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Assessing the Effects of Unit-Based Pricing on Household Waste Reduction During COVID-19 in Japan

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Abstract: Focusing on the COVID-19 period in Japan, this study identifies the effectiveness of a municipal unit-based pricing (UBP) system on household waste reduction through a panel data analysis targeting 770 cities for 2013–2022. It focuses on simple unit pricing (SUP) and two-tiered pricing (TTP) systems as the UBP components. As previous studies have not considered the COVID-19 period when assessing UBP, this study significantly contributes to the literature by providing new evidence. The main findings are as follows: First, SUP effectively reduced household waste during the COVID-19 period, although its effectiveness was slightly neutralized owing to the pandemic environment. Second, TTP efficiently restrained household waste during the COVID-19 period, when people became cautious about their excessive waste volumes beyond the TTP criteria. The study implicates the need to expand the municipal adoption of the UBP system for household waste reduction.

Keywords: COVID-19; Japan; unit-based pricing; simple unit pricing; two-tiered pricing; household waste

1. Introduction

COVID-19 has significantly impacted people's lives in many ways. In Japan, the government's declaration of a state of emergency in 2020 forced people to stay indoors and work and study remotely for a long time. This behavior influenced the volume of household waste. The long-term trend in the nationwide volume of household waste (per capita per day) in Figure 1[1] shows a declining trend, from 527 g in 2013 to 496 g in 2022. Its background is the enhancement of people's environmental consciousness and government policies to reduce waste. The waste volume increased remarkably in 2020, the starting year of COVID-19. Several studies [1,2] interpret the increase in waste in 2020 as the COVID-19 effect through their own questionnaire surveys. However, waste volume has declined rapidly since 2021, returning to its previous declining trend.

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[1] The data are retrieved from the survey on the "State of Discharge and Treatment of Municipal Solid Waste" by Ministry of Environment in Japan. Available online: https://www.env.go.jp/recycle/waste_tech/ippan/index.html.

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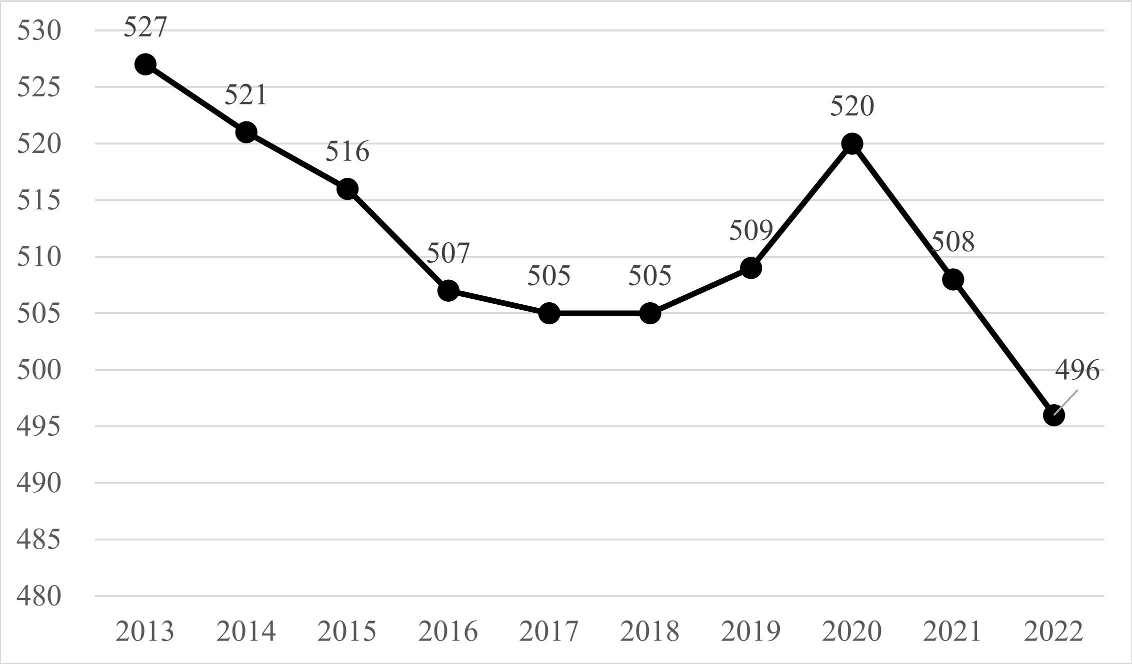

Figure 1. Trend in household waste (per capita, per day, g). Source: Authors' description based on the databases of the Ministry of Environment.

Regarding government policies to reduce household waste generation, the system of imposing charges for waste disposal, namely, unit-based pricing (UBP) of solid waste, is one of the key measures at the municipal level. The adoption of the system has been disseminated among municipalities since the 1990s [3], and the adoption ratio in terms of municipal number reached approximately 60 percent in 2024[2]. Moreover, the central government has encouraged system adoption in municipalities through its basic policy, revised in 2016[3], by stating that municipalities should promote the UBP system for waste disposal, which provides economic incentives to facilitate waste reduction, recycling, and enhancement of environmental consciousness [4]. The UBP system is divided into two types: simple unit pricing (SUP) and two-tiered pricing (TTP) programs [5]. The charge is imposed in proportion to the waste volume in the former system, whereas the charge is imposed or increased beyond a certain volume limit in the latter system. The adoption ratio of SUP out of the total UBP represents approximately 90 percent in terms of the municipal number, whereas that of TTP represents less than 10 percent [4].

The UBP system for waste disposal is evaluated in academic research worldwide, including in Japan. Most studies appreciate the effectiveness of the system in reducing waste volume, although some studies are skeptical about its effectiveness. To the best of our knowledge, no empirical studies have assessed the effectiveness of the UBP system during the COVID-19 period, although COVID-19 has significantly affected the volume of household waste (Figure 1). This study fills the research gap in the area of evaluation of UBP systems.

This study identifies the effectiveness of the UBP system for household waste disposal, including SUP and TTP, with a focus on the COVID-19 period after 2020, through a panel data analysis targeting 770 cities for 2013–2022.

The remainder of this study is organized as follows. Section 2 reviews the literature related to the evaluation of the UBP system and clarifies the contributions of this study. Section 3 presents the empirical analyses for evaluating UBP focusing on the COVID-19 period, including descriptions of key variables, data, estimation methods, and results with discussions. Finally, Section 4 summarizes and concludes the study.

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[2] Available online: https://www.yamayashusaku.com/zenkokutoshi_yuryoka_2406.pdf.

[3] The basic policy is based on the "Act on Waste Management and Public Cleaning." Available online: https://www.japaneselawtranslation.go.jp/ja/laws/view/4529.

2. Literature Review and Contributions

This section reviews the literature related to the evaluation of the UBP systems in foreign countries and Japan and clarifies the study's contributions.

Several empirical studies have verified the effectiveness of the UBP system in selected advanced economies: Carratini et al. [6] in Switzerland, Allers [7] in the Netherlands, Huang et al. [8], and Fullerton and Kinnaman [9] in the United States.

In Japan, empirical studies that evaluate UBP have evolved their methodologies from case studies through cross-sectional data analyses to panel data analyses. Table 1 shows the reviewed literature. The case studies, which support the effectiveness of UBP in solid waste reduction, including questionnaire surveys are Yamatani [10] focusing on Tama city, Sakai et al. [11] targeting four cities (Singu, Takayama, Oume, and Nagoya), and Amano et al. [12] covering 19 cities.

Table 1. List of literature.

Types of Analyses	Literature	Effects of Charge
Case Studies	Yamatani 2011	+
	Sakai et al. 2008	+
	Amano et al. 1999	+
Cross Section Data	Fukuda et al. 2021	-
	Ichinose, et al. 2015	+
	Nakamura & Kawase 2011	+
	Usui 2008	+
	Suwa & Usui 2007	+
	Usui 2003	+
	Yamakawa & Ueta 2002	+
	Sasao 2000	- (urban)
Panel Data	Nomura & Hibiki 2020	+
	Tsuzuki et al. 2018	+
	Usui & Takeuchi 2014	+
	Usui 2011	+

Cross-sectional data analyses provided more objective and generalizable research results than case studies. Ichinose et al. [13] demonstrate the waste reduction effects of UBP by applying an environmental Kuznets curve. Nakamura and Kawase [14] quantify the waste reduction effects of UBP; a one-yen increase in a designated one-liter bag produces a waste reduction of 1.6 percent. Usui [15], Suwa and Usui [16], and Usui [17] verify the interactive effects of waste reduction and recycling promotion. Yamakawa and Ueta [18] demonstrate the sustainable (10 year) effects of UBP on waste reduction using cross-sections with three-point years. In contrast, Fukuda et al. [19] examine the impact of UBP using a geographically weighted regression and argue that current pricing in most municipalities has nonsignificant effects on waste reduction. Sasao [20] shows that the waste reduction effect of UBP is more remarkable in rural areas than in urban areas.

Panel data analyses provide more precise and dynamic estimations than cross-sectional data analyses. Nomura and Hibiki [21] examine the effects of UBP by considering the spatial correlation between municipalities and find significant effects on waste generation. Tsuzuki et al. [22] construct municipal-level panel data considering the municipal mergers known as "the big merger of Heisei" and verify the long-term waste reduction effects of SUP and TTP. Usui and Takeuchi [23] and Usui [24] investigate the rebound effect of UBP, in which the waste reduction effects attenuate after the UBP adoption and find that the long-term waste reduction effects of UBP dominate its rebound effect.

In summary, most studies appreciate the waste reduction effects of UBP; however, some studies report nonsignificant effects. Thus, a consensus on the effectiveness of UBP has not been reached in the literature.

This study contributes to the extant literature in the following ways: First, it evinces the effectiveness of UBP, whereas previous studies indicate mixed results. Second, it provides new evidence by considering the COVID-19 period when assessing UBP. Finally, it provides significant evidence that COVID-19 may change people's consciousness and behavior regarding household waste disposal as suggested by the change in the nationwide volume of waste after 2020 (Figure 1). The critical question arises as to whether people's reactions to UBP have strengthened or weakened.

3. Empirical Analyses

This section presents the empirical analyses for evaluating UBP focusing on the COVID-19 period, including descriptions of variables, data, estimation methods, and results with discussions.

3.1. Variables and Data Collection

This subsection describes the variables and data collection for the econometric estimation. Table 2 lists the variables and data used for the subsequent estimations, and Table 3 presents their descriptive statistics. The estimation contains one dependent variable of household waste, four explanatory variables for controlling time-varying city-specific effects, and two kinds of explanatory dummies: one for examining the effect of UBP municipal adoption and the others for the COVID-19-period dummies.

Table 2. List of variables and data sources.

Variables	Description	Data Sources
Dependent Variable		
was	Household waste (per person, per day), g	W
Explanatory Variables		
hos	Average number of people per household	M
inc	Taxable income per capita, yen	M
pod	Population density based on a habitable area, per km^2	M
sep	Number of garbage collection separation	W
d_sup	Dummy (=1) for municipalities adoption of single unit pricing	Y
d_ttp	Dummy (=1) for municipalities adoption of two-tiered pricing	Y
d_post20	Dummy (=1) for COVID-19 period after 2020	
d_post21	Dummy (=1) for COVID-19 period after 2021	
d_post22	Dummy (=1) for COVID-19 period in 2022	

Note: W: State of Discharge and Treatment of Municipal Solid Waste, by Ministry of Environment. M: Statistical Observations of Municipalities, Ministry of Internal Affairs and Communications. Y: Yamatani [25].

Table 3. Descriptive statistics.

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Variable	Obs.	Mean	Std. Dev.	Min.	Max
was	7,689	662	91	312	1,283
hos	7,689	2.346	0.255	1.656	3.243
ln inc	7,689	14.897	0.140	14.552	15.767
ln pod	7,689	6.962	1.076	4.127	9.604
sep	7,689	14.258	4.979	3.000	36.000

The dependent variable, household waste (was), is expressed in grams per person per day. The data are retrieved from a survey by the Ministry of Environment.

Regarding the explanatory variables, the first category involves the variables for controlling time-varying city-specific effects. The first three variables represent municipal social properties: average number of people per household (hos), taxable income per capita in yen (inc), and population density based on habitable area in terms of persons per square kilometer (pod). These variables are selected from those commonly used in previous studies (Table 1). All data are retrieved from the Statistical Observations of Municipalities of the Ministry of Internal Affairs and Communications[4]. The data of inc and pod are transformed into logarithms (ln inc and ln pod) to avoid scaling problems in the estimation. The effects of these variables on household waste are ambiguous in the literature. While the effect of the number of people per household (hos) on waste is negative owing to the increase in common waste among members in most studies, some studies [1] show its positive effect owing to an additional increase in household waste originating from family support for children and elderly members. The income (inc) effect on waste is positive owing to the increase in consumption in most studies [17,20], but others, such as Nomura and Hibiki [21], present its negative effect assuming dining-out effects stemming from high-income earnings. Regarding the effect of population density (pod) on waste, some studies [17] indicate a positive effect owing to the limited space for waste storage, whereas others [21,22] present a negative effect owing to the incentive for waste reduction. Another control variable represents municipal waste treatment, namely, the number of garbage collection separations (sep). The data are obtained from a survey by the Ministry of Environment. As expected, its negative effects on waste are demonstrated in previous studies.

The second category includes the explanatory variables of the dummies. The first two dummies are those of UBP municipal adoption: the adoption of SUP (d_sup) and TTP (d_ttp), taking a value of 1 during their adoption periods and 0 otherwise[5]. Information on their adoption is obtained from Yamatani [25]. The negative effects of both systems on waste are expected, as most studies appreciate the effects of UBP on waste reduction. Comparing the effects of SUP and TTP, the SUP effect is more robust than the TTP effect because SUP provides an incentive for waste reduction for every unit of waste and TTP confines its incentive only to the volume beyond the criteria. The other three dummies are related to the COVID-19 period: the dummy after 2020 (d_post20), taking a value of 1 after 2020 and 0 otherwise; the dummy after 2021 (d_post21); and the dummy for 2022 (d_post22). Following the observations in Figure 1, the effect of d_post20 on waste is positive, whereas the other dummies (d_post21 and d_post22) are negative. We investigate whether the waste reduction effect of UBP changes during the COVID-19 period and whether its waste reduction effect is strengthened or weakened. Thus, the cross-terms are created and added to the estimation in line with this interest: d_sup*d_post20, d_sup*d_post21, and d_sup*d_post22 for the SUP additional effect and d_ttp*d_post20, d_ttp*d_post21, and d_ttp*d_post22 for the TTP additional effect.

3.2. Panel Data Setting

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[4] Available online: https://www.stat.go.jp/data/s-sugata/index.html.

[5] In case the timing of the adoption is in midyear, a value of 1 is applied from next year.

Based on the above variables, we construct panel data using annual data for 2013–2022[6] in 770 cities. We exclude the following cities and periods from the sample owing to the complexity of examining the UBP effect: the cities that adopt TTP and change it into SUP, 23 wards in Tokyo Metropolitan, and periods before the status of current "city" in case of any changes of status (e.g., mergers and upgrades from towns or villages). Therefore, the panel data comprise 7,689 samples. Among the 770 sample cities, SUP and TTP are adopted by 439 and 21 cities, respectively, in 2022.

For the subsequent estimation, we investigate the stationarity of the constructed panel data by employing panel unit root tests: the Levin, Lin, and Chu test as a common unit root test [26] and the Fisher augmented Dickey–Fuller (ADF) and Fisher Phillips–Perron tests [27,28] as individual unit root tests. The common unit root test assumes the existence of a common unit root process across cross sections, whereas the individual unit root test allows individual unit root processes that differ across cross sections. These tests are based on the null hypothesis that a series of panel data in levels has a unit root by including the "trend and intercept" in the test equations. Table 4 shows that all tests except one variable (ln pod) in the Fisher ADF test reject the null hypothesis of a unit root at the conventional significance level for the variables. Therefore, this study assumes that there is no serious problem with the existence of unit roots in the panel data and uses panel data in levels for the estimation.

Table 4. Panel unit root tests.

	common unit root	individual unit root	
	Levin, Lin, and Chu Test	Fisher-ADF Chi-square	Fisher-PP Chi-square
was	-52.010***	2,123.96***	2,295.75***
hos	-65.969***	3,144.14***	5,718.90***
ln inc	-22.482***	1,669.27**	1,848.61***
ln pod	-51.974***	1,427.35	2,126.09***
sep	-541.839***	1,032.89***	1,149.37***

Note: *** and **denote statistical significance at the 99 and 95 percent levels, respectively.

3.3. Model Specification and Estimation Method

The equation for econometric estimation, following panel data analyses in the literature, is as follows:

$was\ it = \alpha 0 + \alpha 1\ hosit + \alpha 2\ \ln incit + \alpha 3\ \ln podit + \alpha 4\ sepit + \alpha 5\ d\_supit + \alpha 6\ d\_ttpit + \alpha 7\ d\_post20 + \alpha 8\ d\_post21 + \alpha 9\ d\_post22 + \alpha 10\ d\_supit\ d\_post20 + \alpha 11\ d\_supit\ d\_post21 + \alpha 12\ d\_supit\ d\_post22 + \alpha 13\ d\_ttpit\ d\_post20 + \alpha 14\ d\_ttpit\ d\_post21 + \alpha 15\ d\_ttpit\ d\_post22 + fi + \varepsilon it.$ (1)

Here, each of the variable names is denoted in Section 3.1 and Table 2. Subscripts i and t represent the sample city and year, respectively. fi indicates the time-invariant city-specific fixed effects. $\alpha 0 \ldots 15$ represents the estimated coefficients, and ε denotes the residual error term. Equation (1) is the full version of the estimation, including all the variables. The subsequent estimations start with the equation without any dummy variables, followed by the equations with the dummies d_post20, d_post20 and d_post21 and d_post20, d_post21, and d_post22, to demonstrate a series of annual accumulation of additional COVID-19 effects, including the UBP effects on waste reduction

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[6] The sample period is set by the data availability of household waste from the survey by Ministry of Environment. The annual year denotes the fiscal year (April–March) in Japan.

in their cross-terms (the additional effects are shown in a_i-iv and b_i-iv of Tables 5 and 6, respectively, in Section 3.4).

Table 5. OLS estimation.

Estimation	a_i	a_ii	a_iii	a_iv
hos	31.727***	48.399***	50.305***	51.184***
	(4.500)	(6.151)	(6.413)	(6.535)
ln inc	-175,081***	-205.744***	-162.285***	-143.830***
	(-10.183)	(-11.756)	(-8.698)	(-7.594)
in pod	-159.293***	-149.475***	-150.358***	-151.904***
	(-13.349)	(-12.519)	(-12.645)	(-12.794)
sep	-1.420***	-1.427***	-1.455***	-1.456***
	(-5.174)	(-5.220)	(-5.343)	(-5.359)
d_post20		1.304	9.499***	9.109***
		(0.911)	(5.085)	(4.882)
d_post21			-15.038***	-11.415***
			(-7.337)	(-4.924)
d_post22				-8.448***
				(-3.637)
d_sup	-56.202***	-60.255***	-60.365***	-60.363***
	(-15.704)	(-16.824)	(-16.926)	(-16.957)
*d_sup*d_post20*		10.863***	4.328*	4.275*
		(7.233)	(1.891)	(1.871)
*d_sup*d_post21*			9.537***	9.059***
			(3.649)	(3.009)
*d_sup*d_post22*				0.810
				(0.269)
cumulated d_sup	-56.202	-49.392	-46.500	-47.029
d_ttp	-40.298**	-28.901	-30.130	-30.589
	(-2.136)	(-1.534)	(-1.606)	(-1.634)
*d_ttp*d_post20*		-15.007***	-15.846**	-15.805**
		(-3.304)	(-2.276)	(-2.275)
*d_ttp*d_post21*			1.537	2.906
			(0.193)	(0.317)
*d_ttp*d_post22*				-2.654
				(-0.290)
Adjusted R-squared	0.897	0.899	0.899	0.900
Fix Effect (cities)	Yes	Yes	Yes	Yes
Number of cities	770	770	770	770
Obsevations	7,689	7,689	7,689	7,689

Note: ***, **, and * denote statistical significance at the 99, 95, and 90 percent levels, respectively. T-statistics are shown in parentheses.

Table 6. GLS estimation.

Estimation	b_i	b_ii	b_iii	b_iv
hos	40.279***	68.676***	73.357***	76.190***
	(10.005)	(15.912)	(17.195)	(18.080)
ln inc	-197.551***	-235.709***	-183.603***	-157.348***
	(-19.960)	(-23.989)	(-17.689)	(-15.369)
in pod	-181.037***	-170.426***	-169.537***	-171.295***
	(-25.969)	(-25.243)	(-25.614)	(-26.269)
sep	-1.533***	-1.491***	-1.578***	-1.599***
	(-9.453)	(-10.123)	(-10.443)	(-10.497)
d_post20		5.063***	13.387***	13.100***
		(6.681)	(13.865)	(13.863)
d_post21			-15.137***	-11.025***
			(-14.271)	(-9.420)
d_post22				-10.004***
				(-8.549)
d_sup	-51.745***	-56.110***	-56.094***	-56.071***
	(-21.847)	(-23.984)	(-24.237)	(-24.519)
*d_sup*d_post20*		10.402***	2.851**	2.882**
		(13.169)	(2.422)	(2.484)
*d_sup*d_post21*			11.197***	8.475***
			(8.343)	(5.554)
*d_sup*d_post22*				4.847***
				(3.178)
cumulated d_sup	-51.745	-45.708	-42.046	-39.867
d_ttp	-38.272***	-28.355**	-29.922***	-30.393***
	(-4.784)	(-2.542)	(-2.833)	(-2.909)
*d_ttp*d_post20*		-10.469***	-13.209***	-12.496***
		(-3.907)	(-3.234)	(-3.044)
*d_ttp*d_post21*			4.664	2.451
			(1.009)	(0.456)
*d_ttp*d_post22*				1.932
				(0.359)
Adjusted R-squared	0.965	0.965	0.966	0.966
Fix Effect (cities)	Yes	Yes	Yes	Yes
Number of cities	770	770	770	770
Obsevations	7,689	7,689	7,689	7,689

Note: ***, **, and * denote statistical significance at the 99, 95, and 90 percent levels, respectively. T-statistics are shown in parentheses.

Panel data analysis provides an option for choosing a fixed- or random-effects model. Equation (1) applies a fixed-effects model, represented by fi, to the municipal panel data estimation for the following reasons. First, from a statistical perspective, the Hausman specification test is generally used to choose between fixed- and random-effects models [29]. The test was conducted in the primary equation (1) without period dummies and effected a rejection of the null hypothesis of the random effects model at the 99 percent significance level, with the chi-square statistic being 226.7. Thus, this test justifies the adoption of the fixed-effects model. Second, adopting the fixed-effects model helps alleviate the endogeneity problem by absorbing unobserved time-invariant heterogeneity among the sample cities. We assume that geographical factors, such as climate and regional culture, differ among the sample cities and are correlated with household waste (not distributed randomly among the sample cities). As a specification ignoring these effects leads to an inefficient estimation, they should be controlled by incorporating city-specific fixed effects into the specification.

Multicollinearity among explanatory variables is a problem that causes estimation bias, and the variance inflation factor (VIF) is a useful tool for measuring the level of collinearity between regressors. The VIF test is conducted in the primary equation (1) without period dummies and its values are far below the criteria of collinearity, namely, 10 points–3.453 in hos, 2.848 in ln inc, 1.604 in ln pod, 1.025 in sep, 1.027 in d_sup, and 1.007 in d_ttp. Thus, the inclusion of all explanatory variables is justified in the estimation.

Regarding the estimation technique, this study applies the ordinary least squares (OLS) and generalized least squares (GLS) estimators. The reason for applying the GLS estimator is that the sample data are plagued by heteroscedasticity among the sample cities, whereas the OLS estimator effectuates bias in estimates. To examine the existence of heteroscedasticity in the sample cities, a panel cross-section heteroscedasticity likelihood ratio test was conducted in the primary equation (1) without period dummies and resulted in a rejection of the null hypothesis that residuals are homoscedastic at the 99 percent significance level. Thus, this study adds a GLS estimation to ensure the robustness of the estimation results.

3.4. Results with Discussion

Tables 5 and 6 report the results of OLS and GLS estimations of household waste effects, respectively. The estimation results for a_i-iv in Table 5 and b_i-iv in Table 6 represent a series of annual accumulations of additional COVID-19 effects. The results common to both estimations are robust. The main results are summarized as follows:

Regarding the effects of the variables controlling time-varying city-specific effects, the first variable, the number of people per household (hos), has significant positive coefficients in both estimations. This result aligns with that of Asai [1], indicating the additional increase in household waste originating from family support for children and elderly members. The income (ln inc) effects are significantly negative throughout the estimations, which aligns with Nomura and Hibiki [21], speculating on the dining-out effects of high-income households. The effects of population density (in pod) are significantly negative throughout the estimations, which aligns with Nomura and Hibiki [21] and Tsuzuki et al. [22], assuming the incentive for waste reduction under limited spaces. The number of garbage collection separations (sep) has significant negative effects, as verified in many studies.

The COVID-19-period dummies present the expected effects in both estimations: the dummy after 2020 (d_post20) has significant positive effects (except for the a_ii estimation), whereas the dummies after 2021 (d_post21) and after 2022 (d_post22) have negative effects. The negative magnitudes of the sum of d_post21 and d_post22 exceed the positive value of d_post20. These results are consistent with the trends in household waste shown in Figure 1. The results can be interpreted as follows: in 2020, the initial year of COVID-19, people were unexpectedly forced to stay at home for a long time, and thus could not prevent household waste from increasing; however, in 2021 and 2022, the COVID-19 effects mitigated, and people adjusted themselves to the COVID-19 environment, well managing waste disposal.

This study focuses on the waste reduction effects of municipal UBP adoption, particularly during the COVID-19 period. The SUP effects (d_sup) are significantly negative, with a magnitude of 52-60 grams per person/day throughout the estimations. However, the TTP effects (d_ttp) are not necessarily significant in the OLS estimations, a_ii-iv, and their magnitude is 28-38 grams per person per day in the GLS estimation, b_i-iv. These results are consistent with most studies and the original expectation that the SUP effect is more robust than the TTP effect owing to the difference in their waste reduction incentives.

It is important to consider how the waste reduction effects of UBP changed during the COVID-19 period. The additional UBP effects during the COVID-19 period are represented by cross-terms with COVID-19-period dummies. The additional effects of SUPs are significantly positive (except for the OLS estimation, a_iv); however, their magnitude is smaller than the original SUP effects. The magnitude of the cumulative SUP effects as the sum of the original and additional effects is 40-49 grams per person per day throughout the estimations. This suggests that SUP is still effective in reducing household waste even during the COVID-19 period, although its effectiveness is slightly neutralized owing to the pandemic affecting people's behaviors. Regarding the additional effects of TTP, the results common to the OLS and GLS estimations are significantly negative in the cross-term with d_post20, suggesting that people became cautious about whether their waste volumes exceeded the TTP criteria during the pandemic when they stayed at home for a long time and produced more waste than usual.

4. Conclusion

This study identifies the effectiveness of the UBP system for household waste disposal, including SUP and TTP, with a focus on the COVID-19 period after 2020, through a panel data analysis targeting 770 cities for 2013–2022. It is significant because it provides new evidence as previous studies have not considered the COVID-19 period when assessing UBP. The main findings are as follows. First, SUP effectively reduced household waste during the COVID-19 period, although its effectiveness was slightly neutralized owing to the pandemic environment. Second, TTP efficiently restrained household waste during the COVID-19 period, when people became cautious about excessive waste volumes beyond the TTP criteria.

This study implicates the further need to expand the municipal adoption of the UBP system. It verified its effectiveness in reducing household waste during the pandemic. However, its adoption ratio in terms of municipal numbers remains at approximately 60 percent. Thus, UBP dissemination can contribute to waste reduction by enhancing incentives and environmental consciousness of people.

This study has several limitations and scope for further research. First, it focuses only on the waste reduction effect of the UBP system. However, UBP is considered to promote not only waste reduction but also recycling. To examine the effects of UBP recycling, detailed analyses should be conducted based on data decomposing household waste into burnable, non-burnable, and recyclable wastes to explicitly observe the shifts among wastes. Second, this study only considered household waste. However, UBP is applied not only to household waste but also to business-related waste. Thus, comprehensive reviews of the UBP system require additional investigation regarding the effects of UBP on business-related waste.

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