposed (gram/person/day), *PD*: population density (person/km^2), *AI*: annual average income (10,000 JPY), *AH*: average household size, *NC*: the number of sorted items, *D*: dummy variables for sorted items (the details are in Section 2.2.2), *C*: constant, a_1-a_4, *b*: coefficients, ε: error term.

Since four categories of waste are analyzed as described above, the quantity of *WA* (total waste), *WC* (combustible waste), *WO* (other waste) and *WCO* (combustible plus other waste) are used instead of *W* in Eq. (1).

In this study, *R* and its plm package software [10] are used for the analysis.

2.2.2 Data

The data used in the analysis are variables in Eq. (1) in the analyzing period. *PD*, *AI* and *AH* are calculated based on information obtained from the Statistics Bureau (2012) [11]. *WA*, *WC*, *WCO*, *NC*, and *D* are from MOEJ [1]. For the dummy variables *D*, *DPB* (sorted collection of pet bottles), *DCP* (plastic containers and packages), *DW* (white trays), *DPR* (other plastics), *DP* (papers), *DPP* (paper packs), *DPC* (paper containers and packages), *DK* (kitchen waste), *DM* (metals), *DG* (glass), *DC* (cloth), *DB* (pruned branches) and *DO* (waste cooking oil) are considered.

The basic statistics of the variables are shown in Table 1.

3. Results

The process of the analyses is as follows. First, statistically significant explanatory variables for each objective variable are specified using all 17 explanatory variables (the significant level being 5%). A panel data analysis is then applied again using the significant variables.

The results are summarized in Table 2. The model adopted as a result of the statistical tests is a random effect model for the model with *WCO*, and a fixed effect model for the other models.

The coefficients are negative for *PD* and *NC*, and positive for *AH* in the case of *WA*; negative for *PD*, *NC* and *DW*, and positive for *AH* in the case of *WC*; negative for *NC* and *DPC*, and positive for *AH* in the case of *WO*; and negative for *PD*, *NC* and *DPC*, and positive for *AH* in the case of *WCO* (Table 2). In the analysis, only *DW* or *DPC* becomes significant in the dummy variables. *DW* is significant for *WC* and *DPC* is significant for *WO* and *WCO*. Although the adjusted R^2 are small, the *F*-values, which test validity of the models, are significant of 0.1% in all the cases. Therefore, the models have explanatory power.

Table 1 Basic statistics of each variable.

Variables	Min.	Max.	Ave.	SD
WA	461.4	968.6	678.9	82.6
WC	134.0	852.0	517.0	79.7
WO	1.5	201.9	38.8	26.1
WCO	191.5	887.8	556.5	82.0
PD	50.3	9419.6	2747.0	2630.8
AI	229.5	645.2	340.3	55.5
NC	5	29	13.4	4.7
AH	2.2	3.3	2.6	0.2
DPB	0	1	0.99	0.10
DCP	0	1	0.66	0.48
DW	0	1	0.74	0.44
DPR	0	1	0.39	0.49
DPP	0	1	0.90	0.31
DPC	0	1	0.65	0.48
DK	0	1	0.13	0.34
DO	0	1	0.25	0.44
DB	0	1	0.16	0.37
DP	0	1	0.89	0.31
DM	0	1	0.96	0.19
DG	0	1	0.97	0.17
DC	0	1	0.69	0.46

Table 2 Summary of estimates.

Variables	Partial regression coefficients (standardized partial regression coefficients)			
	WA	*WC*	*WO*	*WCO*
PD	-0.13*** (-4.01)	-0.063** (-2.08)	-	-0.088*** (-2.82)
NC	-3.67*** (-0.21)	-2.94*** (-0.17)	-1.28* (-0.23)	-4.17*** (-0.24)
AH	631.63*** (1.76)	315.98*** (0.91)	95.14** (0.84)	420.35*** (1.18)
DW	-	-12.15* (-0.07)	-	-
DPC	-	-	-10.54* (-0.19)	-7.23* (-0.042)

Adjusted R^2: 0.38 (*WA*), 0.24 (*WC*), 0.06 (*WO*), 0.29 (*WCO*);
F-values: 94.99*** (*WA*), 28.49*** (*WC*), 7.26*** (*WO*), 41.35*** (*WCO*);
*: $P < 0.05$, **: $P < 0.1$, ***: $P < 0.001$;
-: significant results are not obtained.

4. Discussion

In this section, we discuss the coefficients of determination, the effect of sorted collection of recyclable waste on the quantity of waste, and the effect of other explanatory variables on the quantity of waste.

4.1 Coefficient of Determination

Adjusted R^2 in the analyses are 0.38 (*WA*), 0.24 (*WC*), 0.06 (*WO*) and 0.29 (*WCO*) (see Table 2). The reason for such small values may be from the shortage of sorted items considered in the model and the differences of an individual's conscience regarding sorted collection of waste.

In this study, we used MOEJ [1] for the dummy variables because of data constraints and the use of unified definition on sorted collection in the estimates. As a result, 13 dummy variables are selected. However, Kamakura City, for example, categorizes its waste into 17 types [12], and Ayase City categorizes its waste into 18 types [13]. It means that some sorted items can be aggregated when the MOEJ develop the database. Examples of items that are not included in the 13 types are batteries, hazardous materials and ceramics. Furthermore, MOEJ statistics aggregate cans and glass bottles into metals and glass, respectively. Therefore, the 13 dummy variables may not be sufficient.

In addition, even though sorted items are stipulated by each city, individuals do not necessarily follow the rule (intentionally or unintentionally). Therefore, it is not possible to understand exactly the effect of sorted collection of recyclable waste in such situations. That is, individual conscience on sorted collection, which is difficult to quantify and handle in the analysis, can affect the quantity of waste disposed.

4.2 Effect of Sorted Collection of Recyclable Waste

Table 3 shows the waste reduction effect and the reduction rate of each waste category of variables related to sorted collection. The waste reduction effect (gram/person/day) is based on the partial regression coefficients in Table 2, and the reduction rate is calculated from the average of waste in Table 1.

First, it is shown that sorted collection of recyclable waste has the effect of reducing waste in all four analyses. Marginal increases in the numbers of sorted items reduce waste 3.67 grams/person/day (*WA*), 2.94 grams/person/day (*WC*), 1.28 grams/person/day (*WO*) and 4.17 grams/person/day (*WCO*), respectively. The corresponding waste reduction rates are 0.54%, 0.57%, 3.30% and 0.75%. That is, a marginal increase in sorted items has the highest effect in reducing *WO* (other waste).

Next, sorted items (dummy variables) have no effect on reducing total waste or *WA* (significance of 5%). On the other hand, white trays (*DW*) reduce

Table 3 Waste reduction effect of variables related to sorted collection of waste.

Variables	Waste reduction effect (g per capita per day) (reduction rate (%))			
	WA	*WC*	*WO*	*WCO*
NC	-3.67 (-0.54)	-2.94 (-0.57)	-1.28 (-3.30)	-4.17 (-0.75)
DW	-	-12.15 (-2.35)	-	-
DPC	-	-	-10.535 (-27.18)	-7.23 (-1.30)-

-: significant results are not obtained.

2.35% of *WC*. According to investigations by some cities, white trays occupy only 0.1-0.7% of combustible waste [14, 15]. Therefore, it should be noted that the results of this study are larger than the actual composition of waste.

For *WO* and *WCO*, only *DPC* have a significant effect, the reduction rates of which are 27.18% and 1.30%, respectively. According to Maeda et al. [14], paper containers and packages occupy 5.5%-6.7% of combustible waste and less than 0.6%-1.5% of unburnable waste (included as other waste in this study). The result of a 1.30% reduction of *WCO* is reasonable, while it should be noted that a 27.18% reduction of *WO* is large compared to the actual component of waste.

Several estimates on dummy variables that deviate from the actual components may be due to the sorted items used in this study. As described above, the number of sorted items is smaller than the actual number, and some items are aggregated by the MOEJ. Therefore, the reduction effect of other items which are aggregated into a certain item can be overlooked.

4.3 Comprehensive Effect

Observing standardized partial regression coefficients of statistically significant explanatory variables (Table 2), variables that have a large effect on waste reduction in each category can be summarized as follows. For *WA*, *PD* has the largest effect. Similarly, for *WC* and *WCO*, *PD* has the largest effect. The reason that it has the largest impact on waste reduction of these categories may be due to the influence of urbanization. Since more people eat out and use home-meal replacement by urbanization, the quantity of kitchen waste consequently decreases. For *WO*, on the other hand, the number of sorted items has the largest effect in reducing waste.

In all cases, increasing the number of sorted items has the effect to reduce waste. However, for *WA*, *WC*, and *WCO*, *PD* has the larger effect.

Finally, we compare the results of this study with a similar study by Sasao [7]. The result, in that the number of sorted items negatively affects the quantity of waste disposed (waste reduction), is identical. On the other hand, the effect of *PD* (negative in this study) and that of *AH* (positive in this study) is different. For the latter, Ikematsu et al. [9] show generally negative effects for both *PD* and *AH*. The estimates of this study are not necessarily identical to existing studies. However, comparing the quantity of *WA* with *PD* and *AH* (Fig. 1), the tendencies corresponding to the results of this study are observed. Therefore, the results are reasonable considering the

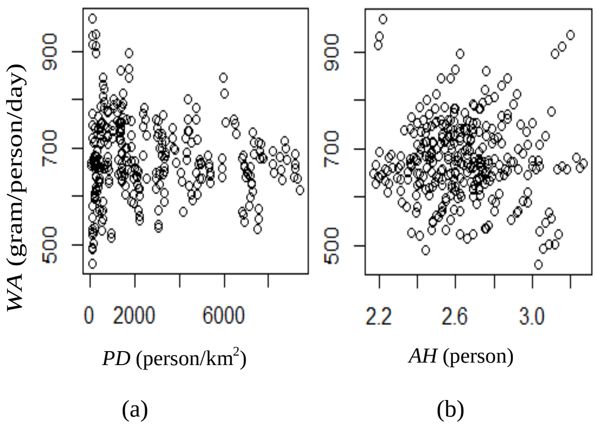

Fig. 1 Scatter plots of *WA* with (a) *PD* and (b) *AH*.

*Waste of other categories also shows similar tendencies.

range of the data used.

5. Conclusions

In this study, the authors analyzed the household waste reduction effect of sorted collection of recyclable waste in Japan using a panel data analysis. The estimate equation is a linear model, and variables related to sorted collection and socioeconomic variables were used for the explanatory variables, while total waste, combustible waste, other waste and combustible plus other waste were used for the objective variables.

As a result, it is shown that an increase in the number of sorted items reduces the quantity of waste disposed (*WA*: 3.67 grams/person/day; *WC*: 2.94 grams/person/day; *WO*: 1.28 grams/person/day; and *WCO*: 4.17 grams/person/day). Sasao [7] indicates that too large a number of sorted items may reduce household efforts of sorted collection by introducing a quadratic term of the number of sorted items in the equation. However, this study did not show the same result, since a significant result was not obtained for the quadratic term of the number of sorted items in this study.

Furthermore, in this study, sorted items effective in reducing combustible waste, other waste, and combustible plus other waste were revealed. It is considered that introducing a white tray as a sorted item would effectively reduce the quantity of combustible waste, as well as introducing paper containers and packages to effect a reduction in the quantity of other waste and combustible plus other waste. However, other kinds of sorted items were not statistically significant to the reduction of any other categories of waste.

For future studies, the authors should address the following issues, individual conscience and sorted items, which we consider as reasons for the low coefficient of determinants in each analysis. It is not possible to obtain statistical data regarding an individual's conscience towards sorted collection of recyclable waste, but a questionnaire survey would offer a possibility of quantifying such information to include with estimate equations. However, since it is difficult to get time-series data by this method, only one-year analysis (i.e., multiple regression analysis) will be possible.

For the number of sorted items, MOEJ data [1] are coarser than the actual sorted items in some cities. Therefore, although the sample size will be smaller, more precise analysis will be possible by selecting comparable cities (in terms of sorted items) by investigating the difference in sorting methods and details of sorted items of cities. This does not only improve coefficients of determination, but will also be useful to broadly investigate the effect of sorted items (dummy variables in this study) in reducing waste.

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