Impact of recycling policies on plastic waste aimed at municipalities: Evidence from Japan

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Abstract

This study investigates the impact of the central government's policy designed to encourage municipalities to recycle plastic waste in Japan. Using an instrumental variable approach, we examine whether the Containers and Packaging Recycling Law (CPRL), which includes policies such as subsidising recycling for municipalities and providing municipalities with recyclers, increases the volume of plastic waste recycling in these municipalities. The results show that CPRL increases the recycling volume of plastic packaging waste, post collection, by approximately 3.1–3.9 kg per capita and that of plastic bottles by 0.4–0.5 kg per capita. We also find evidence that these estimated impacts of CPRL are larger than those of recycling policies that target inhabitants such as unit-based pricing and door-to-door collection. In contrast to previous studies, our results suggest that, in addition to policies for promoting recycling behaviour among inhabitants, policies designed to encourage municipalities play an important role in increasing the volume of plastic recycling.

Keywords: Environmental policy, Extended producer responsibilities, Japan, Municipal solid waste, Plastic waste, Recycling

Abbreviations: CPRL: Containers and Packaging Recycling Law; EPR: Extended Producer Responsibilities; IV: instrumental variables; MSW: municipal solid waste; OLS: ordinary least squares; UPB: unit-based pricing

Introduction

Environmental pollution caused by plastic waste has become a critical global issue, and there is growing concern about the proper processing and disposal of plastics in many countries (Rochman et al. 2013; Jambeck et al. 2015; Huang et al. 2020). Additionally, increasing restrictions on plastic waste imports, particularly in Asian countries, have led governments worldwide to develop policies for the domestic recycling of plastic waste. Countries in the European Union (EU), for instance, aim to make all plastic packaging in the EU market recyclable by 2030 (European Commission 2018). Similarly, Japan aims to reuse or recycle all plastic waste by 2035 (Japanese Ministry of the Environment 2018). A number of studies have already demonstrated that some waste management policies, such as unit-based pricing (UBP) and door-to-door collection, are effective in promoting recycling behaviour among inhabitants (Bucciol et al. 2015; D'Amato et al. 2016; Dijkgraaf and Gradus 2017; Heller and Vatn 2017; Ek and Miliute-Plepiene 2018).

However, there are serious concerns surrounding recycling plastic waste, and it is unlikely to be a preferred solution for public policy, as recycling creates additional costs. Local governments hesitate to implement plastic waste recycling because of the concern that collection and recycling costs will increase (Porter 2002; Kinnaman et al. 2014; Gradus et al. 2017). For instance, Kinnaman et al. (2014) suggest that average social costs are minimised with recycling rates well below observed and mandated levels in Japan. Indeed, in the Japanese context, plastic bottles collected for recycling are traded to recyclers for a reverse fee, which means that the municipality must pay a disposal fee for their collected plastic bottles to recyclers. Moreover, local governments would have to find recyclers to recycle collected plastic waste sustainably and legally in their own country, implying greater opportunity costs. Although in such cases policies to promote recycling improve the behaviour of inhabitants, it would be limited in its ability to motivate municipal governments, which are financially responsible for recycling. Consequently, the amount of plastic waste recycled after collection may not improve much, even if inhabitants take action to sort their waste. Such as the waste problem, therefore, when the emitter and processor of environmental pollution are different, a policy with regulations and incentives towards, not only emitter, processor might be a significant role in improving environmental pollution.

This study investigates the impact of the Containers and Packaging Recycling Law (CPRL) designed to encourage municipalities to recycle plastic waste in Japan. The policy shock generated by CPRL provides an opportunity to test whether direct policy interventions by the central government that are targeted at municipalities, such as subsidising recycling and providing suitable recyclers to municipalities, increase the recycling volume at the municipality level. We offer estimates for the causal impacts of CPRL on the recycling volume of plastic waste using a panel dataset of all 1,718 Japanese municipalities for 2007–2018 and an instrumental variables (IV) strategy.

This study contributes to the literature on the policy impacts on recycling in several ways. While there are numerous studies that investigated the impact of policies on household recycling at the home separation and collection stages (Kinnaman and Fullerton 2000; Jenkins et al. 2003; Allers and Hoeben 2010; Dijkgraaf and Gradus 2014; Dijkgraaf and Gradus 2017; Heller and Vatn 2017; Ek and Miliute-Plepiene 2018), the impact of policies aimed at promoting recycling by municipalities has been unexplored. Brouwer et al. (2018) and Dijkgraaf and Gradus (2020) explored the impact of post-collection separation on the amount of waste recycled. They found that separated plastic waste post-collection was of higher quality than household-separated plastic waste. Usui et al. (2015) examined the motivation of municipalities for implementing waste collection for recycling. The authors reported that the existence of waste treatment facilities, such as refuse-derived fuel facilities and self-owned landfill sites, determines a municipality's decision-making on the collection and separation of waste. However, to the best of our knowledge, the effectiveness of the central government's policies aimed at municipalities for recycling volume has not been previously examined.

Additionally, this study investigated the policy effects that vary according to the types of plastic materials, including those traded for a fee or a reverse fee. While previous studies have not focused on the transaction price of waste in post-collection, by using a detailed dataset for each type of plastic waste, this study allows an investigation into the policy effects according to the types of plastic materials with different transaction prices. Our results suggest that even accounting for trading collected plastic bottles for a reverse fee, the CPRL policy increases the recycling volume of plastic waste by local municipalities.

Second, based on an empirical analysis, this is the first study to find that recycling policy based on extended producer responsibility (EPR) promotes plastic recycling by municipal governments and improves recycling volume. The Japanese government established CPRL based on the EPR, which obliges the producer that manufactures, uses, or imports containers and packaging to pay commissioning fees based on its recycling output. How EPR affects post-collection recycling of plastic waste is important to understand the environmental impact throughout the life cycle of the product. Previous studies have focused mainly on the impact of EPR instruments on social welfare and incentives for the eco-design of products, based on theoretical models (Runkel 2003; Fleckinger and Glachant 2010; Brouillant and Oltra 2012). However, it is unclear how the EPA would actually work for plastic waste recycling at the waste management stage.

Finally, this study provides a methodological contribution to address waste management policy endogeneity by using IV strategy and performing a rigorous robustness check of the estimation results. In our context, reverse causation is a concern because the choice of policies is not exogenous when the CPRL is implemented in municipalities where a large amount of plastic waste is expected to be recycled. To address endogeneity concerns, in this study, motivated by Ichinose et al. (2015), we propose the use of the CPRL implementation rate of the previous year in the prefecture, to which each municipality belongs, as an instrumental variable for CPRL implementation.[1]

To summarise our main findings, after dealing with the potential problem of endogeneity, there is a significant positive effect of CPRL on the recycling volume of plastic waste in municipalities. Other things being equal, the results show that the introduction of CPRL increases the amount of plastic packaging waste recycling by 3.1–3.9 kg per capita and that of plastic bottle recycling by 0.4–0.5 kg per capita. These policy impacts are larger than those realised by other policies, such as UBP, door-to-door collection, and inter-municipal recycling cooperation. Further, the subsidies for municipal governments, based on the recycling volume and the quality of the collected plastic waste, increases the volume of plastic packaging waste recycling. These results suggest that while it is important to have policies aimed at motivating residents, policies aimed at municipal governments are also crucial in increasing plastic waste recycling.

The remainder of this paper is organised as follows: Section 2 describes the background of CPRL and Japanese waste management systems. Section 3 introduces the empirical strategy, model specifications, and data. Section 4 provides the estimation results. Section 5 contains an array of robustness checks. Finally, Section 6 concludes the paper and discusses policy implications.

Background

To examine the relationship between CPRL and recycling volume, we focus on two types of plastic waste material: plastic packaging waste and plastic bottles. In Japan, as of 2019, 8.5 million tons of plastic waste were being generated annually (Plastic Waste Management Institute in Japan 2020). Plastic containers and packaging waste, including plastic packaging waste and plastic bottles, are the highest contributor, accounting for 46.8% of the total plastic waste. In addition, 4.12 million tons of plastic waste are generated annually in the form of MSW, and plastic containers and packaging waste account for 77.2% of the total MSW. However, while the material recycling rates for glass bottles and paper have been raised to 67.6% and 64.4%, respectively,[2,3] the material recycling rate for plastic waste is still merely 22%.

In response to the problem of recycling plastic waste, in 1997, the Japanese government adopted the CPRL based on EPR to encourage municipalities' domestic recycling efforts. This law targets packaging waste including plastic packaging waste, plastic bottles, glass bottles, and paper packaging containers in MSW, and each municipality can decide to apply the CPRL to each type of waste.[4] In addition, municipalities collect and treat packaging waste from the MSW and are financially responsible for the costs associated with it.

The CPRL has two policies to encourage municipalities to recycle plastic waste. First, the central government finds recyclers to sell the plastic waste collected by municipalities instead of the municipalities having to find their own recyclers. Under the CPRL, the municipalities sell the collected waste through competitive bidding by recycling companies selected by the central government. As of 2018, 56 recycling companies were participating in CPRL, and they were obliged to engage in domestic recycling and re-commercialise container and packaging waste purchased from municipalities. Therefore, CPRL allows the municipalities implementing it to reduce their opportunity cost of finding recyclers that engage in domestic recycling.

The second point is the issuance of subsidies by the central government in accordance with municipalities' volume and quality of plastic waste recycling.[5] In 2008, the Japanese government implemented an amendment to CPRL, allowing municipalities to obtain subsidies based on the recycling volume and quality of container and packaging waste. These subsidies are financed by the recycling fees obtained from producers, who are responsible for recycling packaging waste collected by municipalities into new products. Under the CPRL based on EPR, the producer that manufactures, uses, or imports containers and packaging is obliged to pay commissioning fees based on its recycling output.

To decide the value of subsidy, the central government, unannounced, inspects the quality of each type of plastic waste in almost all municipalities implementing CPRL and gives them a ranking from A to D, with A ranking indicating the highest quality, and D ranking indicating the lowest. Under the subsidy policy, if recycling companies' recycling costs are lower than originally expected, half of the lower amount is distributed to the municipality as a subsidy based on the rank, and the other half is distributed to the recyclers. Therefore, municipalities have an incentive to increase the recycling volume and the quality of plastic waste.

Importantly, the central government cannot force the municipalities to implement this law; therefore, some municipalities either sell to recyclers that they have identified independently or incinerate plastic waste as combustible waste at self-owned facilities. The reason for this is the downward trend in the transaction price of plastic waste. For instance, in the municipalities that enforced this law, the average transaction price of plastic packaging waste was 62,751 yen (567.74 US$)/ton in 2009, but it decreased to 50,105 yen (453.33 US$)/ton in 2018.[6] The plastic bottles are traded for a reverse fee that requires municipalities to pay the recycling company for disposal costs. The average transaction price of plastic bottles was minus 4,166 yen (37.69 US$)/ton in 2009, but it decreased to minus 33,408 yen (302.26 US$)/ton in 2018. Therefore, some municipalities do not implement CPRL if they can deal independently with a recycler buying plastic waste at a high price; however, in such a case, the plastic waste might be exported overseas. Figure 1 shows the spatial distribution of CPRL implementation for each type of plastic waste in 2018. The municipalities enforcing the CPRL are spread across most of Japan. Figure 2 shows the state of CPRL adoption in municipalities for plastic packaging waste and plastic bottles as of 2018. Different municipalities adopted the CPRL in different periods. The trend in the adoption rate decreased significantly in 2005 because of municipal mergers. As of 2018, 64% of Japanese municipalities had introduced plastic packaging waste systems, and 70% had introduced systems for plastic bottle recycling. These rates have been gradually increasing for several years.

Some municipalities attempt to increase their recycling volume through policies other than the CPRL, as each municipality typically implements MSW management in its own jurisdiction. Some municipalities implement door-to-door collection in the collection process, whereby households place plastic waste in a clear bag in front of their home. The door-to-door collection has an incentive for households to separate the recyclable waste and improve the cleanliness of their plastic waste. For instance, based on Italian data, Bucciol et al. (2015) found that door-to-door collection increases the sort-to-total waste ratio by 15.7%. Previous studies have shown that, in the home separation stage, UBP has reduced waste and incentivised households to separate waste for recycling (Dijkgraaf and Gradus 2017). The share of Japanese municipalities introducing UBP systems has increased from 53% in 2007 to 61% in 2018 (Ministry of Environment 2018). In the treatment process, some municipalities implement inter-municipal cooperation for recycling with neighbouring municipalities. These economies of scale achieved through cooperation might reduce treatment costs and increase waste recycling efficiency (Callan and Thomas 2001; Chifari et al. 2017).

Econometric methods

Model specifications and data

The aim of our analysis is to estimate the effect of CPRL on the amount of plastic waste recycled in the post-collection stage. We use municipal-level panel data from 2007 to 2018 and 20,616 observations corresponding to all 1,718 municipalities over a period of 12 years. Although the CPRL was introduced in 1997, because of data limitations and municipal mergers, a dataset from 2007 onwards was used. This is reasonable, as the number of municipalities has decreased by approximately 44% from 1997 to 2006 owing to several municipal mergers.[7] Municipal mergers are strategic and non-random and cause an attrition bias problem that weakens the reliability of the related panel data (Wooldridge 2002; Ichinose et al. 2015; Usui et al. 2015). Indeed, since the adoption rate of CPRL decreased significantly in 2005 because of municipal mergers, the estimation including these periods would cause an attrition bias problem (Figure 2).

Our sample is suitable for analysing the relationship between adopting CPRL and the recycling volume of plastic waste. First, the dataset merges the state of policy introduction by year with all municipality-by-year panels on the volume of recycled plastic waste for 2007–2018, allowing the estimation of causal effects of CPRL. Second, the detailed and standardised data reported annually by the Japanese central government enable us to analyse the effect of CPRL on recycling volume at the post-collection stage. Moreover, with detailed data for subsidies for each type of plastic waste material, we estimate the impact of subsidies for municipal governments on the quantity of recycled plastic waste. Finally, the Japanese municipal solid waste (MSW) management exhibits large differences across municipalities and periods in terms of waste generation, disposal, recycling, and waste management policies, such as UBP and door-to-door collection. These conditions also allow a comparison of the policy effects between CPRL and other recycling policies.

For the preliminary analysis, Figure 3 shows the differences between the CPRL implementing and non-implementing municipalities' average recycling volume per capita for each type of waste. The graphs also show predictive linear regression lines with 95% confidence intervals. The plastic packaging waste depicted in Panel (a) reveals that the recycling volume, on average, was 4.4 kg per capita in the subsample of municipalities with CPRL, compared to 2.6 kg per capita in the subsample of municipalities without CPRL. This difference, 1.8 kg per capita, is statistically significant at the 1% level. As showed in Panel (b), the average recycling volume of plastic bottles in municipalities with CPRL is 2.2 kg per capita, which is 0.2 kg larger than that in municipalities without

CPRL; the difference is statistically significant at the 5% level. Panel (c) compares the recycling volume of glass bottles and shows that the recycling volume is 0.2 kg per capita higher in municipalities with CPRL; this difference is statistically insignificant. Finally, as showed by the data on paper container waste in Panel (d), the evidence on the difference is less clear. The evidence provided in Figure 3 is suggestive. As mentioned in the previous section, while plastic waste makes up an important share of MSW, the recycling rate is considerably lower than that of glass bottles and paper waste. Therefore, recycling policies for plastic containers and packaging waste such as CPRL are likely to improve plastic waste recycling.

Our working hypothesis is that the implementation of CPRL in municipalities increases the recycling volume. First, we estimate the amount of recycled plastic waste per capita as a function of the recycling system. We include the municipality-specific control that corresponds closely to the set of factors typically analysed in studies on recycling volumes (Ek and Miliute-Plepiene 2018; Dijkgraaf and Gradus 2020) as follows:

$$y_{i,w,t} = \beta_1 CPRL_{i,w,t} + \beta_2 Dens_{i,t} + \beta_3 Old65_{i,t} + \beta_4 Inc_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t}, \quad (1)$$

where $y_{i,w,t}$ is the recycled plastic amount in kilograms (kg) of waste type *w* per capita of municipality *i* in year *t*. The waste type *w* includes plastic packaging waste and plastic bottles. $CPRL_{i,w,t}$ is the dummy variable that takes the value of 1 for a municipality implementing CPRL in waste type *w*. *Dens* is the population density, *Old65* is the share of older people (over 65 years old), and *Inc* is the average income per capita. μ_i is the municipality fixed effect, λ_t is the year fixed effect, and ε_{it} is the error term.

Additionally, following previous studies, we estimate alternative models and include other policy variables expected to affect the amount of plastic waste recycling. In the second model, the investigation focused on which policy is more effective for recycling plastic waste. The equation now becomes

$$y_{iwt} = \beta_1 CPRL_{i,w,t} + \beta_2 Dens_{i,t} + \beta_3 Old65_{i,t} + \beta_4 Inc_{i,t} + \beta_5 Freq_{i,w,t} + \beta_6 UBP_{i,t} + \beta_7 Door_{i,w,t} + \beta_8 Coope_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t}, \quad (2)$$

where $Freq$ is the frequency of curbside collection of plastic waste *w* per month. Several studies suggested that a higher collection frequency of recyclable waste increases the amount of these materials (Abbot et al. 2011; Dijkgraaf and Gradus 2017; Dijkgraaf and Gradus 2020). As of 2018, plastic packaging waste and plastic bottles were collected at the curbside, on average, twice a month (Japanese Ministry of the Environment 2018). UBP is an indicator that equals 1 if a given municipality implements a UBP system for burnable waste; otherwise, it equals 0. UBP provides an incentive for households to sort plastic waste (Dijkgraaf and Gradus 2017). Thus, it is expected that municipalities with UBP collect more unpriced plastic waste. Conversely, there is potential for an indirect effect on the total recycling quantity in the event of a reduction in product consumption (Dijkgraaf and Gradus 2014). $Door$ is a dummy variable that equals 1 for a municipality implementing the door-to-door collection of waste type w. As door-to-door collection requires households to place plastic waste in a clear bag outside their home, it is expected that municipalities with door-to-door collection will collect higher-quality waste (Bucciol et al. 2015). $Coope$ is a dummy variable that equals 1 for a municipality that implements inter-municipal cooperation with neighbouring municipalities in the recycling process. As stated earlier, the implementation of inter-municipal cooperation is expected to increase the recycling volume because of economies of scale. Table 1 presents the summary statistics of the data.

Data on the status of CPRL implementation in municipalities from 2007 to 2018 were obtained from the Japan Containers and Packaging Recycling Association's website (n.d.). These data were matched to recycling volume data on plastic packaging waste and plastic bottles waste in the post-collection stage by municipalities from an annual survey report on MSW by the Japanese Ministry of Environment from 2007 to 2018. Data on the implementation status of UBP, door-to-door collection, inter-municipal cooperation, frequency of curbside collection, and population data in each municipality were also extracted from an annual survey report on MSW by the Japanese Ministry of Environment. Data on population density and share of older people in each municipality were obtained from the 2005, 2010, and 2015 National Census of the Japanese Ministry of Internal Affairs and Communications for the respective years. Data on the annual average income per capita by municipalities were obtained from the e-Stat database of the Official Statistics of Japan. These data were also matched to recycling volume data by municipalities in each year.

Instrumental variables strategy

We address the possible endogeneity of CPRL implementation using an IV strategy in the empirical analysis. Municipalities might implement CPRL if a large amount of plastic waste recycling is expected in their administrative area. Therefore, it is difficult to determine whether it is the intervention from the central government through CPRL or other underlying characteristics of the municipality that increase recycling volume. In this case, the OLS estimator will produce biased estimates because the variable capturing whether the municipality implements the CPRL is likely to be correlated with the error term. To deal with the potential problem of endogeneity, in this study, we propose the use of the CPRL implementation rate of the previous year in the prefecture, to which each municipality belongs, as an instrumental variable for CPRL implementation. This instrumental variable is motivated by a study by Ichinose et al. (2015), who found that Japanese municipalities belonging to the same prefecture tend to implement similar waste management policies. Therefore, we assume that the correlation between the state of the policy in other municipalities belonging to the same prefecture in the previous year and CPRL implementation in the municipality is robust. The assumption is that the CPRL implementation rate in the previous year in the prefecture to which each municipality belongs is not caused by the amount of recycled plastic waste in each municipality, and it does not directly affect the outcome variables. The first-stage equation takes the following form:

$$CPRL_{i,w,t} = \alpha Perf_{j,w,t-1} + \zeta \boldsymbol{Z}_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t}, \quad (3)$$

where $CPRL_{i,w,t}$ is a dummy variable, which equals 1 if municipality *i* implements CPRL for waste type *w*. $Perf_{j,w,t-1}$ is the rate of CPRL implementation for waste type w in prefecture j in year t-1. The vector $\boldsymbol{Z}_{i,t}$ contains other potential variables that may play a role in selecting a municipality implementing CPRL, which corresponds to the variable in the second-stage regression (as outlined above). μ_i is the municipality fixed effect, and λ_t is the year fixed effect. ε_{it} is the error term, which contains unobservable factors that can be related to the implementation of CPRL, to the recycling outcomes, or to both.

Tables 2 and 3 report the first-stage results for each type of waste. Column (1) includes only the variable of the CPRL implementation rate in the previous year in the prefecture to which each municipality belongs. Column (2) adds the municipality-specific control variables. Columns (3)–(6) add the policy variables, including frequency of curbside collection, door-to-door collection, UBP, and inter-municipal cooperation for recycling.

In the results for plastic packaging waste in Table 2, the CPRL implementation rate of the prefecture is statistically significant at the 1% level in all models. These results indicate that CPRL implementation in the municipality tends to be influenced by other municipalities belonging to the same prefecture, which is in line with the findings of Ichinose et al. (2015). Table 3 represents the results for plastic bottles. The CPRL implementation rate of the prefecture is also positive and statistically significant at the 1% level in all models. Based on these first-stage results, the identification assumptions are as follows: the amount of recycled plastic waste in each municipality does not depend on the implementation of CPRL in the previous year among other municipalities belonging to the same prefecture. The state of CPRL implementation in the previous year in other municipalities belonging to the same prefecture does not directly affect the recycling volume of plastic waste in each municipality. The frequency of curbside collection, UBP, and inter-municipal cooperation in the recycling process are other potential instruments. These variables in $Z_{i,t}$ cannot be excluded from the second stage because they are related to the amount of recycled plastic waste or the error term in equation (2).

Results

The impact of CPRL on plastic waste recycling

For the first part of the analysis, we assess the impact of the plastic recycling policy aimed at municipalities by the central government's introduction of CPRL. Tables 4 and 5 report the estimation results for plastic packaging waste and plastic bottles by ordinary least squares (OLS) estimations with the VCE robust estimator to correct for clustered standard errors, which considers the correlation of error terms between municipality clusters. All regressions include fixed effects for each municipality and time-specific dummies. The results for glass bottles and paper packaging containers are shown in Appendix A.

Beginning with the first specification, in Table 4, Column (1), which includes no control variables, presents the CPRL implementation as associated with an increase in the recycling output of plastic packaging waste. Even if municipality control variables are included in the model (Column 2), it does not change the estimated CPRL effect. CPRL is statistically significant at the 1% level, and the value of the coefficient is stable. Columns (3)–(6) include the policy variables (frequency of collection, door-to-door collection, UBP, and inter-municipal cooperation). The preferred specification is Column (6), which includes municipal-specific variables and all policy variables. We find that the CPRL dummy is, again, positive and statistically significant at the 1% level. The estimate implies that CPRL implementation is associated with an increase in the recycling output of plastic packaging waste by 1.41 kg per capita.

Comparing the influence on the amount of recycling, the influence of CPRL is larger than that of other policies. The estimated coefficient on the frequency of curbside collection is 0.44 and statistically significant at the 1% level, as shown in Column (3). As expected, there is a positive relationship between the frequency of collection and the quantity of recycled plastic packaging waste. In Column (4), the coefficient on door-to-door collection is also positive, which is statistically significant at the 5% level. The estimate implies that door-to-door collection is associated with an increase in the recycling volume of plastic packaging waste by approximately 1.39 kg per capita. In Column (5), the UBP positively influences the recycling volume, but the effect is not statistically significant. In Column (6), implementing inter-municipal cooperation is associated with a 0.27 kg per capita increase in the recycling volume of plastic packaging waste, but the effect is not statistically significant.

Table 5 reports the estimation results for plastic bottle recycling. Column (6) indicates that CPRL implementation is associated with approximately a 0.1 kg per capita increase in the recycling volume of plastic bottles. These results suggest that CPRL implementation can increase the amount of recycled plastic waste in municipalities, even when plastic bottles are traded to recyclers for a reverse fee. The results of the policy variables for plastic bottles are similar to the results for plastic packaging waste. In Column (3), the estimated coefficient on the frequency of curbside collection is 0.055, which is statistically significant at the 1% level. In Column (4), the estimate implies that the coefficient on door-to-door collection has a positive sign but is statistically insignificant. In Column (5), the coefficient on UBP also has a positive sign but is statistically insignificant. In Column (6), the estimated coefficient of inter-municipal cooperation in the recycling process is positive and statistically significant at the 1% level. We find that inter-municipal cooperation increases the amount of plastic bottle recycling by 0.25 kg per capita.

IV estimates (Benchmark results)

For the second part of the analysis, we employ an IV strategy to address the endogeneity of the CPRL policy. The regressions in Tables 4 and 5 assume that the error term is uncorrelated with the CPRL dummy. However, as we explained, municipalities that anticipate an upward trend in their plastic waste volume may be particularly willing to commit to CPRL implementation, so the OLS estimates will be biased away from zero.

Tables 6 and 7 show the estimation results of IV regressions using the CPRL implementation rate in the previous year in the prefecture to which each municipality belongs as an instrumental variable. In all specifications, we report the results of diagnostics to check the validity of our IV strategy. To test whether our instrumental variable can be legitimately excluded from the estimated equation, we test its validity using the Kleibergen-Paap test for weak identification, eliminating the concern that the instrumental variable is weakly correlated with the explanatory variable (Stock et al. 2002; Stock and Yogo 2005). The values of the F statistics reported across the table are well above the Stock-Yogo critical values indicating a strong correlation between the instrumental variable and endogenous variable.[8] Additionally, the Cragg-Donald Wald F statistic on the instrument for the test for weak identification is also significantly large. Further, we test the under-identification using Kleibergen-Paap rk LM statistics to determine whether the excluded instruments have relevance and correlate with the endogenous regressor. The null hypothesis is that the instrumental variable is invalid, and the excluded instruments cannot be excluded from the estimated equation. In all models, the reported p-values of the LM test show that the joint null hypothesis that the instrument is invalid can be rejected at the 1% significance level, suggesting that the instrumental variable is correctly excluded.

Table 6 presents the results for plastic packaging waste recycling. The CPRL dummy continues to be positive and statistically significant at the 1% level in all models. Compared to the OLS estimates presented in Table 4, the IV regressions change the estimated CPRL effects to a greater degree. The CPRL increases the amount of recycling plastic packaging waste by approximately 3.0–3.9 kg per capita, which is larger than other policies. Table 7 presents the results for plastic bottle recycling. The coefficients of CPRL are positive and statistically significant in all models. As shown in Column (6), CPRL increases plastic bottle recycling by approximately 0.49 kg per capita, which is statistically significant at the 5% level. The finding that the IV estimates are larger than the OLS estimates shows endogeneity bias leading to an underestimation of the relationship between CPRL implementation and the recycling volume of plastic waste in the OLS estimation. In summary, our benchmark IV regressions suggest that CPRL has a measurable positive effect on the amount of plastic waste recycling, indicating that the policy works as intended.

The impact of subsidies on plastic waste recycling

For the third part of the analysis, we assess the effect of subsidies for municipalities on the amount of recycling. In 2008, the Japanese government implemented an amendment to CPRL, which allows municipalities to obtain subsidies based on the recycling volume and the quality of collected plastic waste. To capture this effect, we use the variable regarding subsidy paid in accordance with the recycling volume and the quality of collected waste for each local government. The equation now becomes

$$y_{iwt} = \beta_1 Sub_{i,w,t-1} + \beta_2 Dens_{i,t} + \beta_3 old65_{i,t} + \beta_4 Inc_{i,t} + \beta_5 Freq_{i,w,t} + \beta_6 UBP_{i,t} + \beta_7 Door_{i,w,t} + \beta_8 Coope_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t}, \quad (4)$$

where $Sub_{i,w,t-1}$ is the value of the subsidy paid per capita in the previous year. The hypothesis is that the municipalities that received more subsidies in the previous year would achieve more plastic waste recycling. Other variables include municipal control variables and policy variables, which correspond to the variable in equation (2). μ_i is the municipality fixed effect, λ_t is the year fixed effect, and ε_{it} is the error term.

Table 8 shows the estimation results for plastic packaging waste and plastic bottles. All six regressions include municipality fixed effects and year fixed effects. Columns (1) and (4) do not include any control variables. Columns (2) and (5) include municipal control variables, and Columns (3) and (6) include the policy variables.

Columns (1)–(3) report the results for plastic packaging waste. The coefficient on the subsidy variable has a positive sign and is statistically significant in all models. These results indicate that implementing a subsidy policy on plastic packaging waste recycling encourages recycling among the municipalities. For instance, the coefficient in the third column implies that a subsidy of 1000 yen (9.05 US$) per capita to the municipality increases plastic packaging waste recycling by approximately 2 kg per capita.

For plastic bottles, Columns (4)–(6) show that the estimated coefficients on the subsidy variable are positive but statistically insignificant in all models. Thus, we do not find statistically significant evidence that a subsidy to municipalities for plastic bottle recycling increases the amount of recycling. This is to be expected, as subsidies for plastic bottle recycling are quite low. Indeed, the average subsidy for recycling plastic bottles was only 1.1 yen (0.01 US$) per capita from 2009 to 2018, while that for recycling plastic packaging waste was 32.7 yen (0.30 US$) per capita in the same period.[9]

Robustness checks

Alternative IV strategy: Geographical neighbouring relationships

In the remaining analysis, we aim to demonstrate the robustness of our results by applying alternative IV strategies. First, we use the spatial weight of CPRL implementation based on the actual neighbouring relationships between municipalities as an alternative definition of the neighbouring municipalities for the instrumental variable. This instrumental variable is motivated by a study by Usui et al. (2015), who found that a municipality's implementation of recyclable collection or separation programs shows spatial interactions with its neighbouring municipalities in Japan. Using this alternative IV strategy, the selection equation takes the following form:

$$CPRL_{i,w,t} = \gamma WCPRL_{j,w,t-1} + \zeta \boldsymbol{Z}_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t}, \quad (5)$$

where $WCPRL_{j,w,t-1}$ is a weighted average of CPRL implementation for waste type w in other geographical neighbouring municipalities j in year t-1. The spatial weight matrix W_{ij} is defined as follows:

$$W_{ij} = \frac{c_{ij,}}{\sum_{i=1}^{N} c_{ij}} \ , \qquad c_{ij}(i, j = 1,2, \dots, N; i \neq j) \tag{6}$$

where c_{ij} takes the value of 1 when municipalities i and j are contiguous, and 0 otherwise. The spatial weight matrix W is based on the actual neighbouring relationships between municipalities using queen-type contiguity. The vector $Z_{i,t}$ contains other potential variables that correspond to the variable in the second-stage regression (as mentioned previously). μ_i is the municipality fixed effect, λ_t is the year fixed effect, and ε_{it} is the error term.

Table 9 shows the results for plastic packaging waste and plastic bottles. Panel A reports the first-stage results. In Columns (1) and (4), the coefficient on the weighted average of the CPRL implementation is positive and statistically significant at the 1% level. The estimated coefficient of CPRL is stable with the municipality-specific control variables in Columns (2) and (5). Moreover, in Columns (3) and (6), the weighted average of CPRL implementation remains statistically significant at the 1% level. In all models, the F-statistics of Kleibergen-Paap and Cragg-Donald Wald on the instrument to test weak identification are significantly large, indicating a strong correlation between the instrumental variable and the endogenous variable. Additionally, the reported p-values of the LM statistic for under-identification show that the joint null hypothesis that the instruments are invalid can be rejected at the 1% significance level. These results indicate that CPRL implementation in the municipality tends to be influenced by neighbouring municipalities, which is in line with our benchmark IV regressions. Panel B reports the second-stage results. The CPRL dummy variable continues to be positive and statistically significant at the 1% level in all models. This IV strategy yields estimates of the CPRL effect close to the benchmark IV estimates.

Alternative IV strategy: Intensity of CPRL policy

As a further robustness check, we use the intensity of CPRL policy in neighbouring municipalities as an instrumental variable. Four types of waste are subject to CPRL—plastic packaging waste, plastic bottles, glass bottles, and paper packaging containers—and each municipality has the option to apply CPRL to each type of waste. It is expected that a municipality would be more likely to implement CPRL if the neighbouring municipalities are proactive in implementing CPRL and adopting it for various types of waste. In the first-stage regression, the following specification is estimated:

$$CPRL_{i,w,t} = \delta WIntens_{j,t-1} + \zeta \boldsymbol{Z}_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t}, \tag{7}$$

where $WIntens_{j,t-1}$ is a weighted average of the number of types of waste for which CPRL is adopted in other geographical neighbouring municipalities j in year t-1. The spatial weight matrix W is based on the actual neighbouring relationships between municipalities using queen-type contiguity (as mentioned previously). As mentioned previously, the vector $Z_{i,t}$ contains other potential variables that correspond to the variable in the second-stage regression. μ_i is the municipality fixed effect, λ_t is the year fixed effect, and ε_{it} is the error term.

The results are summarised in Table 10. In Panel A, the first-stage results show that municipalities' adoption of CPRL is more likely to be affected by the more positive CPRL adoption by neighbouring municipalities. The F-statistics of Kleibergen-Paap and Cragg-Donald Wald are significantly large. Moreover, the LM-statistic for under-identification is statistically significant at the 1% level in all models, suggesting that the joint null hypothesis that the instruments are invalid can be rejected. In the second-stage results in Panel B, we find that CPRL positively affects the amount of plastic packaging waste recycling and plastic bottle recycling post-collection.

Placebo test

Finally, for completeness, we check the robustness of our findings using a placebo test. Additionally, we assess the spillover effect of an environmental policy intervention on the recycling activity in municipal governments. Ek and Miliute-Plepiene (2018) found a positive spillover effect from policy interventions such as the implementation of food waste collection on the amount of packaging waste in households. In the present study, to test whether waste management policy interventions have spillover effects on recycling in the public sector, we estimate the effect of CPRL on the recycling volume of other recyclable waste (e.g. metals, cloth, and fertiliser), which is not subject to the CPRL policy.

The results are reported in Table B in Appendix B. In all models, the coefficient on the CPRL dummy variable is statistically insignificant for the recycling volume of other waste, supporting the main specification. The other policy variables for plastic packaging waste and plastic bottles do not affect the recycling volume of other recyclable waste.

Further, we find no evidence of the spillover effects of CPRL on recycling in the public sector.

Conclusions

This study investigated the impact of CPRL, which is designed to encourage municipalities to recycle plastic waste. Using IV strategy and panel datasets from 2007 to 2018 for all Japanese municipalities, we investigated whether the central government's policy aimed at municipal governments increase the volume of plastic waste recycling, post-collection. The results show that CPRL increases the recycling volume of plastic packaging waste by 3.1–3.9 kg per capita and that of plastic bottles by 0.4–0.5 kg per capita. The results also show that even if collected plastic bottles are traded for a reverse fee, CPRL increases the recycling volume by municipalities, suggesting that municipalities responded to the subsidies and incentives by increasing their recycling efforts. These results are robust to other IV strategies and various controls, including the existence of other policies and regional factors. Additionally, this study provides new insights into the impact of recycling policy based on EPR on the recycling volume of plastic waste at the waste management stage in municipalities. These findings are significant, given the growing concerns about proper recycling and disposal of plastics in many countries.

This study highlights the effects of central government intervention on the motivation for domestic recycling among municipal governments. In principle, this study has at least two policy implications. First, central governments need to be proactive in encouraging recycling in municipalities, in addition to promoting policies aimed directly at inhabitants. Our empirical results indicate that recycling policies aimed at municipalities are more effective for plastic waste recycling than those aimed at inhabitants. In many countries, governments implement policies with regulations and incentives that impact residents' recycling motivations and behaviours, and the effects of these policies have been verified in many studies. However, these recycling policies are not always desirable for local governments, which are financially responsible for waste management. In that sense, the lack of increase in the amount of waste recycled after collection might be attributed to the uncoordinated regulations of the central government.

Second, it might be necessary to offer financial incentives to municipalities to increase the domestic recycling of plastic waste. Our results suggest that subsidies for plastic bottle recycling do not increase domestic recycling volume because the subsidies are quite low. Indeed, in the Japanese context, used plastic bottle exports amounted to approximately half (3.07 million tons) of the generated plastic bottles in 2019 (Council for PET Bottle Recycling 2019). These results show that municipalities that do not benefit from the recycling of plastic waste may need financial support for recycling management and running costs to increase recycling volume.

There are some limitations of this study and avenues for future research. First, because of difficulties in data availability on the disposal and recycling costs of plastic waste, this study focuses on the recycling volume of plastic waste; thus, future work should investigate the consequences for CPRL on the cost-benefit of plastic recycling. Second, this study focuses on the effects of CPRL on plastic recycling at the waste management stage in municipal governments. Under the CPRL based on EPR, the producer that manufactures, uses, or imports containers and packaging is obliged to pay commissioning fees based on their production output for recycling; thus, it may be efficient to improve the eco-design of their products (Runkel 2003; Brouillat and Oltra 2012). Therefore, it would be of great interest to find the impact of CPRL based on EPR on the eco-design and use of recycled plastic products at the manufacturing stage, and whether these impacts will increase the amount of recycling at the waste management stage. Further research is needed to understand how EPR might affect the reduction of recycling cost and the plastic use of products.

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[1] Local governments in Japan have two tiers: prefectural governments and municipalities (cities, towns, and villages). As of January 2021, Japan had 47 prefectures and 1,718 municipalities.

[2] According to the Glass Bottle 3R Promotion Association's website (in Japanese).

[3] According to the Paper Recycling Promotion Center's website (in Japanese).

[4] In Japan, MSW is collected and disposed of by local municipalities, whereas industrial waste is usually collected and disposed of by private companies.

[5] For details on the guidelines, refer to Japan Containers and Packaging Recycling Association (2020).

[6] As of 2 April 2021, 1,000 Japanese yen was approximately 9.05 US dollars.

[7] An additional 139 (approximately 7%) municipalities merged between 2007 and 2018. The pre-merger data for these 139 municipalities were aggregated to the 51 post-merger municipal units.

[8] Stock et al. (2002) suggest that an instrument is not weak if the F-statistic exceeds 10%.

[9] The average subsidy for recycling plastic bottles and plastic packaging waste was calculated by the reports of Japan Containers and Packaging Recycling Association (n.d.)

Appendix A

Table A shows the estimation results for glass bottles in Panel (a) and paper containers in Panel (b). In Panel (a), the coefficient on the CPRL dummy is positive and statistically significant at the 1% level in all models. The estimate implies that CPRL implementation for glass bottles is associated with an increase in the recycling volume of glass bottles by 0.48–0.50 kg per capita. Column (6) indicates that the inter-municipal cooperation variable increases plastic bottle recycling by approximately 0.59 kg per capita, which is larger than that of the CPRL policy. On the other hand, in Panel (b), the CPRL for paper containers does not have an impact on recycling volume. This is because fewer municipalities are implementing CPRL for paper containers. As of 2018, the rate of CPRL implementation for paper containers was only 8%, and it has remained nearly unchanged for over a decade.

Table A (a): Estimation results for glass bottles

	Glass bottles					
	(1)	(2)	(3)	(4)	(5)	(6)
	Coef.	*Coef.*	*Coef.*	*Coef.*	*Coef.*	*Coef.*
CPRL	0.497 ***	0.501 ***	0.493 ***	0.489 ***	0.482 ***	0.460 **
	(0.187)	(0.186)	(0.186)	(0.186)	(0.186)	(0.183)
Freq			0.071	0.080	0.080	0.082
			(0.053)	(0.052)	(0.052)	(0.052)
Door				-0.512	-0.529	-0.531
				(0.327)	(0.326)	(0.326)
UBP					0.201	0.195
					(0.143)	(0.141)
Coope						0.594 ***
						(0.167)
Intercept	5.853 ***	6.698 ***	6.581 ***	6.598 ***	6.487 ***	6.404 ***
	(0.136)	(0.983)	(0.986)	(0.985)	(0.988)	(0.938)
Control variables	No	Yes	Yes	Yes	Yes	Yes
Municipal fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
F-statistic	29.00	24.23	22.77	21.51	20.30	19.39
Obs.	20,616	20,616	20,616	20,616	20,616	20,616

Note: Standard errors are in parentheses. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$. Robust standard errors are clustered at the municipal level. All regressions include municipality and year fixed effects. The control variables include the population density, the share of older people, and the average income per inhabitant.

Table A (b): Estimation results for paper packaging containers

	Paper packaging containers					
	(1)	(2)	(3)	(4)	(5)	(6)
	Coef.	*Coef.*	*Coef.*	*Coef.*	*Coef.*	*Coef.*
CPRL	-0.357	-0.367	-0.537	-0.538	-0.540	-0.533
	(0.457)	(0.453)	(0.438)	(0.438)	(0.438)	(0.434)
Freq			0.364 ***	0.366 ***	0.366 ***	0.367 ***
			(0.077)	(0.081)	(0.081)	(0.082)
Door				-0.079	-0.077	-0.078
				(0.379)	(0.381)	(0.381)
UBP					-0.194	-0.194
					(0.147)	(0.147)
Coope						-0.041
						(0.131)
Intercept	1.355 ***	2.692 **	2.048 *	2.050 *	2.160 *	2.165 *
	(0.058)	(1.117)	(1.097)	(1.098)	(1.104)	(1.103)
Control variables	No	Yes	Yes	Yes	Yes	Yes
Municipal fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
F-statistic	3.18	2.75	4.59	4.48	4.24	4.02
Obs.	20,616	20,616	20,616	20,616	20,616	20,616

Note: Standard errors are in parentheses. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$. Robust standard errors are clustered at the municipal level. All regressions include municipality and year fixed effects. The control variables include the population density, the share of older people, and the average income per inhabitant.

Appendix B

Table B: Estimation results for other recyclable waste (not subject to CPRL policy)

	Other recyclable waste (not subject to CPRL policy)					
	(1)	(2)	(3)	(4)	(5)	(6)
	Coef.	*Coef.*	*Coef.*	*Coef.*	*Coef.*	*Coef.*
CPRL (for Plastic packaging waste)	0.766	0.887	1.743			
	(1.279)	(1.250)	(1.523)			
CPRL (for Plastic bottles)				1.133	1.324	1.820
				(1.452)	(1.410)	(1.593)
Freq (for Plastic packaging waste)			-0.327			
			(0.406)			
Door (for Plastic packaging waste)			2.162			
			(2.556)			
Freq (for Plastic bottles)						-0.273
						(0.507)
Door (for Plastic bottles)						3.911
						(4.027)
UBP			-9.951			-10.048
			(8.580)			(8.562)
Coope			-1.351			-1.151
			(1.447)			(1.501)
Intercept	54.861 ***	40.428 *	46.232 ***	54.554 ***	40.103 *	45.955 ***
	(1.192)	(20.858)	(16.889)	(1.374)	(20.856)	(16.654)
Control variables	No	Yes	Yes	No	Yes	Yes
Municipal fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
F-statistic	3.27	4.52	3.56	2.92	4.34	3.52
Obs.	20,616	20,616	20,616	20,616	20,616	20,616

Note: Standard errors are in parentheses. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$. Robust standard errors are clustered at the municipal level. All regressions include municipality and year fixed effects. The control variables include the population density, the share of older people, and the average income per inhabitant.

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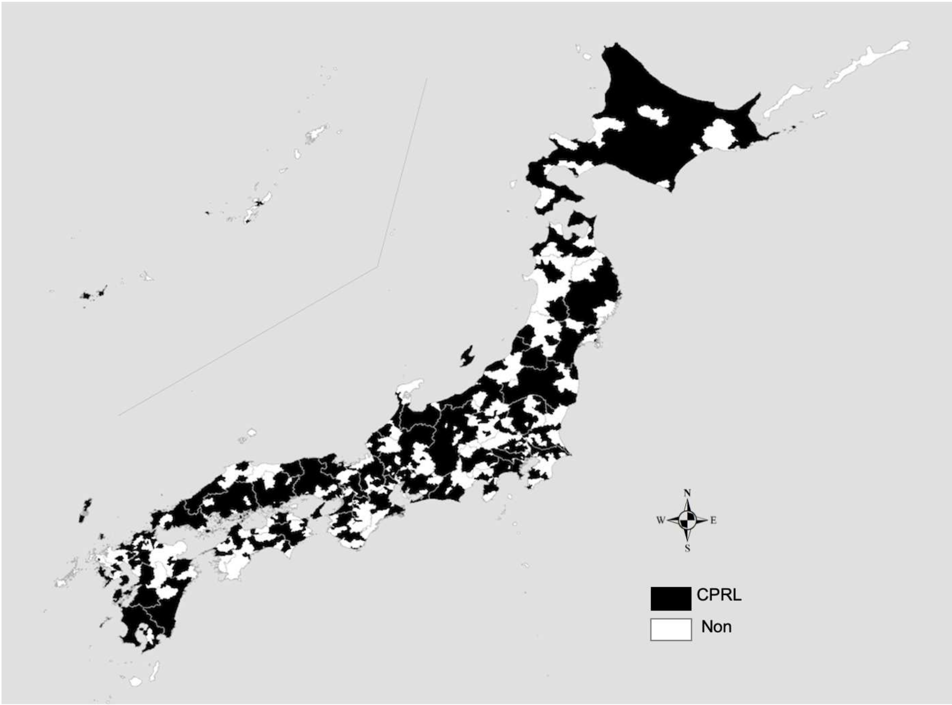
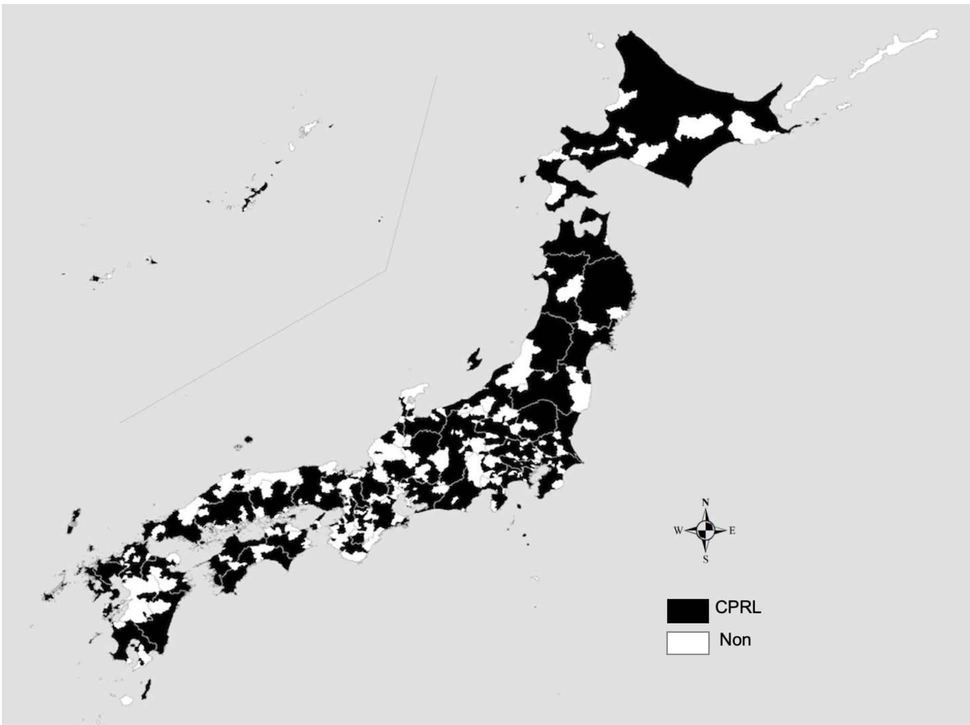
Figure 1: CPRL implementation across Japanese municipalities in 2018

(a) Plastic packaging waste

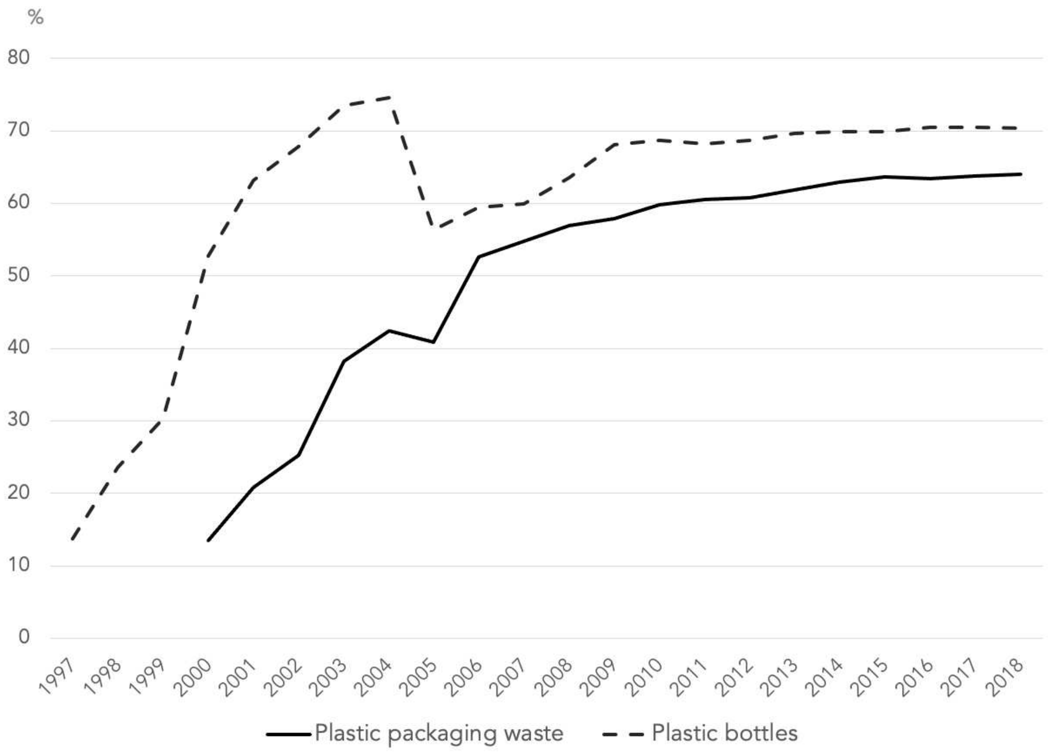


(b) Plastic bottle



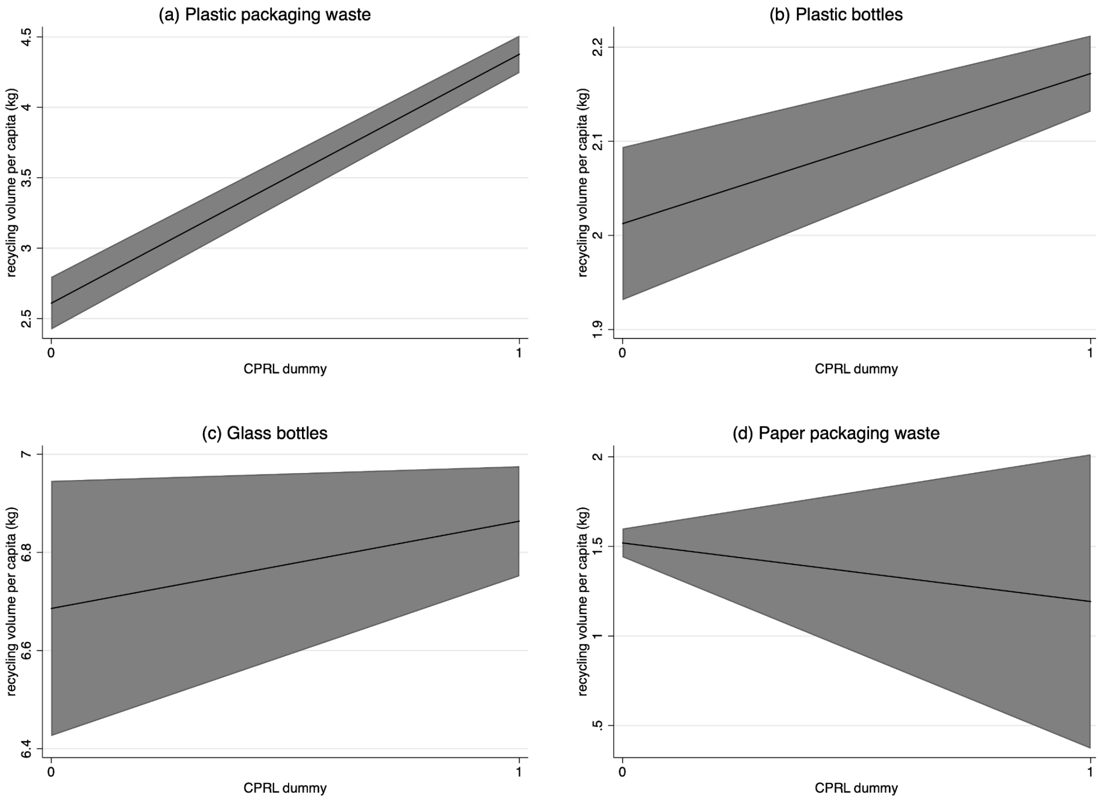
Note: This figure depicts the state of CPRL adoption in municipalities as of 2018. Panel (a) shows the state of CPRL adoption for plastic packaging waste, and Panel (b) shows the state of CPRL adoption for plastic bottles. This figure was created using information from Japan Containers and Packaging Recycling Association on CPRL.

Figure 2: The rate of CPRL implementation among Japanese municipalities



Note: This figure depicts the trend of yearly rate of municipalities adopting CPRL of plastic packaging waste (solid line) and plastic bottles (dashed line). Plastic packaging waste has been included in the CPRL since 2000. The trend in the adoption rate of CPRL decreased significantly in 2005 because of municipal mergers. This figure was created using information from Japan Containers and Packaging Recycling Association on CPRL.

Figure 3: CPRL adoption and recycling volume



Note: The graphs show the differences between CPRL-implementing and -non-implementing municipalities' average recycling volume per capita for plastic packaging waste (Panel a), plastic bottles (Panel b), glass bottles (Panel c), and paper containers (Panel d). The graphs also show fitted linear regression lines with 95% confidence intervals. The y-axis describes the amount of recycling output per capita, and the x-axis describes the dummy variable that takes the value of 1 for municipalities implementing CPRL. Regression coefficients and robust standard errors are in parentheses. Plastic packaging waste: 1.769*** (0.163); Plastic bottles: 0.159** (0.06); Glass bottles: 0.178 (0.190); Paper containers: -0.327 (0.460).

Table 1: Summary statistics

	Variable	Units	Average	SD	Min	Max
Plastic packaging waste	Recycling volume	kg/capita/year	3.644	4.820	0.000	37.001
	CPRL	dummy	0.585	0.493	0.000	1.000
	Subsidy	1000yen/kg/capita	19.652	47.862	0.000	1812.175
	Frequency	times/month	1.922	1.852	0.000	7.000
	Door-to-door	dummy	0.030	0.169	0.000	1.000
	Pref	%	56.895	18.391	4.000	93.900
PET bottle	Recycling volume	kg/capita/year	2.119	1.422	0.000	36.145
	CPRL	dummy	0.668	0.471	0.000	1.000
	Subsidy	1000yen/kg/capita	0.743	1.459	0.000	52.701
	Frequency	times/month	2.123	1.390	0.000	7.000
	Door-to-door	dummy	0.053	0.224	0.000	1.000
	Pref	%	65.467	22.041	0.000	100.000
	UBP	dummy	0.585	0.493	0.000	1.000
	Cooperation	dummy	0.218	0.413	0.000	1.000
	Density	capita/100km2	8.620	17.645	0.000	141.409
	Over 65 years old	%	28.523	7.599	0.000	100.000
	Income	hundred thousand yen	27.972	4.296	18.890	113.329

Note: SD, standard deviation. There are a total of 20,616 observations (which correspond to all 1,718 municipalities over 12 years). See the text for sources.

Table 2: First-stage results for plastic packaging waste (explaining the implementation of CPRL)

	Plastic packaging waste					
	(1)	(2)	(3)	(4)	(5)	(6)
	Coef.	*Coef.*	*Coef.*	*Coef.*	*Coef.*	*Coef.*
Pref (lag)	0.006 ***	0.006 ***	0.005 ***	0.005 ***	0.005 ***	0.005 ***
	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)
Freq			0.079 ***	0.078 ***	0.078 ***	0.074 ***
			(0.003)	(0.003)	(0.003)	(0.003)
Door				0.012	0.012	-0.003
				(0.036)	(0.036)	(0.034)
UBP					0.009	0.009
					(0.011)	(0.011)
Coope						0.195 ***
						(0.015)
Control variables	No	Yes	Yes	Yes	Yes	Yes
Municipal fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
F-statistic	348.36	344.41	268.500	268.18	267.45	237.69
Obs.	20,616	20,616	20,616	20,616	20,616	20,616

Note: Standard errors are in parentheses. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$. Robust standard errors are clustered at the municipal level. All regressions include municipality and year fixed effects. The control variables include the population density, the share of older people, and the average income per inhabitant.

Table 3: First-stage results for plastic bottles (explaining the implementation of CPRL)

	Plastic bottles					
	(1)	(2)	(3)	(4)	(5)	(6)
	Coef.	*Coef.*	*Coef.*	*Coef.*	*Coef.*	*Coef.*
Pref (lag)	0.006 ***	0.006 ***	0.006 ***	0.006 ***	0.006 ***	0.006 ***
	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0004)
Freq			0.018 ***	0.018 ***	0.017 ***	0.016 ***
			(0.003)	(0.003)	(0.003)	(0.003)
Door				-0.015	-0.020	-0.017
				(0.024)	(0.024)	(0.024)
UBP					0.045 ***	0.044 ***
					(0.011)	(0.011)
Coope						0.085 ***
						(0.014)
Control variables	No	Yes	Yes	Yes	Yes	Yes
Municipal fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
F-statistic	261.44	255.78	254.700	254.69	254.78	250.55
Obs.	20,616	20,616	20,616	20,616	20,616	20,616

Note: Standard errors are in parentheses. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$. Robust standard errors are clustered at the municipal level. All regressions include municipality and year fixed effects. The control variables include the population density, the share of older people, and the average income per inhabitant.

Table 4: Estimation results by OLS (plastic packaging waste)

	Plastic packaging waste					
	(1)	(2)	(3)	(4)	(5)	(6)
	Coef.	*Coef.*	*Coef.*	*Coef.*	*Coef.*	*Coef.*
CPRL	1.997 ***	1.987 ***	1.458 ***	1.455 ***	1.452 ***	1.416 ***
	(0.164)	(0.163)	(0.156)	(0.157)	(0.157)	(0.157)
Freq			0.448 ***	0.426 ***	0.422 ***	0.419 ***
			(0.052)	(0.053)	(0.053)	(0.053)
Door				1.391 **	1.375 **	1.355 **
				(0.616)	(0.615)	(0.617)
UBP					0.273	0.272
					(0.217)	(0.217)
Coope						0.271
						(0.180)
Intercept	2.367 ***	2.347 ***	2.072 **	2.055 **	1.906 **	1.887 **
	(0.109)	(0.850)	(0.811)	(0.814)	(0.825)	(0.816)
Control variables	No	Yes	Yes	Yes	Yes	Yes
Municipal fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
F-statistic	17.440	14.830	19.110	18.040	17.800	17.180
Obs.	20,616	20,616	20,616	20,616	20,616	20,616

Note: Standard errors are in parentheses. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$. Robust standard errors are clustered at the municipal level. All regressions include municipality and year fixed effects. The control variables include the population density, the share of older people, and the average income per inhabitant.

Table 5: Estimation results by OLS (plastic bottles)

	Plastic bottles					
	(1)	(2)	(3)	(4)	(5)	(6)
	Coef.	*Coef.*	*Coef.*	*Coef.*	*Coef.*	*Coef.*
CPRL	0.125 **	0.131 **	0.122 **	0.122 **	0.122 **	0.106 *
	(0.062)	(0.062)	(0.061)	(0.061)	(0.061)	(0.060)
Freq			0.055 ***	0.056 ***	0.056 ***	0.053 ***
			(0.017)	(0.017)	(0.017)	(0.017)
Door				0.201	0.201	0.210
				(0.172)	(0.172)	(0.171)
UBP					0.001	-0.001
					(0.047)	(0.047)
Coope						0.251 ***
						(0.058)
Intercept	2.203 ***	2.316 ***	2.240 ***	2.228 ***	2.228 ***	2.200 ***
	(0.045)	(0.526)	(0.523)	(0.521)	(0.527)	(0.519)
Control variables	No	Yes	Yes	Yes	Yes	Yes
Municipal fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
F-statistic	13.34	11.25	11.19	10.57	9.98	9.96
Obs.	20,616	20,616	20,616	20,616	20,616	20,616

Note: Standard errors are in parentheses. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$. Robust standard errors are clustered at the municipal level. All regressions include municipality and year fixed effects. The control variables include the population density, the share of older people, and the average income per inhabitant.

Table 6: Estimation results by IV regressions (plastic packaging waste)

	Plastic packaging waste					
	(1)	(2)	(3)	(4)	(5)	(6)
	Coef.	*Coef.*	*Coef.*	*Coef.*	*Coef.*	*Coef.*
CPRL	3.915 ***	3.783 ***	3.155 ***	3.124 ***	3.079 ***	3.107 ***
	(0.444)	(0.442)	(0.520)	(0.519)	(0.520)	(0.562)
Freq			0.307 ***	0.289 ***	0.288 ***	0.288 ***
			(0.056)	(0.056)	(0.056)	(0.057)
Door				1.363 ***	1.349 ***	1.354 ***
				(0.344)	(0.343)	(0.343)
UBP					0.247 *	0.247 *
					(0.139)	(0.139)
Coope						-0.080
						(0.170)
Control variables	No	Yes	Yes	Yes	Yes	Yes
Municipal fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
F-statistic	12.42	11.88	28.74	27.80	27.36	28.79
Weak-ID test Kleibergen-Paap F-stat	348.36	344.41	268.5	268.18	267.45	237.690
Weak-ID test Cragg-Donald F-stat	662.43	657.72	504.55	504.20	501.87	445.400
Under-ID test LM stat	320.169 ***	315.488 ***	250.515 ***	250.261 ***	249.698 ***	222.767 ***
Obs.	20,616	20,616	20,616	20,616	20,616	20,616

Note: Standard errors are in parentheses. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$. Robust standard errors are clustered at the municipal level. All regressions include municipality and year fixed effects. The control variables include the population density, the share of older people, and the average income per inhabitant.

Table 7: Estimation results by IV regressions (plastic bottles)

	Plastic bottles					
	(1)	(2)	(3)	(4)	(5)	(6)
	Coef.	*Coef.*	*Coef.*	*Coef.*	*Coef.*	*Coef.*
CPRL	0.462 **	0.547 ***	0.532 ***	0.533 ***	0.532 ***	0.497 **
	(0.194)	(0.204)	(0.205)	(0.205)	(0.205)	(0.207)
Freq			0.048 ***	0.048 ***	0.049 ***	0.047 ***
			(0.011)	(0.011)	(0.011)	(0.010)
Door				0.208 *	0.210 *	0.216 *
				(0.113)	(0.114)	(0.114)
UBP					-0.017	-0.018
					(0.034)	(0.034)
Coope						0.215 ***
						(0.035)
Control variables	No	Yes	Yes	Yes	Yes	Yes
Municipal fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
F-statistic	13.45	13.40	14.85	14.01	13.23	16.02
Weak-ID test Kleibergen-Paap F-stat	261.44	255.78	254.7	254.69	254.78	250.55
Weak-ID test Cragg-Donald F-stat	581.32	566.81	562.03	561.92	564.64	550.85
Under-ID test LM stat	235.879 ***	231.261 ***	230.580 ***	230.582 ***	230.868 ***	227.711 ***
Obs.	20,616	20,616	20,616	20,616	20,616	20,616

Note: Standard errors are in parentheses. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$. Robust standard errors are clustered at the municipal level. All regressions include municipality and year fixed effects. The control variables include the population density, the share of older people, and the average income per inhabitant.

Table 8: Estimation results for subsidies on plastic waste recycling

	Plastic packaging waste			Plastic bottles		
	(1)	(2)	(3)	(4)	(5)	(6)
	Coef.	*Coef.*	*Coef.*	*Coef.*	*Coef.*	*Coef.*
Sub (lag)	2.426 ***	2.392 ***	1.943 **	3.978	3.324	1.904
	(0.890	(0.883)	(0.839)	(12.072)	(11.994)	(11.918)
Freq			0.367 ***			0.049 **
			(0.055)			(0.019)
Door			1.831 **			0.134
			(0.804)			(0.186)
UBP			0.542 **			0.026
			(0.213)			(0.058)
Coope			0.653 ***			0.244 ***
			(0.185)			(0.069)
Intercept	3.283 ***	3.148 ***	2.130 **	2.025 ***	2.707 ***	2.560 ***
	(0.066)	(1.093)	(0.998)	(0.030)	(0.527)	(0.534)
Control variables	No	Yes	Yes	No	Yes	Yes
Municipal fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
F-statistic	3.48	3.02	7.12	16.40	13.13	10.79
Obs.	17,180	17,180	17,180	17,180	17,180	17,180

Note: Standard errors are in parentheses. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$. Robust standard errors are clustered at the municipal level. All regressions include municipality and year fixed effects. There are a total of 17,180 observations (which correspond to all 1,718 municipalities over ten years) in this analysis because the subsidy policy for municipalities on the amount of recycling began in 2008. The control variables include the population density, the share of older people, and the average income per inhabitant.

Table 9: Estimation results for the alternative IV strategy (geographically neighbouring relationships)

	Plastic packaging waste			Plastic bottles		
	(1)	(2)	(3)	(4)	(5)	(6)
	Coef.	*Coef.*	*Coef.*	*Coef.*	*Coef.*	*Coef.*
Panel A: First stage (Introduction of CPRL)						
*W*CPRL (lag)	0.378 ***	0.377 ***	0.282 ***	0.320 ***	0.317 ***	0.304 ***
	(0.020)	(0.020)	(0.019)	(0.020)	(0.020)	(0.020)
Control variables	No	Yes	Yes	No	Yes	Yes
Policy variables	No	No	Yes	No	No	Yes
Municipal fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
F-statistic	347.84	343.59	228.04	245.93	241.40	229.85
Panel B: Second stage (Recycling volume)						
CPRL	3.136 ***	2.994 ***	1.868 ***	0.533 ***	0.609 ***	0.515 ***
	(0.407)	(0.405)	(0.540)	(0.177)	(0.179)	(0.184)
Freq			0.384 ***			0.047 ***
			(0.055)			(0.010)
Door			1.355 ***			0.217 *
			(0.341)			(0.113)
UBP			0.266 *			-0.018
			(0.139)			(0.032)
Coope			0.177			0.214 ***
			(0.162)			(0.034)
Control variables	No	Yes	Yes	No	Yes	Yes
Municipal fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
F-statistic	12.49	11.60	28.50	14.66	13.93	16.49
Weak-ID test Kleibergen-Paap F-stat	347.84	343.59	228.04	245.93	241.4	229.800
Weak-ID test Cragg-Donald F-stat	1050.24	1038.94	621.57	813.53	791.09	722.390
Under-ID test LM stat	300.844 ***	299.758 ***	216.314 ***	207.427 ***	205.299 ***	201.146 ***
Obs.	20,616	20,616	20,616	20,616	20,616	20,616

Note: Standard errors are in parentheses. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$. Robust standard errors are clustered at the municipal level. All regressions include municipality and year fixed effects. The control variables include the population density, the share of older people, and the average income per inhabitant.

Table 10: Estimation results for the alternative IV strategy (intensity of CPRL policy)

	Plastic packaging waste			Plastic bottles		
	(1)	(2)	(3)	(4)	(5)	(6)
	Coef.	*Coef.*	*Coef.*	*Coef.*	*Coef.*	*Coef.*
Panel A: First stage (Introduction of CPRL)						
*W*Intense (lag)	0.508 ***	0.506 ***	0.335 ***	0.432 ***	0.425 ***	0.387 ***
	(0.034)	(0.034)	(0.032)	(0.033)	(0.033)	(0.032)
Control variables	No	Yes	Yes	No	Yes	Yes
Policy variables	No	No	Yes	No	No	Yes
Municipal fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
F-statistic	219.86	216.00	110.08	170.58	166.75	143.85
Panel B: Second stage (Recycling volume)						
CPRL	3.936 ***	3.721 ***	2.608 ***	1.001 ***	1.136 ***	0.960 ***
	(0.538)	(0.535)	(0.806)	(0.229)	(0.236)	(0.254)
Freq			0.327 ***			0.039 ***
			(0.072)			(0.011)
Door			1.354 ***			0.225 *
			(0.342)			(0.115)
UBP			0.254 *			-0.037
			(0.139)			(0.033)
Coope			0.023			0.173 ***
			(0.209)			(0.038)
Control variables	No	Yes	Yes	No	Yes	Yes
Municipal fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
F-statistic	11.70	11.08	27.91	15.41	13.66	15.82
Weak-ID test Kleibergen-Paap F-stat	219.859	216.004	110.078	170.584	166.747	143.851
Weak-ID test Cragg-Donald F-stat	555.099	543.563	256.927	460.301	441.295	355.905
Under-ID test LM stat	190.02	189.642	106.339	149.918	149.023	134.479
Obs.	20,616	20,616	20,616	20,616	20,616	20,616

Note: Standard errors are in parentheses. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$. Robust standard errors are clustered at the municipal level. All regressions include municipality and year fixed effects. The control variables include the population density, the share of older people, and the average income per inhabitant.