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Does Unit-Based Pricing Really Reduce Waste? A Causal Inference Approach with Panel Data

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Abstract

Preventing waste generation is the first priority of waste management policies in many countries. In this paper, we examine the effect of unit-based pricing policy using a causal inference approach. Although previous research has examined the impact of unit-based pricing, few studies implement a causal inference framework. We apply the approach called "Weighted Fixed Effects Regression Models for Causal Inference" developed by Imai and Kim (2016, 2019) and find that the effect of unit-based pricing is overestimated by standard linear fixed effects models. We also find evidence that the effect of unit-based pricing is not strictly increasing in the price of waste collection.

1 Introduction

1.1 Motivation

The substantial increase in the amount of municipal solid waste (MSW) is one of the most severe environmental issues in the world. Kaza et al. (2019) shows that, in 2016, approximately 2.01 billion tons of MSW was generated throughout the world, and the amount is projected to increase to 3.40 billion tons by 2050. Rapid growth of the amount of waste not only deteriorates environmental quality or our health but also worsens the financial condition of municipalities who have responsibility for disposing MSW. In fact, a substantial amount of taxes are used for waste disposal every year, and this situation reduces municipalities'

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resources for other important services, such as education, welfare services, and employment measures.[1]

An extensive number of municipalities in many areas of the world have introduced a unit-based pricing system that requires residents to pay a fee for waste collection to address the problem of the increasing MSW. This pricing system has become one of the most widespread policies for MSW reduction, and several empirical studies have been conducted to assess the effectiveness. However, assessment of the causal effect of unit-based pricing faces several problems, such as omitted variables, similar to prior research on the effects of other policies.

In this study, we apply the weighted fixed effects approach developed by Imai and Kim (2016, 2019) to reexamine the effect of the unit-based pricing system on waste generation. This approach has desirable properties for assessing causal inference with panel data compared with the typical linear fixed effects model, which has been widely used in recent studies of unit-based pricing. In particular, in contrast to the standard linear fixed effects model, this approach can consistently estimate the causal effect even if the data comprise records of more than two periods; additionally, the method does not require the assumption of linearity. Moreover, the definition of the counterfactual outcome, the key factor for conducting causal inference, in the weighted fixed effects model is intuitively easier to understand than that in the linear fixed effects model (Imai and Kim (2019)).

This study also relaxes the implicit assumption that the waste reduction effect of unit-based pricing strictly increases as the price of waste collection increases. This assumption has been used by most studies on unit-based pricing. Although plausible, this assumption is not always true. For instance, unit-based pricing may have no effect on waste reduction when the

[1] See Kaza et al. (2019) for details.

price per unit of waste collection is relatively low, while pricing may have significant effect when the price per unit is sufficiently high. In this scenario, the effect of unit-based pricing is no longer strictly increasing as the price of the waste collection increases. We relax this assumption by applying several types of treatment groups depending on the level of the price introduced by the unit-based pricing policy.

Our analysis is based on panel data provided by the Japanese Ministry of the Environment that include longitudinal and precise data on MSW at the municipality level in Japan. To the best of our knowledge, this is the first study that examines the effect of unit-based pricing policy by applying a causal inference approach that is specifically designed for panel data and conducts causal inference on the effect of unit pricing policy by allowing for nonlinearity and a nonstrictly increasing relation between the effect of unit-based pricing and the price of waste collection imposed by the policy.

1.2 Literature review

Major progress has been made in the study of unit-based pricing since the late 1970s. Wertz (1976) conducted one of the pioneering studies in this field. He focused on San Francisco's unit-based pricing policy and estimated the price elasticity of garbage collection as -0.15. Although many subsequent studies have been published, such as Ferrara and Missios (2005), estimation bias induced by the omitted variable problem remains one of the most considerable issues to address.

To address this issue, some studies, such as Kinnaman and Fullerton (2000) and Huang et al. (2011), have applied instrumental variable methods. Another approach is to construct panel data and to use the linear fixed effects model to capture unobserved time-invariant characteristics. For example, Dijkgraaf and Gradus (2004, 2009) examined the effect of unit-based pricing policy by applying the linear fixed effects model to province-level panel data. Allers and Hoeben (2010) introduced the difference-in-differences approach to analyze unit-based pricing and examined its effect using a two-way linear fixed effects model that includes both unit fixed effects and time fixed effects. Usui and Takeuchi (2014) applied the two-way linear fixed effects model, focusing on the long-run effect of unit-based pricing. The linear fixed effects model is widely used to estimate the causal effect of policy interventions; however, the model cannot properly estimate the causal effect if the data are from more than two periods[2]. As most panel data analyses conducted in this field are based on multiperiod data, the results of previous studies unavoidably contain some bias. Moreover, this approach crucially depends on the linearity assumption, which is difficult to justify.

Other methods can be used to address the issue of unobserved variables. Valente and Bueno (2019) analyzed the introduction of unit-based pricing in Trento, Italy and applied a synthetic control method that accounts for time-varying effects of unobserved characteristics. In a sense, Valente and Bueno (2019) and our study both aim to improve ordinary fixed effects models. However, the former focused on capturing the time-varying effects of unobserved characteristics, whereas our research focuses on relaxing the linearity assumption and considering the proper definition of the counterfactual outcome.

The rest of this paper is organized as follows. Section 2 presents the status of MSW disposal in Japan, and section 3 explains the data. In section 4, we describe the econometric model. Then, section 5 presents the estimation results. Finally, section 6 provides our conclusions and suggestions for future research.

[2]See Imai and Kim (2016,2019) for details.

2 MSW Disposal in Japan

In Japan, waste management is controlled by the Waste Management and Public Cleansing Act. According to the Act, waste is roughly categorized into two kinds, general waste and industrial waste, depending upon who generates the waste and the type of waste. The Act defines industrial waste as the twenty types of waste discharged from specific business activities and general waste as waste that is not industrial waste. Moreover, general waste is divided into household waste and business waste. Because the goal of the unit-based pricing policy in Japan is reduction of household waste, we focus on household waste.

Each of the more than 1,700 municipalities in Japan is responsible for proper treatment of the household waste generated within its jurisdiction. The only exception is recycling, which is governed by a series of acts from the 2000s that cover six types of waste (automobiles, home appliances, containers and packaging, food waste, construction waste, and small electric products). For example, if a resident of a municipality stops using a car, the manufacturer, not the municipality, is responsible for its proper disposal.

Although the central government (the Japanese Ministry of the Environment) provides some subsidies, especially when a municipality builds a facility such as an incinerator, most of the waste management policies (with the exception of the above) are determined by each municipality independently. Therefore, a wide range of policies exist among municipalities.

////// Insert Figure 1 around here //////

Figure 1 shows histograms of the yearly waste generation per capita among municipalities in 2015, including information on unit-based pricing. One might assume that changing the relative price of waste disposal affects household behavior; however, the introduction of unit-based pricing does not appear to affect either waste generation or the recycling rate. Should we conclude that there is no response to unit pricing in Japan? Figure 1 provides a snapshot of waste generation. To answer this question, we must investigate the changes in waste generation in each municipality over time, which requires a panel data set and proper handling of the timing of policy intervention.

3 Data

Since 1998, the Japanese Ministry of the Environment has provided a database on MSW at the municipality level called the "State of Discharge and Treatment of Municipal Solid Waste". We can use this database to develop municipality-level panel data on MSW for approximately 20 years. However, in Japan, a boom of municipal mergers occurred from the mid-1990s to mid-2000s. Such municipal mergers cause an attrition problem that weakens the reliability of panel data analysis. Thus, we restrict our focus to data from 2005 to 2015, when the number of municipal mergers is relatively low.[3] Figure 2 shows the number of municipalities listed for each year in the State of Discharge and Treatment of Municipal Solid Waste database[4]. In this analysis, we exclude data from municipalities that experienced mergers during 2005–2015.

////// Insert Figure 2 around here //////

Although the categories of MSW differ among Japanese municipalities, the category of burnable waste is used most widely. In addition, the amount of discharged burnable waste is the largest among the categories of MSW. For instance, according to the State of Discharge and Treatment of Municipal Solid Waste, in 2015, the total amount of burnable waste for

[3] The year 2015 is the latest year for which data are available at the time of writing this paper.
[4] http://www.env.go.jp/recycle/waste_tech/ippan/index.html

all municipalities was 19,730,444 tons; that of mixed waste, the second largest category, was 1,719,203 tons; and that of unburnable waste, the third largest category, was 1,027,363 tons. Therefore, in this analysis, we select the amount of burnable waste per person per year as the outcome variable and use unit-based pricing for burnable waste as the treatment variable. Moreover, we omit municipalities that do not include burnable waste as a category.

The data on unit-based pricing are taken from Yamaya (2018) because the State of Discharge and Treatment of Municipal Solid Waste database does not provide such information. However, Yamaya (2018) presented precise data on unit-based pricing, including the year when the municipalities started the unit-based pricing system, only for cities[5]. Therefore, we restrict our focus to cities and develop a city-level panel dataset covering the years from 2005 to 2015.

The unit-based pricing system in Japan takes several forms. Two primary types of fee systems exist: (1) fees based on the amount of discharged MSW and (2) fees for the amount of waste exceeding a specified amount that can be discharged with no fee. In the former case, residents have to pay for garbage bags designed by the municipality or purchase a sticker that must be attached to the garbage bag. In the latter case, residents can discharge a given amount of waste for free: if they want to discharge more than the allowed amount, they are required to pay for the additional garbage bag, similar to the previous case. Since only a small number of cities apply the latter system, we focus on the former. In fact, the former type is used by 442 cities, while the latter is used by 25 cities[6]. In addition, although three sizes of garbage bags—small, medium, and large—are used, we consider only the price per

[5]To the best of our knowledge, Yamaya (2018) is the only study to collect data on unit-based pricing on a national level in Japan.

[6]See Yamaya (2018) for details.

large-sized bag, in line with Usui and Takeuchi (2014).

To estimate the effect of unit-based pricing on residents' recycling activity, we also use six types of recyclable waste as outcome variables: paper, metal, glass, polyethylene terephthalate bottles (PET bottles), plastic, and cloth. These data are obtained from the State of Discharge and Treatment of Municipal Solid Waste database. In the analysis, we calculate the percentage of discharged waste accounted for by each recyclable.

For the time-varying confounders, we include five variables: per capita income (`inc`), population density (`dens`), ratio of persons aged 65 years or over (`old`), average number of persons per family (`family`), and cultivated acreage per person (`culti`). These variables are used widely in previous studies on unit-based pricing. In addition, to capture the type of MSW collection in each city, we develop a dummy variable that takes a value of 1 if the city adopts a door-to-door collection system and 0 otherwise (`collec`). We compile the data on the collection system of each city from the State of Discharge and Treatment of Municipal Solid Waste database. Data on population and the number of persons aged 65 years or over are from the *Basic Resident Register System of Japan*[7], and the remaining data are from the *Regional Statistics Database* provided by Japanese Government Statistics[8].

////// Insert Table 1 around here //////

Table 1 shows the summary statistics for all variables used in the econometric analysis. In estimating the effect of unit-based pricing on the amount of burnable waste, we use the

[7]To equalize the date when the data were collected as much as possible, we take a one-year lead for population density, ratio of persons aged 65 years or over, and number of persons per family in the econometric analysis. In fact, family size and the population by age group are from the data as of March 31 in each year t, while the other variables used in the analysis are from the data of each Japanese fiscal year t running from April 1 in year t to March 31 in year $t + 1$. Thus, taking a one-year lead for family size and the population by age group, rather than using the original data, reduces the gap between the data collection periods of the explanatory variables.

[8]https://www.stat.go.jp/data/s-sugata/naiyou.html#toukei1

natural logarithm of the outcome variable (`bwaste`).

4 Econometric Model

We believe economic incentives contribute to decreasing waste generation from households when they are well-designed. Our motivation in this paper is to estimate the causal effect of unit-based pricing on waste generation as precisely as possible. For that purpose, we introduce a newly developed estimation method.

4.1 Weighted fixed effects model

The standard two-way linear fixed effects model can be written as follows:

$$Y_{it} = \alpha + \upsilon_i + \tau_t + \beta X_{it} + \gamma \mathbf{Z_{it}} + \epsilon_{it}, \tag{1}$$

where Y_{it} denotes the outcome variable of unit i in period t, α is a constant term, υ_i is a unit fixed effect, τ_t is a time fixed effect, X_{it} is an indicator variable that takes a value of 1 if unit i is treated in period t and 0 otherwise, $\mathbf{Z_{it}}$ is the vector of time-variant confounders, and ϵ_{it} implies an error term. This model is used widely in studies on policy assessment because it can provide the difference-in-differences (DiD) estimator. However, the equality of the DiD estimator and the two-way linear fixed effects estimator is valid only when the data consist of two periods and the unit receives treatment in the second period only. However, in many cases, panel data consist of more than two periods. In fact, according to Imai and Kim (2016), the two-way linear fixed effects estimator is equivalent to the following estimator:[9]

$$\hat{\beta}^{FE} \equiv \frac{1}{K} \left\{ \frac{1}{NT} \sum_{i}^{N} \sum_{t}^{T} \left(\hat{Y_{it}}^{FE}(1) - \hat{Y_{it}}^{FE}(0) \right) \right\} \tag{2}$$

[9]For details, see proposition 4 of Imai and Kim (2016).

where N is the number of units, T is the number of periods, and for $x = 0, 1$

$$\hat{Y_{it}}^{FE}(x) = \begin{cases} Y_{it} & \text{if } \; X_{it} = x, \\ \underbrace{\frac{1}{T-1}\sum_{t' \neq t} Y_{it'}}_{\text{(i)}} + \underbrace{\frac{1}{N-1}\sum_{i' \neq i} Y_{i't}}_{\text{(ii)}} - \underbrace{\frac{1}{(T-1)(N-1)}\sum_{i' \neq i}\sum_{t' \neq t} Y_{i't'}}_{\text{(iii)}} & \text{if } \; X_{it} = 1 - x. \end{cases} \tag{3}$$

and

$$K \equiv \frac{1}{NT}\sum_{i=1}^{N}\sum_{t=1}^{T}\left\{X_{it}\left(\frac{\sum_{t' \neq t}(1 - X_{it'})}{T-1} + \frac{\sum_{i' \neq i}(1 - X_{i't})}{N-1} - \frac{\sum_{i' \neq i}\sum_{t' \neq t}(1 - X_{i't'})}{(T-1)(N-1)}\right)\right.$$
$$\left. + (1 - X_{it})\left(\frac{\sum_{t' \neq t} X_{it'}}{T-1} + \frac{\sum_{i' \neq i} X_{i't}}{N-1} - \frac{\sum_{i' \neq i}\sum_{t' \neq t} X_{i't'}}{(T-1)(N-1)}\right)\right\}.$$

We interpret the definition of the counterfactual outcome shown in (3) by considering the situation in which municipality i introduces unit-based pricing at time t. As shown in the second line of (3), the counterfactual outcome for the treated unit i at time t calculated by the two-way fixed effects model consists of three components:

(i) the average of unit i's outcome for all periods except time t,

(ii) the average of all units' outcome at time t except unit i and

(iii) the average outcome for all units except i for all periods except t.

Thus, the counterfactual in the two-way linear fixed effects model uses the data of all the other observations except unit i at time t. This fact implies that in the two-way linear fixed effects model, not only the data of observations in the control group but also those in the treated group may be used to calculate the counterfactual outcome for the treated unit. Therefore, it is difficult to interpret the two-way linear fixed effects estimator as representing a causal effect of the treatment. To remedy this bias, the two-way linear fixed effects model uses

K, the proportion of properly matched observations for which the counterfactual outcome is calculated by using the observations with the opposite treatment status. However, as shown by Imai and Kim (2016), this adjustment is not sufficient to yield a consistent average treatment effect (ATE) estimator. In addition, the two-way linear fixed effects model relies heavily on the assumption of linearity.

Thus, in this study, we apply the weighted fixed effects model developed by Imai and Kim (2016, 2019) to estimate the causal effect of unit pricing on the amount of MSW. This approach is superior to the two-way linear fixed effects model because it can relax the linearity assumption. In addition, a multiperiod DiD estimator can be obtained even if the data comprise more than two periods.

Suppose we are interested in estimating a causal effect from data that contain N units and T periods[10]. First, the weighted fixed effects model applies three types of matched sets, defined as follows:

$$\mathcal{M}_{it}^{\mathrm{DiD}} = \{(i', t') : i' = i, t' = t - 1, X_{i't'} = 0\}, \tag{4}$$

$$\mathcal{N}_{it}^{\mathrm{DiD}} = \{(i', t') : i' \neq i, t' = t, X_{i't'} = X_{i't'-1} = 0\}, \tag{5}$$

$$\mathcal{A}_{it}^{\mathrm{DiD}} = \{(i', t') : i' \neq i, t' = t - 1, X_{i't'} = X_{i't} = 0\}. \tag{6}$$

$\mathcal{M}_{it}^{\mathrm{DiD}}$ refers to the set that consists of observations of unit i in the previous period if it does not receive treatment in the present period. $\mathcal{N}_{it}^{\mathrm{DiD}}$ consists of observations other than those of unit i in the present period that do not receive treatment in either the previous or present period. $\mathcal{A}_{it}^{\mathrm{DiD}}$ is the set that consists of observations other than those of unit i in the previous period that do not receive treatment in either the previous or present period.

[10]For simplicity, we omit the time-variant confounders.

By using the definition of the three sets shown above, a multiperiod DiD estimator can be defined as follows:

$$\hat{\tau}_{DiD} = \frac{1}{\sum_{i=1}^{N}\sum_{t=1}^{T} D_{it}} \sum_{i=1}^{N}\sum_{t=1}^{T} D_{it}(\hat{Y}_{it}(1) - \hat{Y}_{it}(0)). \tag{7}$$

This estimator captures the ATE. In the above equation, D_{it} takes a value of 1 if unit i in period t belongs to the treated group and both $\mathcal{M}_{it}^{DiD}$ and $\mathcal{N}_{it}^{DiD}$ contain at least one observation and 0 otherwise:

$$D_{it} = X_{it}1\{\#\mathcal{M}_{it}^{DiD}\#\mathcal{N}_{it}^{DiD} > 0\}, \tag{8}$$

where $\#\mathcal{M}_{it}^{DiD}$ and $\#\mathcal{N}_{it}^{DiD}$ represent the number of observations contained in $\mathcal{M}_{it}^{DiD}$ and $\mathcal{N}_{it}^{DiD}$, respectively. In addition, $\hat{Y}_{it}(x)$ is defined as follows:

$$\hat{Y}_{it}(x) = \begin{cases} Y_{it} & \text{if } \ x = 1, \\ \underbrace{Y_{it-1}}_{\text{(i)}} + \underbrace{\frac{\sum_{(i',t)\in\mathcal{N}_{it}^{DiD}} Y_{i't}}{\#\mathcal{N}_{it}^{DiD}}}_{\text{(ii)}} - \underbrace{\frac{\sum_{(i',t')\in\mathcal{A}_{it}^{DiD}} Y_{i't'}}{\#\mathcal{A}_{it}^{DiD}}}_{\text{(iii)}} & \text{if } \ x = 0. \end{cases} \tag{9}$$

The key to conducting causal inference is precise estimation of the counterfactual. However, as noted above, for panel data from more than two periods, the definition of the counterfactual used in the normal two-way linear fixed effects model lacks a reasonable explanation. On the other hand, as shown in (9), the weighted fixed effects model defines unit i's counterfactual output in a much clearer way[11].

(i) the waste of municipality i in the period just before introducing unit-based pricing, $t-1$,

[11] The weighted fixed effects model defines the unit i's counterfactual output in period t as the total of unit i's output in one period before it receives the treatment, period $t-1$, and the average of the differences between the output in the present period and that in the previous period of all but unit i with receiving no treatment in both periods.

(ii) the average amount of discharged waste at time t for municipalities that do not introduce unit-based pricing at time t and $t-1$ and

(iii) the average amount of waste in period $t-1$ for all municipalities in which unit-based pricing is not introduced at both $t-1$ and t.

Imai and Kim (2016) show that, under certain conditions, the multiperiod DiD estimator defined as (7) is equivalent to the following weighted two-way linear fixed effects model estimator[12]:

$$\hat{\beta}_{DiD} = \arg\min_{\beta} \sum_{i=1}^{N} \sum_{t=1}^{T} W_{it}\{(Y_{it} - \bar{Y}_i^* - \bar{Y}_t^* + \bar{Y}^*) - \beta(X_{it} - \bar{X}_i^* - \bar{X}_t^* + \bar{X}^*)\}^2, \tag{10}$$

where $\bar{X}_i^* = \frac{\sum_{t=1}^{T} W_{it} X_{it}}{\sum_{t=1}^{T} W_{it}}$; $\bar{X}_t^* = \frac{\sum_{n=1}^{N} W_{it} X_{it}}{\sum_{n=1}^{N} W_{it}}$; $\bar{X}^* = \frac{\sum_{n=1}^{N}\sum_{t=1}^{T} W_{it} X_{it}}{\sum_{n=1}^{N}\sum_{t=1}^{T} W_{it}}$; $\bar{Y}_i^* = \frac{\sum_{t=1}^{T} W_{it} Y_{it}}{\sum_{t=1}^{T} W_{it}}$; $\bar{Y}_t^* = \frac{\sum_{n=1}^{N} W_{it} Y_{it}}{\sum_{n=1}^{T} W_{it}}$; $\bar{Y}^* = \frac{\sum_{n=1}^{N}\sum_{t=1}^{T} W_{it} Y_{it}}{\sum_{n=1}^{N}\sum_{t=1}^{T} W_{it}}$; and the weight, W_{it}, is defined as follows:

$$W_{it} = \sum_{i'=1}^{N} \sum_{t'=1}^{T} D_{i't'} w_{it}^{i't'} = \begin{cases} 1 & \text{if } (i,t) = (i',t'), \\ \frac{1}{\#\mathcal{M}_{i't'}^{\text{DiD}}} & \text{if } (i,t) \in \mathcal{M}_{i't'}^{\text{DiD}}, \\ \frac{1}{\#\mathcal{N}_{i't'}^{\text{DiD}}} & \text{if } (i,t) \in \mathcal{N}_{i't'}^{\text{DiD}}, \\ \frac{(2X_{it}-1)(2X_{i't'}-1)}{\#\mathcal{A}_{it}^{\text{DiD}}} & \text{if } (i,t) \in \mathcal{A}_{i't'}^{\text{DiD}} \text{and} \\ 0 & \text{otherwise.} \end{cases}$$

In this study, we use (10) to estimate the effect of unit pricing on MSW discharge[13]. Thus, we eliminate any bias caused by misspecification of the linear assumption and the mixture of the treatment status in the case of more than two periods.

[12]See Theorem 2 in Imai and Kim (2016) for details.

[13]The actual estimation was done using the `wfe` package in `R`. For more information, please see https://cran.r-project.org/web/packages/wfe/index.html

4.2 Treatment variable

As shown in Table 1, the price of garbage bags differs among municipalities. To equalize the treatment status of observations in the treatment group as much as possible, we classify treatment groups into several types based on the price of garbage bags. In particular, we define the treatment variable as shown in Table 2.

////// Insert Table 2 around here //////

For example, under the definition of X_1, cities where the price of a municipality-designed garbage bag for burnable waste is set as more than 0 yen but less than or equal to 10 yen are defined as the treated group.[14] The other cities, excluding those that set the garbage bag price as more than 10 yen, are defined as the control group. Since only six cities set the price of a garbage bag strictly higher than 80 yen, we do not set an upper limit for X_8 and X'_4. In contrast to standard estimation methods that directly use the price of a garbage bag as an explanatory variable, using X_i or X'_i relaxes the assumption that the amount of discharged waste strictly increases or decreases as the price of garbage bags increases.

We have to control for the timing of the introduction of unit-based pricing to estimate the effect of the treatment precisely. For instance, introducing unit-based pricing at some time near the end of the year would have little effect on the amount of waste discharged in that year. To address problem, we consider a one-year lag of the treatment variable in our estimation.

[14] 10 Japanese yen is approximately equal to 9 US cents as of July 31, 2019.

5 Estimation Results

5.1 The full model

Table 3 shows the results of the estimation with each treatment variable defined in Table 2. The column titled "Treatment" defines the treatment used in each estimation. For instance, the second row shows the estimation results of models with the treatment variable defined as the treatment group cities where the price of a garbage bag is more than 0 yen but less than or equal to 10 yen; other cities, excluding those that set the price of garbage bag as more than 10 yen, are the control group. The second column titled "N of UBP" indicates the number of cities that belong to the treatment group for at least one year between 2005 and 2015. The "FE" column shows the coefficient of the treatment variable estimated using a standard two-way linear fixed effects model, β; the "WFE" column shows the estimation results of the average treatment effect, τ^{DiD}, as defined in (7), by the weighted fixed effects model. The numbers in parentheses are the heteroskedasticity-robust standard errors.

////// Insert Table 3 around here //////

First, we focus on the results of the models with X_i. The results show that, in the case of the two-way linear fixed effects model, the sign of ATE is negative and statistically significant when the price per bag is higher than 30 yen. By contrast, in the weighted fixed effects model, the coefficients are not statistically significant in all cases. This result raises a question about the effectiveness of unit-based pricing.

In the case of the models with X_i, large variation is observed in the number of treated units among models, and this variation may affect the estimation results. In fact, the models with X_1 and X_7 have only 6 and 11 treated units, respectively. Therefore, we focus on models with X_i', which defines the treatment variable by dividing the price range per 20 yen, and the variation between the number of treated unit among models is smaller than those with X_i. However, even in this case, the results of weighted fixed models with X_i' show that unit-based pricing has no statistically significant effect on the amount of waste discharge.

5.2 The case without prefectures hit by huge earthquakes

Two large earthquakes that occurred in Japan will cause inevitable bias in the results of our analysis. One is Niigata Chuetsu Earthquake, which hit mainly Niigata prefecture in October, 2004. Although the earthquake occurred one year before 2005, which is the first year of our data, it significantly affected the amount of waste discharge in 2005 and beyond. In fact, in the case of Ojiya city, one of the most affected areas, the amount of waste discharge per capita in 2005 is approximately ten times higher than the city-level national average in that year. The other is the Great East Japan Earthquake, which hit eastern Japan in March, 2011. In this case, in addition to the shaking, a tsunami caused by the earth quake inflicted immense damage on human lives and provoked great confusion in social infrastructure, such as waste management systems.

These two earthquakes registered an intensity of 7, the maximum intensity, on the Japanese scale of 0 to 7[15]. To exclude the effects of these earthquakes, we redefine the data. In particular, we remove the cities in Niigata prefecture to exclude the effect of the Niigata Chuetsu Earthquake and those in three disaster-stricken prefectures, namely, Iwate prefecture, Miyagi prefecture, and Fukushima prefecture, to exclude the effect of the Great East Japan Earth-

[15]Japan has experienced 4 earthquakes with a seismic intensity of 7 since 2000: Niigata Chuetsu Earthquake in 2004, Great East Japan Earthquake in 2011, Kumamoto Earthquake in 2016, and Hokkaido Eastern Iburi Earthquake in 2018.

quake[16]. Table 4 shows the results of the estimation of ATE after excluding the data of cities in the areas affected by the large earthquakes.

////// Insert Table 4 around here //////

The results of the models with X_i are the same as those in the case of the full data shown in Table 3, except for the result of the WFE model with X_8. Although not statistically significant at the 5% level, the result provides some evidence that unit-based pricing has a negative effect on the amount of waste discharge when the price per bag is greater than 70 yen. In the case of models with X_i', the results of the models with X_i' estimated by the weighted fixed effects model show that the amount of waste discharge decreases when the price per bag is sufficiently high (higher than 60 yen).

Residents may decide the amount of waste reduction by comparing the benefit of waste reduction, that is, avoiding the payment of the disposal fee, with the cost, such as the effort required to reduce waste. Thus, if the price of a garbage bag is low, the cost of waste reduction outweighs the benefit and unit-based pricing does not affect the amount of waste discharge.

The above results also illustrate the difference between the two estimation methods: the two-way linear fixed effects model and the weighted fixed effects model. The two-way linear fixed effects model tends to overestimate the waste reduction effect of unit-based pricing compared to the weighted fixed effects model. In particular, the two-way linear fixed effects model indicates that unit-based pricing reduces the amount of waste discharge when the price per bag is higher than 30 yen in the models with X_i and higher than 20 yen in the models with X_i'. By contrast, the weighted fixed effects model shows a reduction in the amount of waste

[16]The term "three disaster-stricken prefectures" is widely used in Japan to indicate the prefectures where the number of deaths caused by the Great East Japan Earthquake exceeded 1,000.

discharge only when the price per bag is higher than 60 yen. In addition, the magnitude of the ATE estimated in the two-way linear fixed effects model is far more excessive than that in the weighted fixed effects model. These results show that the assumption of linearity and the definition of the counterfactual outcome used in the two-way linear fixed effects model affects the result of the estimation and may lead to ineffective use of unit-based pricing.

////// Insert Figure 3 around here //////

The reason the weighted fixed effects model has a tendency to yield smaller estimates is worth considering. One of the main differences between the two-way fixed effects estimator and the weighted fixed effects estimator is the definition of the counterfactual outcome. Specifically, the former estimator uses the data of both treated and untreated observations to calculate the counterfactual outcome of the treated unit, whereas the latter estimator uses only the data of untreated observations. As shown by (3) and (9), the counterfactual outcome calculated by the two-way fixed effects model $\hat{Y}_{it}^{FE}(0)$ and the counterfactual outcome calculated by the weighted fixed effects model $\hat{Y}_{it}(0)$ both include three components. For the purpose of explanation, we consider a situation where municipality i introduces unit-based pricing at time t and compare the difference in each component of the two estimators.

We begin by focusing on the first component (i) in both (3) and (9). In the case of $\hat{Y}_{it}(0)$, this component represents the amount of waste in municipality i in the period just before the introduction of unit-based pricing, $t-1$. On the other hand, in the case of $\hat{Y}_{it}^{FE}(0)$, the first component is the average of municipality i's discharged waste for all periods except period t during which the unit-based pricing policy is enforced by the municipality. If unit-based pricing reduces the amount of discharged waste, then, in general, the amount of discharged waste in municipalities that have introduced unit-based pricing will be smaller than that in the municipalities without this policy. Thus, if municipality i has maintained unit-based pricing for a long time after time t, the number of observations (which is used in the calculation of the first component of $\hat{Y}_{it}^{FE}(0)$) under the condition that unit-based pricing is conducted by the municipality increases, and the first component of $\hat{Y}_{it}^{FE}(0)$ will be smaller than that of $\hat{Y}_{it}(0)$. Since the first components of $\hat{Y}_{it}^{FE}(0)$ and $\hat{Y}_{it}(0)$ have a positive effect on the total value of $\hat{Y}_{it}^{FE}(0)$ and $\hat{Y}_{it}(0)$, the difference in the definition of the first component of each counterfactual outcome will make the waste reduction effect of unit-based pricing estimated by the two-way fixed effects model much smaller than that estimated by the weighted fixed effects model.

Next, the second component of $\hat{Y}_{it}(0)$ is the average amount of discharged waste at time t for municipalities that do not introduce unit-based pricing at time t or $t-1$. By contrast, the second component of $\hat{Y}_{it}^{FE}(0)$ is the average amount of discharged waste at time t for all municipalities except municipality i. If unit-based pricing reduces the amount of discharged waste, the second component of $\hat{Y}_{it}^{FE}(0)$ will be smaller than that of $\hat{Y}_{it}(0)$ because $\hat{Y}_{it}^{FE}(0)$ uses the waste discharge data of municipalities with unit-based pricing when calculating the counterfactual outcome. Since the second components of $\hat{Y}_{it}^{FE}(0)$ and $\hat{Y}_{it}(0)$ have a positive effect on the total value of $\hat{Y}_{it}^{FE}(0)$ and $\hat{Y}_{it}(0)$, respectively, the difference in the definition of the second component of the counterfactual outcome will make $\hat{Y}_{it}^{FE}(0)$ smaller than $\hat{Y}_{it}(0)$. Therefore, the waste reduction effect of unit-based pricing estimated by the two-way fixed effects model is much smaller than that estimated by the weighted fixed effects model.

Finally, we consider the third component. In the case of $\hat{Y}_{it}(0)$, this component is the average amount of waste in period $t-1$ for all municipalities where unit-based pricing is not introduced in either $t-1$ or t. By contrast, in the case of $\hat{Y}_{it}^{FE}(0)$, this component is the average amount of waste discharge for all municipalities except for municipality i and for all periods except for period t. The latter definition uses discharged waste data from municipalities that introduced unit-based pricing, whereas the former estimator does not include such data. Thus, if unit-based pricing reduces the amount of discharged waste, the third component of $\hat{Y}_{it}^{FE}(0)$ will be smaller than that of $\hat{Y}_{it}(0)$. Since the third components of $\hat{Y}_{it}^{FE}(0)$ and $\hat{Y}_{it}(0)$ have a negative effect on the total value of $\hat{Y}_{it}^{FE}(0)$, the difference in the definition of the third component between the two estimators will make $\hat{Y}_{it}^{FE}(0)$ larger than $\hat{Y}_{it}(0)$. Therefore, the waste reduction effect of unit-based pricing estimated by the two-way fixed effects model is much larger than that estimated by the weighted fixed effects model.

In summary, the above discussion yields the following result:

$$\begin{aligned}\hat{Y_{it}}(0)-\hat{Y_{it}}^{FE}(0) \quad &= \underbrace{\left[Y_{it-1}-\frac{1}{T-1}\sum_{t'\neq t}Y_{it'}\right]}_{\text{1st component }(+)}+\underbrace{\left[\frac{\sum_{(i',t)\in\mathcal{N}_{it}^{DiD}}Y_{i't}}{\#\mathcal{N}_{it}^{DiD}}-\frac{1}{N-1}\sum_{i'\neq i}Y_{i't}\right]}_{\text{2nd component }(+)}\\ &\quad-\underbrace{\left[\frac{\sum_{(i',t)\in\mathcal{A}_{it}^{DiD}}Y_{i't'}}{\#\mathcal{A}_{it}^{DiD}}-\frac{1}{(T-1)(N-1)}\sum_{i'\neq i}\sum_{t'\neq t}Y_{i't'}\right]}_{\text{3rd component }(+)}<0 \qquad (11)\end{aligned}$$

Ultimately, the relative sizes of the estimates depend on the specific distribution of the data. In our case, the effect that makes the two-way fixed effects estimator larger than the weighted fixed effects estimator surpasses the opposing effect, so the latter estimator is larger than the former.[17]

[17]The adjustment parameter, K, used in the calculation of the two-way fixed effects estimator also affects the relative size of the estimators.

5.3 The effect on recyclables

Now, we examine the effect of unit-based pricing on recycling behavior. Tables 5 shows the estimation results of the effect of unit-based pricing on the ratios of seven types of recyclables per burnable waste (total recyclables, paper, metal, glass, PET bottles, plastics, and cloth) with data excluding the cities in four disaster-stricken prefectures, as is the case with Table 4. The numbers in parentheses are the heteroskedasticity-robust standard errors. By focusing on the results of the weighted fixed effects model, we can see that the implementation of unit-based pricing has no effect on the ratios of metal, glass, PET bottles, plastics, and cloth; however, a statistically significant positive effect on paper recycling is observed. In fact, ATE is positive and statistically significant when the treatment variable is X_4'. These cases show that city residents increase their efforts to separate recyclable paper from burnable waste when they are faced with a unit-based pricing system with a sufficiently high garbage bag price. Since paper waste accounts for a substantial portion of the total amount of recyclables, we also observe this trend in the case of the total amount of recyclables.

////// Insert Table 5 around here //////

This finding is consistent with results of the analysis of burnable waste: residents in municipalities with sufficiently high garbage bag prices reduce their amount of burnable waste. This result implies that city residents who face high disposal fees attempt to reduce waste discharge by separating recyclable paper from burnable waste. Recycling activity puts some burden on residents in terms of time and effort. Moreover, residents may have a propensity to increase their effort to separate recyclables from waste when the benefit of avoiding paying disposal fees by reducing waste exceeds the cost of recycling. The benefit of reducing waste increases as the price of municipality-designed garbage bags increases. Thus, residents in a municipality with relatively expensive garbage bags increase their amount of recyclables and reduce waste discharge, whereas residents in a municipality with relatively inexpensive garbage bags do not exhibit such behavior.

6 Conclusion

In this study, we examined the causal effect of unit-based pricing policies using the weighted fixed effects model, which can provide more precise causal inference of the effect of the policy even in the case of data from more than two periods and allows the linearity assumption to be relaxed. The results of this study can be summarized as follows. First, the effect of unit-based pricing is overestimated when we use the conventional linear fixed effects model; therefore, the analysis of the effect of unit-based pricing crucially depends on the assumption of linearity and the definition of the counterfactual.

Although the estimated effect of unit-based pricing derived from the weighted fixed effects model is smaller than that from the two-way linear fixed effects model, the result of the weighted fixed effects model implies that unit-based pricing reduces the amount of discharged waste when the price is sufficiently high. Thus, unit-based pricing is effective for waste reduction, but no effect of unit-based pricing is observed when the price is relatively low. This finding suggests that there exists a threshold value for price, and the effect of unit-based pricing appears only when the price exceeds the threshold. This value is difficult for the model to determine using the price per garbage bag itself as a continuous explanatory variable, which is common in previous studies on this topic.

We also examined the effect of unit-based pricing on the recycling rate for several recyclables and found that the policy may increase the recycling rate of paper but has no significant effect on other recyclables. According to these observations, the unit-based pricing policy has some effect on promoting recycling, but the effect is limited.

Finally, we discuss the remaining issues requiring further study. The most important issue is the applicability of the results. Because of data limitations, we focused on the effect of unit-based pricing in the case of burnable waste. There are, of course, other types of waste, such as incombustible waste. Thus, whether the results of the present paper hold in the case of other types of waste must be examined. Additionally, the effect of the policy must be investigated using data from countries other than Japan. Addressing these issues will contribute to the design of more effective waste management policies.

A Figures

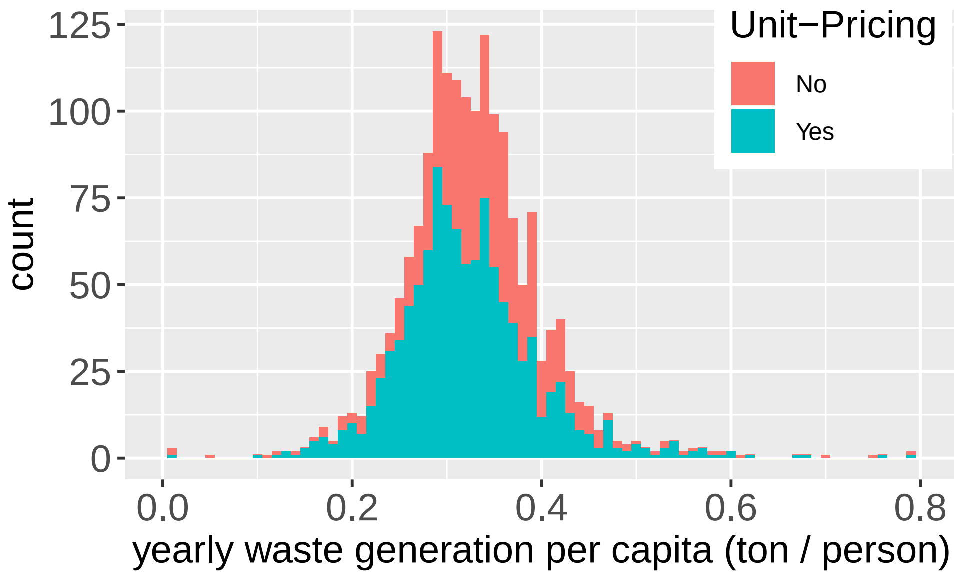

Figure 1: Range of waste generation per capita and recycling rate among municipalities
Source: http://www.env.go.jp/recycle/waste_tech/ippan/index.html

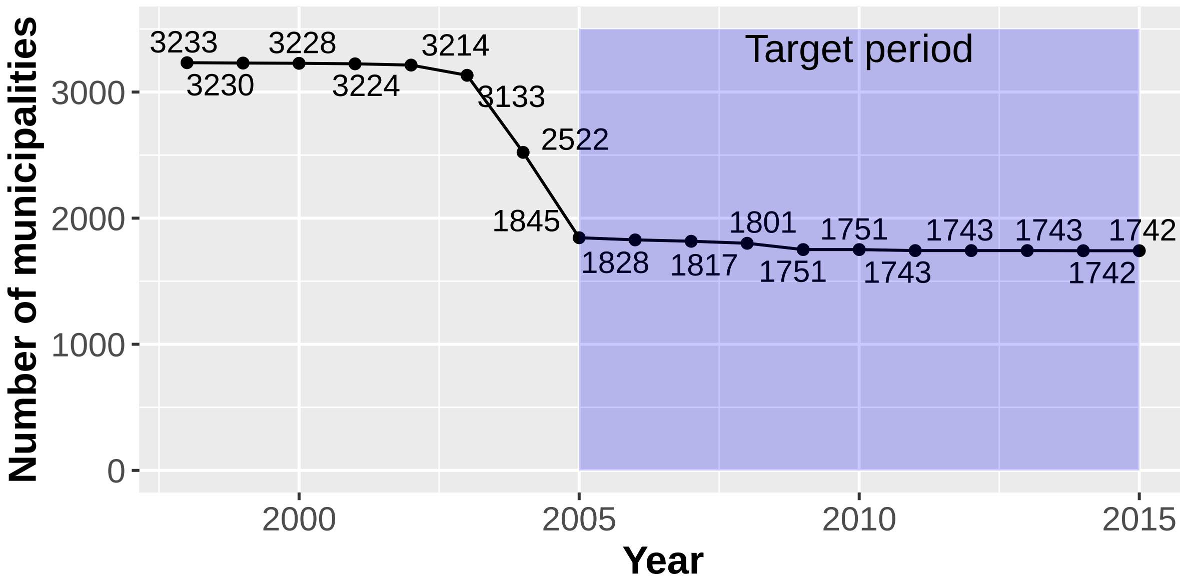

Figure 2: Change in number of municipalities

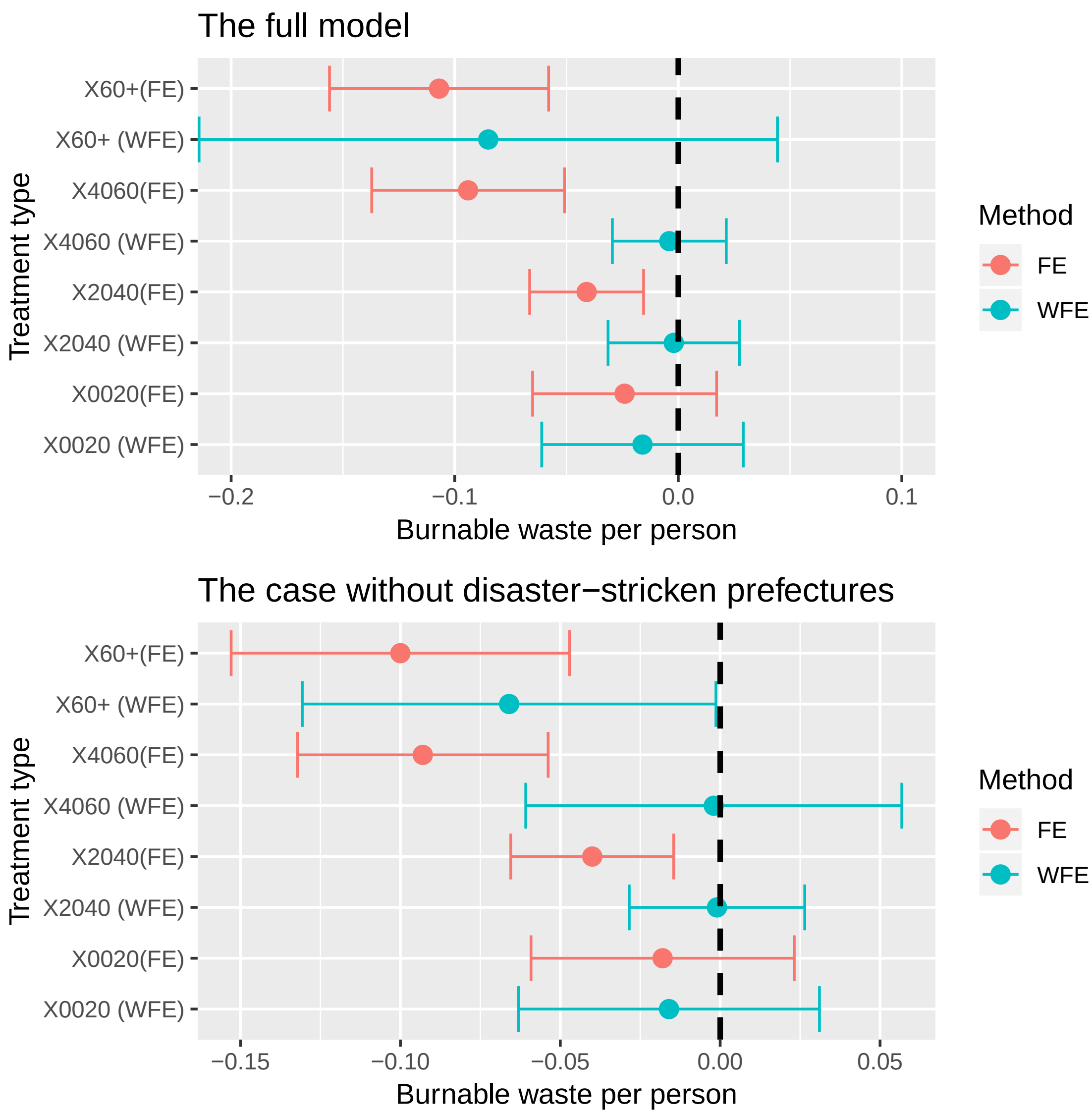

Figure 3: Estimation results (Full model (above) and the case without disaster-stricken prefectures (below)

B Tables

Table 1: Summary statistics

Variable	Unit	Mean	S.D.	Min	Max	N
Outcome variable						
`bwaste`	ton	0.23	0.05	0.09	2.32	8,195
`rec`	%	7.58	7.35	0.00	42.91	8,195
`paper`	%	7.00	6.75	0.00	38.62	8,195
`metal`	%	0.18	0.51	0.00	17.44	8,195
`glass`	%	0.13	0.44	0.00	15.55	8,195
`PET`	%	0.02	0.11	0.00	1.58	8,195
`pla`	%	0.01	0.08	0.00	2.43	8,195
`cloth`	%	0.21	0.60	0.00	40.77	8,195
Price per bag						
`price`	yen	21.5	25.07	0.00	120	8,195
Time-variant confounder						
`dens`	number/ha	14.71	23.80	0.12	142.7	8,195
`inc`	thousand yen	2,959	448	1,213	6,452	8,195
`old`	ratio	0.25	0.05	0.10	0.49	8,195
`family`	number	2.54	0.30	1.74	3.64	8,195
`collec`	dummy	0.07	0.26	0.00	1.00	8,195
`culti`	ha	0.05	0.07	0.00	0.83	8,195

Table 2: Definition of treatment variables

Variable	**Definition of treatment**	**Variable**	**Definition of treatment**
X_1	$0 <$ garbage bag price ≤ 10	X'_1	$0 <$ garbage bag price ≤ 20
X_2	$10 <$ garbage bag price ≤ 20	X'_2	$20 <$ garbage bag price ≤ 40
X_3	$20 <$ garbage bag price ≤ 30	X'_3	$40 <$ garbage bag price ≤ 60
X_4	$30 <$ garbage bag price ≤ 40	X'_4	$60 <$ garbage bag price
X_5	$40 <$ garbage bag price ≤ 50		
X_6	$50 <$ garbage bag price ≤ 60		
X_7	$60 <$ garbage bag price ≤ 70		
X_8	$70 <$ garbage bag price		

Table 3: Estimation results: Burnable waste per person

Treatment	N of UBP	FE			WFE	
X_1:$(0, 10]$	6	0.007	(0.024)		-0.013	(0.04)
X_2:$(10, 20]$	53	-0.031	(0.025)		-0.021	(0.124)
X_3:$(20, 30]$	95	-0.031	(0.017)	†	-0.015	(0.011)
X_4:$(30, 40]$	76	-0.052	(0.019)	**	0.008	(0.019)
X_5:$(40, 50]$	106	-0.092	(0.028)	***	-0.009	(0.013)
X_6:$(50, 60]$	28	-0.114	(0.037)	**	-0.001	(0.012)
X_7:$(60, 70]$	11	-0.120	(0.042)	**	-0.082	(0.052)
X_8:$(70, \infty]$	54	-0.103	(0.029)	***	-0.063	(0.038)
X'_1:$(0, 20]$	59	-0.024	(0.021)		-0.016	(0.023)
X'_2:$(20, 40]$	171	-0.041	(0.013)	**	-0.002	(0.015)
X'_3:$(40, 60]$	134	-0.094	(0.022)	***	-0.004	(0.013)
X'_4:$(60, \infty]$	65	-0.107	(0.025)	***	-0.085	(0.066)

$^{\dagger}p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4: Results without areas affected by huge earthquakes

Treatment	**N of UBP**	**FE**			**WFE**		
X_1:$(0, 10]$	6	0.011	(0.024)		-0.011	(0.035)	
X_2:$(10, 20]$	52	-0.025	(0.024)		-0.022	(0.126)	
X_3:$(20, 30]$	95	-0.028	(0.017)		-0.016	(0.012)	
X_4:$(30, 40]$	73	-0.053	(0.019)	**	0.011	(0.019)	
X_5:$(40, 50]$	92	-0.087	(0.025)	***	-0.018	(0.016)	
X_6:$(50, 60]$	25	-0.113	(0.036)	**	-0.003	(0.012)	
X_7:$(60, 70]$	9	-0.066	(0.026)	**	-0.032	(0.097)	
X_8:$(70, \infty]$	54	-0.103	(0.029)	***	-0.068	(0.035)	†
X'_1:$(0, 20]$	59	-0.018	(0.021)		-0.016	(0.024)	
X'_2:$(20, 40]$	166	-0.040	(0.013)	**	-0.001	(0.014)	
X'_3:$(40, 60]$	119	-0.093	(0.020)	***	0.002	(0.030)	
X'_4:$(60, \infty]$	62	-0.100	(0.027)	***	-0.066	(0.033)	*

$^{\dagger}p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5: Estimation results: Recyclables without areas affected by huge earthquakes

Treatment	Rec		Paper		Metal		Glass	
	FE	**WFE**	**FE**	**WFE**	**FE**	**WFE**	**FE**	**WFE**
X'_1:$(0, 20]$	-0.187	0.507	-0.170	0.289	-0.006	-0.004	-0.210	-0.382
	(0.571)	(0.488)	(0.521)	(0.370)	(0.024)	(0.022)	(0.256)	(0.454)
X'_2:$(20, 40]$	0.674	-0.222	0.615	-0.253	-0.027	-0.094	-0.003	-0.007
	(0.313) *	(6.189)	(0.297) *	(6.174)	(0.058)	(0.101)	(0.022)	(0.023)
X'_3:$(40, 60]$	1.595	1.511	1.405	1.447	-0.015	0.018	0.009	0.019
	(0.445) ***	(1.450)	(0.418) ***	(1.402)	(0.031)	(0.010) †	(0.015)	(0.013)
X'_4:$(60, \infty]$	2.453	1.029	2.367	1.169	0.078	0.043	0.015	0.026
	(0.557) ***	(0.519) *	(0.536)***	(0.492) *	(0.028) **	(0.046)	(0.026)	(0.032)

Treatment	PET-bottle		Plastic		Cloth	
	FE	**WFE**	**FE**	**WFE**	**FE**	**WFE**
X'_1:$(0, 20]$	0.001	-0.001	-0.008	0.006	-0.001	0.002
	(0.011)	(0.016)	(0.007)	(0.010)	(0.014)	(0.019)
X'_2:$(20, 40]$	0.008	0.003	-0.001	0.003	0.040	0.047
	(0.012)	(0.08)	(0.004)	(0.004)	(0.026)	(0.032)
X'_3:$(40, 60]$	-0.014	-0.000	0.021	0.072	0.037	-0.025
	(0.006) *	(0.005)	(0.022)	(0.026)	(0.040)	(0.032)
X'_4:$(60, \infty]$	-0.008	0.018	0.002	-0.005	0.053	0.015
	(0.009)	(0.014)	(0.005)	(0.010)	(0.031) †	(0.052)

$^{\dagger}p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

References

Allers, M., and C. Hoeben. 2010. Effects of Unit-Based Garbage Pricing: A Differences-in-Differences Approach. *Environmental and Resource Economics* 45:405-428.

Callan, S. J., and J. M. Thomas. 1999. Adopting a Unit Pricing System for Municipal Solid Waste: Policy and Socio-Economic Determinants. *Environmental and Resource Economics* 14:503-518.

Dijkgraaf, E., and R. Gradus. 2004. Cost savings in unit-based pricing of household waste: the case of The Netherlands. *Resource and Energy Economics* 26:353-371.

Dijkgraaf, E., and R. Gradus. 2009. Environmental activism and dynamics of unit-based pricing systems. *Resource and Energy Economics* 31:13-23.

Dijkgraaf, E., and R. Gradus. 2015. Efficiency Effect of Unit-Based Pricing Systems and Institutional Choices of Waste Collection. *Environmental and Resource Economics* 61:641-658.

Ferrara, I., and P. Missios. 2005. Recycling and waste diversion effectiveness: evidence from Canada *Environmental and Resource Economics* 30:221-238.

Fullerton, D., and T. Kinnaman. 1996. Household Responses for Pricing Garbage by the Bag. *American Economic Review* 86:971-984.

Fullerton, D., and T. Kinnaman. 2000. Garbage and Recycling with Endogenous Local Policy. *Journal of Urban Economics* 48:419-442.

Hoornweg, D., and P. Bhada-Tata. 2012. What a waste: a global review of solid waste management. World Bank, Washington DC.

Huang, J. C., Halstead, J. M., and S. B. Saunders. 2011. Managing municipal solid waste with unit-based pricing: policy effects and responsiveness to pricing. *Land Economics* 87:645-660.

Ichinose, D., Yamamoto, M., and Y. Yoshida. 2015. The Decoupling of Affluence and Waste Discharge under Spatial Correlation: Do Richer Communities Discharge More Waste? *Environment and Development Economics* 20:161-184.

Imai, K., and Kim, I. 2016. When Should We Use Linear Fixed Effects Regression Models for Causal Inference with Longitudinal Data? Discussion paper (longer version), Princeton University.

Imai, K., and Kim, I. Forthcoming. When Should We Use Linear Fixed Effects Regression Models for Causal Inference with Longitudinal Data? *American Journal of Political Science.*

Jenkins, R., Kopits, E., and D. Simpson. 2009. Policy Monitor—The Evolution of Solid and Hazardous Waste Regulation in the United States. *Review of Environmental Economics and Policy* 3:104-120.

Jenkins, R., Salvador, M., Palmer, K., and M. Podolsky. 2003. The Determinants of Household Recycling: A Material-Specific Analysis of Recycling Program Features and Unit Pricing. *Journal of Environmental Economics and Management* 45:294-318.

Kaza, S., Yao, L. C., Bhada-Tata, P., and F. Van Woerden (2018), "What a Waste 2.0 : A Global Snapshot of Solid Waste Management to 2050. Urban Development", World Bank.

Kim, G. S., Chang, Y. J., and D. Kelleher. 2008. Unit Pricing of Municipal Solid Waste and Illegal Dumping: An Empirical Analysis of Korean Experience. *Environmental Economics and Policy Studies* 9:167-176.

Kinnaman, T. 2009. A Landfill Closure and Housing Values. *Contemporary Economic Policy* 27(3):380-389.

Kinnaman, T., and D. Fullerton. 2000. Garbage and Recycling with Endogenous Local Policy. *Journal of Urban Economics* 48(3):419-442.

Levinson, A. 1999. NIMBY Taxes Matter: The Case of State Hazardous Waste Disposal Taxes. *Journal of Public Economics* 74:31-51.

Usui, T. 2008. Estimating the effect of unit-based pricing in the presence of sample selection bias under Japanese recycling law. *Ecological Economics* 66:282-288.

Usui, T., and K. Takeuchi. 2014. Evaluating Unit-Based Pricing of Residential Solid Waste: A Panel Data Analysis *Environmental and Resource Economics* 58:245-271.

Valente, M., and M. Bueno. 2019The effects of pricing waste generation: A synthetic control approach. *Journal of Environmental Economics and Management* 96:274-285.

Yamaya. 2018. Zennkoku Toshi Kateigomi Yuryouka Zisshizyoukyou no Kenbetsu Ichirann (in Japanese). `http://www2.toyo.ac.jp/~yamaya/zenkokutoshi_yuryoka_1811.pdf`