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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 even during the COVID-19 period; however, its effectiveness was slightly neutralized owing to the pandemic environment. Second, TTP also restrained household waste efficiently; however, its effect was smaller than that of SUP, and its reduction effect accelerated during the COVID-19 period (in 2020) because people became cautious about 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

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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 (The data are retrieved from the survey on the "State of Discharge and Treatment of Municipal Solid Waste" by the Ministry of Environment in Japan. Available online: https://www.env.go.jp/recycle/waste_tech/ippan/index.html, accessed on 1 October 2024) 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.

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 66 percent in 2024 (available online: https://www.yamayashusaku.com/zenkokutoshi_yuryoka_2410.pdf, accessed on 1 October 2024). Moreover, the central government has encouraged system adoption in municipalities through its basic policy in 2005 (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, accessed on 1 October 2024) 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].

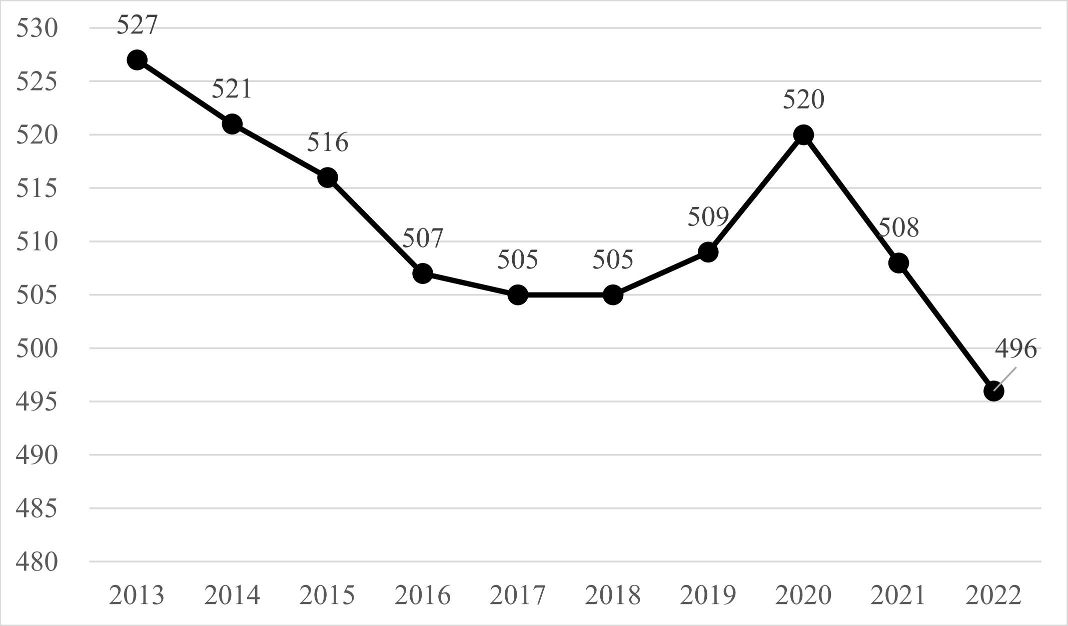

Figure 1. Trend in household waste (per capita, per day, g): rapid increase in the waste in 2020. Source: Authors' description based on the databases of the Ministry of Environment.

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; however, 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; however, COVID-19 has significantly affected the volume of household waste (Figure 1). The COVID-19 pandemic is a critical period for evaluating UBP because it might alter household behaviors. Under the pandemic, people were unexpectedly forced to stay at home, and thus could not prevent household waste from increasing. In that case, the unique question posed by the pandemic is whether people are inclined to be less or more sensitive to the volume of waste under UBP. This study, filling this research gap, contributes to understanding UBP policy efficacy in pandemic times.

The purpose of this study is to identify 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.

2. Literature Review and Contributions

This section reviews the literature related to the evaluation of the unit-based pricing (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: majority of studies support UBP effectiveness.

Types of Analyses	Literature	Effects of Charge
Case Studies	Yamatani 2011 [10]	+
	Sakai et al., 2008 [11]	+
	Amano et al., 1999 [12]	+
Cross-Section Data	Irokawa & Murano 2018 [13]	+ (except designated cities)
	Ichinose, et al., 2015 [14]	+
	Nakamura & Kawase 2011 [15]	+
	Usui 2008 [16]	+
	Suwa & Usui 2007 [17]	+
	Usui 2003 [18]	+
	Yamakawa & Ueta 2002 [19]	+
	Fukuda et al., 2021 [20]	−
	Sasao 2000 [21]	− (urban)
Panel Data	Nomura & Hibiki 2020 [22]	+
	Tsuzuki et al., 2018 [23]	+
	Usui & Takeuchi 2014 [24]	+
	Usui 2011 [25]	+

Cross-sectional data analyses provide more objective and generalizable research results than case studies. Irokawa and Murano [13] identify the waste reduction effects of UBP in cities with various population sizes. Ichinose et al. [14] demonstrate the waste reduction effects of UBP by applying an environmental Kuznets curve. Nakamura and Kawase [15] 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 [16], Suwa and Usui [17], and Usui [18] verify the interactive effects of waste reduction and recycling promotion. Yamakawa and Ueta [19] demonstrate the sustainable (10 years) effects of UBP on waste reduction using cross-sections with three-point years. In contrast, Fukuda et al. [20] 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 [21] 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 [22] examine the effects of UBP by considering the spatial correlation between municipalities and find significant effects on waste generation. Tsuzuki et al. [23] 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 [24] and Usui [25] 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. The most vital shortcoming of previous research is the lack of empirical studies for assessing the UBP efficacy under the COVID-19 pandemic. This study contributes to providing new evidence on the UBP evaluation in pandemic times.

The critical research question is whether people's reactions to UBP have strengthened or weakened under the pandemic.

3. Empirical Analyses

This section presents empirical analyses for evaluating the unit-based pricing (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.

	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 [26].

Table 3. Descriptive statistics.

Variable	Obs.	Mean	Std. Dev.	Min	Max
was	7689	662	91	312	1283
hos	7689	2.346	0.255	1.656	3.243
ln inc	7689	14.897	0.140	14.552	15.767
ln pod	7689	6.962	1.076	4.127	9.604
sep	7689	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 three control variables are commonly adopted in all of the studies with panel data analyses for UBP evaluation: Nomura and Hibiki [22], Tsuzuki et al. [23], Usui and Takeuchi [24], and Usui [25]. All data are retrieved from the Statistical Observations of Municipalities of the Ministry of Internal Affairs and Communications (available online: https://www.stat.go.jp/data/s-sugata/index.html, accessed on 1 October 2024). The data of inc and pod are transformed into logarithms (ln inc and ln pod) to avoid scaling problems in the estimation. How these variables relate to household behaviors under UBP is described as follows. 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 [18,21], but others, such as Nomura and Hibiki [22], present its negative effect, assuming dining-out effects stemming from high-income earnings. Regarding the effect of population density (pod) on waste, some studies [18] indicate a positive effect, owing to the limited space for waste storage, whereas others [22,23] 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). This variable is used in the panel data studies, such as Nomura and Hibiki [22], and Usui [25], and its negative effects on waste are demonstrated. The data are obtained from a survey by the Ministry of Environment.

The second category includes the explanatory variables of the dummies. The first two dummies are those of UBP municipal adoption: the adoption of simple unit pricing (SUP) (d_sup) and two-tiered pricing (TTP) (d_ttp), taking a value of one during their adoption periods and zero otherwise (In case the timing of the adoption is in midyear, a value of 1 is applied from next year.). Information on their adoption is obtained from Yamatani [26]. 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 one after 2020 and zero otherwise; the dummy after 2021 (d_post21); and the dummy for 2022 (d_post22) (It is true that pandemic-related data can include such indicators as infection rates and government response stringency index. In this study, however, the pandemic anomalies are simply represented by the time dummies: d_post20, d_post21, and d_post22. In comparative studies among countries, however, the pandemic-related data are definitely needed to show the differences in the pandemic anomalies). 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

Based on the above variables, we construct panel data using annual data for 2013–2022 (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 770 cities. We exclude the following cities and periods from the sample, owing to the complexity of examining the unit-based pricing (UBP) effect: the cities that adopt two-tiered pricing (TTP) and change it into simple unit pricing (SUP), 23 wards in Tokyo Metropolitan, and periods before the status of current "city" in case of any changes in status (e.g., mergers and upgrades from towns or villages). Therefore, the panel data comprise 7689 samples. Among the 770 sample cities, SUP and TTP are adopted by 439 and 21 cities, respectively, in 2022.

3.3. Model Specification and Estimation Method

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

$$\text{was it} = \alpha0 + \alpha1\ \text{hosit} + \alpha2\ \text{ln incit} + \alpha3\ \text{ln podit} + \alpha4\ \text{sepit} + \alpha5\ \text{d\_supit} + \alpha6\ \text{d\_ttpit} + \alpha7\ \text{d\_post20} + \alpha8\ \text{d\_post21} + \alpha9\ \text{d\_post22} + \alpha10\ \text{d\_supit d\_post20} + \alpha11\ \text{d\_supit d\_post21} + \alpha12\ \text{d\_supit d\_post22} + \alpha13\ \text{d\_ttpit d\_post20} + \alpha14\ \text{d\_ttpit d\_post21} + \alpha15\ \text{d\_ttpit d\_post22} + \text{fi} + \varepsilon\text{it}. \tag{1}$$

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. α0. . .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 in their cross-terms (the additional effects are shown in i–iv of Table 4 in Section 3.5).

Table 4. Estimation results: results support UBP effectiveness even under COVID-19.

Estimation	**i**	**ii**	**iii**	**iv**
hos	31.727 ** (2.183)	48.399 *** (2.991)	50.305 *** (3.185)	51.184 *** (3.270)
ln inc	−175.081 *** (−5.284)	−205.744 *** (−5.628)	−162.285 *** (−4.442)	−143.830 *** (−3.999)
in pod	−159.293 *** (−5.464)	−149.475 *** (−5.143)	−150.358 *** (−5.152)	−151.904 *** (−5.206)
sep	−1.420 *** (−2.697)	−1.427 *** (−2.669)	−1.455 *** (−2.730)	−1.456 *** (−2.727)
d_post20		1.304 (0.685)	9.499 *** (5.216)	9.109 *** (4.987)
d_post21			−15.038 *** (−8.821)	−11.415 *** (−7.743)
d_post22				−8.448 *** (−5.044)
d_sup	−56.202 *** (−10.346)	−60.255 *** (−10.770)	−60.365 *** (−10.846)	−60.363 *** (−10.902)
d_sup d_post20		10.863 *** (4.051)	4.328 * (1.648)	4.275 (1.628)
d_sup d_post21			9.537 *** (4.784)	9.059 *** (4.613)
d_sup d_post22				0.810 (0.383)
cumulated d_sup	−56.202	−49.392	−46.393	−46.219
d_ttp	−40.298 *** (−12.742)	−28.901 *** (−6.788)	−30.130 *** (−7.073)	−30.589 *** (−7.187)
d_ttp d_post20		−15.007 ** (−2.133)	−15.846 ** (−2.077)	−15.805 ** (−2.074)
d_ttp d_post21			1.537 (0.341)	2.906 (0.678)
d_ttp d_post22				−2.655 (−0.574)
Adjusted R−squared	0.897	0.899	0.899	0.900
Fixed Effect (cities)	Yes	Yes	Yes	Yes
Number of cities	770	770	770	770
Observations	7689	7689	7689	7689

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 [27]. 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-squared 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 fixed effect estimator with standard errors clustered at the city level (clustering estimator). The reason for applying the clustering estimator is that the sample data are plagued by heteroscedasticity among the sample cities, whereas the ordinary 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 adopts the clustering estimator to ensure the estimation robustness.

3.4. Brief Summary of Results

The focus of this study is the effects of unit-based pricing (UBP) on household waste disposal during the COVID-19 period after 2020. The main findings from the estimation results can be highlighted as follows. First, simple unit pricing (SUP) effectively reduced household waste even during the COVID-19 period; however, its effectiveness was slightly neutralized, owing to the pandemic environment. Second, two-tiered pricing (TTP) also restrained household waste efficiently; however, its effect was smaller than that of SUP, and its reduction effect accelerated during the COVID-19 period (in 2020) because people became cautious about excessive waste volumes beyond the TTP criteria.

3.5. Detailed Results with Discussion

Table 4 reports the estimation results of household waste effects of unit-based pricing (UBP). The estimation results for i-iv in Table 4 represent a series of annual accumulations of additional COVID-19 effects. 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. The magnitudes of the hos effects from 32 to 51 g per person per day are large enough considering the mean of household waste (was), 662 g shown in Table 3. 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 (minus 144–206 g are large enough), which aligns with Nomura and Hibiki [22], speculating on the dining-out effects of high-income households. The effects of population density (in pod) are significantly negative throughout the estimations (minus 149–159 g are large enough), which aligns with Nomura and Hibiki [22] and Tsuzuki et al. [23], assuming the incentive for waste reduction under limited spaces. The number of garbage collection separations (sep) has significantly negative effects, as verified in many studies.

The COVID-19-period dummies present the expected effects: the dummy after 2020 (d_post20) has significantly positive effects (except for the estimation ii), whereas the dummies after 2021 (d_post21) and after 2022 (d_post22) have significantly 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 by well managing waste disposal.

This study focuses on the waste reduction effects of municipal unit-based pricing (UBP) adoption, particularly during the COVID-19 period. The simple unit pricing (SUP) effects (d_sup) are significantly negative, with magnitudes of 56–60 g per person/day throughout the estimations. The two-tiered pricing (TTP) effects (d_ttp) are also significantly negative, with magnitudes of 29–40 g, which are smaller than those of SUP. This result is consistent with most studies and the original expectation that the SUP effect is larger 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 SUP are significantly positive (except for the coefficients of cross-term with d_post20 and d_post22 in the estimation 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 46–49 g per person per day throughout the estimations. This suggests that SUP is still effective in reducing household waste even during the COVID-19 period; however, its effectiveness is slightly neutralized, owing to the pandemic affecting people's behaviors. To be specific, the impact of household economic behaviors during COVID-19 can be explored such that people still kept the sensitivity to the waste volume and UBP system even under the pandemic; however, their concerns might be slightly shifted toward the infection prevention. Regarding the additional effects of TTP, they 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.

A robustness check is conducted by dividing total sample cities into larger cities and smaller ones in their population. Lining sample cities up from the larger ones to the smaller ones in terms of their population size in 2022, the first and second halves are considered to be the groups of larger and smaller cities. TTP dummy is excluded in the estimation because the cities adopting TTP are only 21, and their division makes estimation unstable. Table 5 compares the results on the total sample, and the samples of larger cities and smaller cities, and shows that the sign and significance of the coefficients related to COVID-19 and SUP effects are almost the same despite the differences in their magnitudes (however, the coefficients of control variables differ in the significance and the sign between larger cities and smaller ones). Thus, the robustness of SUP effects is secured in the estimation of the total sample.

Lastly, the study investigates the necessity to use a dynamic panel data model because the level of household waste might be persistent over time. Table 6 reports the result of a dynamic panel data estimation with an estimator of the generalized method of moments, equipping one- or one- and two-year lagged explanatory control valuables as instrumental variables. It shows that the dynamic terms of household waste, was(-1) and was(-2), have negative and insignificant (or weak) coefficients. Adding more year-lags would make the time-series sample too short within the period for 2013–2022. Thus, this justifies the usage of a static panel data model in this study.

Table 5. Robustness check: similar results in large and small cities.

Estimation	**Total Sample**	**"The Sample of Larger Cities"**	**"The Sample of Smaller Cities"**
hos	51.604 *** (3.299)	130.408 *** (6.301)	−4.415 (−0.222)
ln inc	−143.466 *** (−3.991)	−216.706 *** (−4.032)	−59.281 (−1.516)
in pod	−151.296 *** (−5.188)	−152.979 *** (−3.301)	−60.365 * (−1.702)
sep	−1.347 ** (−2.574)	−1.239 ** (−2.133)	−1.071 (−1.289)
d_post20	8.105 *** (4.540)	14.533 *** (7.346)	9.596 *** (2.924)
d_post21	−11.236 *** (−7.864)	−8.891 *** (−6.034)	−11.839 *** (−3.984)
d_post22	−8.622 *** (−5.389)	−9.469 *** (−7.507)	−2.801 (−0.720)
d_sup	−60.472 *** (−10.898)	−49.660 *** (−8.346)	−70.927 *** (−4.874)
d_sup d_post20	5.326 ** (2.047)	5.592 (1.627)	0.634 (0.155)
d_sup d_post21	8.885 *** (4.610)	5.549 *** (2.832)	8.644 ** (2.468)
d_sup d_post22	0.985 (0.478)	1.723 (0.921)	−4.428 (−1.027)
Adjusted R−squared	0.900	0.909	0.901
Fixed Effect (cities)	Yes	Yes	Yes
Number of cities	770	385	385
Observations	7689	3850	3839

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

Table 6. Dynamic panel data estimation: the dynamic term is insignificant.

was (−1)	−0.038 (−1.011)	−0.047 (−1.127)
was (−2)		−0.050 * (−1.807)
hos	−123.669 *** (−2.945)	−95.777 ** (−2.228)
ln inc	−44.848 (−0.716)	−6.221 (−0.101)
in pod	−11.812 (−0.201)	−12.448 (−0.215)
sep	−56.062 *** (−6.566)	−56.271 *** (−6.395)
d_post20	9.427 ** (2.267)	12.432 *** (3.074)
d_post21	−12.626 *** (−3.590)	−12.672 *** (−3.566)
d_post22	−10.408 *** (−3.367)	−10.290 *** (−3.267)
d_sup	−243.773 * (−1.770)	−242.919 * (−1.696)
d_sup d_post20	0.140 (0.029)	−1.887 (−0.392)
d_sup d_post21	1.636 (0.408)	1.630 (0.403)
d_sup d_post22	−0.016 (−0.004)	0.661 (0.174)

Table 6. *Cont.*

d_ttp	−332.648	−218.382
	(−0.396)	(−0.355)
d_ttp d_post20	−71.065 *	−74.424 *
	(−1.758)	(−1.822)
d_ttp d_post21	0.784	1.771
	(0.148)	(0.333)
d_ttp d_post22	−9.977	−16.290
	(−0.667)	(−1.069)
Number of cities	770	770
Observations	6149	5379

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

4. Conclusions

This study identifies the effectiveness of the unit-based pricing (UBP) system for household waste disposal, including simple unit pricing (SUP) and two-tiered pricing (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 even during the COVID-19 period; however, its effectiveness was slightly neutralized, owing to the pandemic environment. Second, TTP also restrained household waste efficiently; however, its effect was smaller than that of SUP, and its reduction effect accelerated during the COVID-19 period (in 2020) because 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. For that purpose, central and local governments should reinforce the policy instruments to improve public awareness on the need to reduce household waste and the significance of the UBP system, and to provide financial incentives for municipalities that intend to adopt the UBP system. Another implication of this study is the solid efficacy of the UBP system even during pandemic times. This lesson will be able to be applied to other public health emergencies, so that there will be no need to change this system for waste reduction in emergency response planning.

This study has several limitations and scope for further research. First, the study should expand on the policy implications by comparing with other regions/countries that have implemented similar UBP systems. It contributes to providing the implications on whether the research results in Japan's UBP system can be generalized to other UBP adopters. Second, 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. Third, 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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