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SPECIAL FEATURE: ORIGINAL ARTICLE

Plastic flow and its management

Survey and analysis on the use and disposal of plastic shopping bags before and after the introduction of charges

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Abstract

Japan implemented mandatory charging for single-use plastic shopping bags in 2020. In this study, we verified the policy effect and its persistence by analyzing the changes in the number of plastic shopping bags taken and discarded by consumers before and after the charging came into effect. Online surveys were conducted in 2016, 2021, 2022, and 2023 for consumers residing in municipalities in Tokyo. The results showed that the number of plastic shopping bags taken decreased to approximately 30% after the charging was implemented, from 5.8 bags per person per week in 2016 to 1.7–1.9 in 2021–2023, and the number of bags discarded decreased from 6.2 to 3.0–3.4. The number of bags taken in 2021–2023 after the charging was implemented did not change significantly. Regarding the relationship with other waste policies, in municipalities that have introduced designated trash bags, the number of plastic shopping bags taken and discarded was fewer than in other municipalities even before the charging was introduced, by removing the option of reusing plastic bags as trash bags. This result indicates that, when introducing such policies, the relationship with existing waste policies must be analyzed to predict their effect.

Keywords Plastic shopping bag · Designated trash bag · Separate collection for recycling · Single-use plastic · Tokyo

Introduction

Plastic shopping bags that are available at retail stores, such as supermarkets and convenience stores, for carrying products are often discarded after a single use and perceived as one of the most problematic single-use plastics, given their easily observable presence in the environment [1]. In the Ocean Plastics Charter endorsed at the G7 summit in 2018 [2], countries were required to take action to increase the efficient use of resources by significantly reducing the unnecessary use of single-use plastics, thereby reducing greenhouse gas (GHG) emissions and preventing waste and litter from being released into the environment. Various solutions, including bans or taxes on single-use bags, will be required to reduce plastic waste [3]. Particularly in emerging and developing countries in which the infrastructure for collecting and properly treating plastic waste is immature, reduction in single-use plastics is essential to solve plastic pollution issues including marine litter. The impacts of plastic life cycle on climate change and pathways to mitigate these impacts have been discussed [4]. Previous research has recommended application of life cycle assessment (LCA) to evaluate climate change and other environmental impacts of plastic shopping bag use [5]. Several LCA studies have evaluated its life cycle GHG emissions, or carbon footprints, around the world; for example, the carbon footprints associated with plastic shopping bag use were evaluated in China, Hong Kong, India [6], Japan [7], Singapore [8], and Finland [9] in comparison with the use of alternatives such as paper and durable cotton shopping bags. Overall, the reduction of plastic bags was found to contribute to mitigating the climate change impacts although certain conditions sometimes accompanied the findings. Thus, effective measures to reduce plastic bag use are significant in developed countries as well although the amount of mismanaged plastic waste that may lead to marine litter is comparably small in

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these countries owing to the matured waste management system (e.g., the amount of macroplastic emissions from the land to the ocean were estimated at 146 to 4273 t/year in Japan [10], which corresponded to 0.004 to 0.1% of the total single-use plastic packaging use of the nation, 4074 t/year in 2015 [11]).

To curb the excessive use of single-use plastics, regulations including bans and levies on plastic bags have been introduced worldwide at the national and local levels [1]. For example, 271 local governments in the United States implemented plastic bag ordinances covering 9.7% of the nation's population (as of September 2017); most ordinances banned single-use plastic bags [12]. The effect of such regulations has been surveyed in various countries, and there have been examples of policies leading to reduced consumption of plastic bags [13], with Ireland at the top of the list (with more than 90% reduction in the use of plastic bags in retail stores after the implementation of the levy [14]). In Portugal, the implementation of a plastic bag tax resulted in a 74% reduction of plastic bag consumption [15]. Meanwhile, an analysis in Toronto, Canada showed that the plastic bag levy resulted in a 3.4% increase in the number of people who typically brought *reusable* shopping bags to grocery stores [16]. Regulations on plastic bags have not only been implemented in developed countries; for example, in Turkey, the practice of offering plastic bags free of charge was banned as of 2019 [17]. In the survey results in Islamabad, Pakistan, where the government imposed a ban on single-use plastic bags in August 2019, plastic bag consumption fell for 77.5% of the study sample after the ban [18]. On the other hand, in South Africa, the plastic bag levy had succeeded in reducing consumption in the short term; however its effectiveness was diminished over time [19]. Similarly, retailer-level panel data in a specific municipality of Nepal indicated that plastic bag use was reduced by 63% in a month after the ban, whereas it was slightly rebounded a year after the ban [20].

In Japan, plastic shopping bags came into use in the 1970s; their use increased due to their convenience, and each person used approximately 350 plastic shopping bags yearly around 2005 [21]. Against this backdrop, the Japanese government implemented mandatory charges for single-use plastic shopping bags with handles mandatory on July 1, 2020 (hereafter, "charging" refers to this charging mandated in Japan). The effect of charging for plastic shopping bags has also been surveyed in Japan. Seo and Kudo [22] explored the factors that influenced the reduction of use of plastic bags, including charging, and found that attempting to reduce their use could significantly influence environmental risk perception and reuse behavior. A consumer questionnaire conducted by the Ministry of the Environment [23] showed that between March and November 2020, before and after the charging came into effect, respectively, the percentage of people who refused plastic shopping bags during shopping in a week increased from 30.4 to 71.9%. In addition, a public opinion survey on plastic waste problems conducted by the Cabinet Office [24] showed that in September and October 2022, the percentage of people who refused plastic shopping bags before and after the charging came into effect was 16.1% and 44.1%, respectively, and the percentage of people who refused when plastic shopping bags were chargeable but accepted them when free was 25.3%. Although these surveys examined the percentage of people who refused plastic shopping bags, the number of reductions in plastic shopping bag use was not investigated. In addition, an interview of industry groups by the Ministry of the Environment [25] showed that the percentage of plastic shopping bag refusal at convenience stores and supermarkets increased from 23 and 57%, respectively, before charging to approximately 75% and 80% after charging, respectively. The use of plastic shopping bags at drug stores was also decreased by approximately 84%. However, in this survey, the decline in the domestic supply of plastic shopping bags was only approximately 50%, which raised the question of a large discrepancy between the reduction in the refusal rate and the number of plastic shopping bags used. In addition, the questionnaire survey of consumers by the Ministry of the Environment [23] was conducted before the charging came into effect and after the publication of a report in late 2019 on the decision to charge for plastic shopping bags [26]; thus consumers' behaviors might have already assumed that plastic shopping bags would be charged. However, these surveys did not examine whether the effect of the charging policy was maintained after it was implemented.

Used plastic shopping bags are sometimes reused as trash bags to dispose waste (trash bag). According to Fukuoka et al. [27], 14% (number of bags) of plastic shopping bags in household garbage were reused as trash bags. However, this report covered the municipalities that had not introduced designated trash bags. In municipalities that have introduced designated trash bags, plastic shopping bags should not be reused as trash bags (although they could be reused to sort waste within a trash bag). In addition, in some municipalities, plastic shopping bags are collected and recycled as "plastic containers and packaging other than plastic bottles" (hereafter referred to as "plastic waste"), according to the Containers and Packaging Recycling Law. Therefore, policies related to plastic waste collection may affect the disposal and use of plastic shopping bags; however the relationship between the effect of regulations on plastic shopping bags and other local waste policies has not been considered in the previous studies in Japan and, to the best of our knowledge, in other countries.

In this study, we focused on the differences in waste policies, such as the introduction of designated trash bags and curbside separate collection of plastic packaging waste for recycling (hereinafter, referred to as "separate collection of

plastic waste"), in municipalities (ku [wards] and shi [cities]) in Tokyo, Japan. Furthermore, this study verified the policy effect and its persistence by clarifying the number of plastic shopping bags taken and discarded by consumers before and after charging was introduced (2016 and 2021–2023) and analyzed changes over time after charging for plastic shopping bags (2021–2023). The survey format was an online questionnaire, and the effect of charging and its persistence were assessed using a two-way analysis of variance (ANOVA). However, towns and villages in the island and western areas of Tokyo have relatively small populations, making it difficult to secure a sufficient sample for the questionnaire; thus they were excluded from the survey.

Material and methods

Classification of municipalities based on the waste policy implementations

When focusing on the waste policies related to the introduction of designated trash bags and the implementation of separate collection of plastic waste for recycling, the municipalities surveyed in Tokyo can be classified into (a–d) in Table 1 and Fig. 1. For example, Chuo-ku, which does not have designated trash bags but has implemented separate collection of plastic waste for recycling, is classified into waste policy category (a); Bunkyo-ku, which has neither the designated trash bags nor the separate collection of plastic waste, is classified into category (b); Hachioji-shi, which has both the designated trash bags and the separate collection of plastic waste, is classified into category (c); and Komae-shi, which has the designated trash bags but has not implemented the separate collection of plastic waste, is classified into category (d). Note that Kodaira-shi, Kunitachi-shi, and Higashikurume-shi, classified into category (a) in the 2016 survey, had introduced the designated trash bags by the time of the 2021 survey and became category (c) municipalities. Hino-shi, classified into category (d) in the 2016 survey, had implemented the separate collection of plastic waste by the time of the 2021 survey and became category (c) municipality. Machida-shi, which was classified into category (d) in the 2016 survey, had implemented the separate collection of plastic waste in the southern district by the time of the 2021 survey; thus its classification was changed to category (c), while other districts of Machida-shi remained in category (d). There was no municipality whose classification changed between the 2021 and 2022 surveys. Furthermore, Musashimurayama-shi, classified into category (a) in the 2022 survey, had introduced the designated trash bags by the time of the 2023 survey and became category (c) municipality. Shibuya-ku, which was classified into category (b) in the 2022 survey, had implemented the separate collection of plastic waste by the time of the 2023 survey and became category (a) municipality. In Kita-ku, which was classified into category (b) in the 2022 survey, the Takinogawa district had implemented the separate collection of plastic waste by the time of the 2023 survey; thus its classification was changed to category (a), while the classification of the rest of Kita-ku remained in category (b). Furthermore, some municipalities classified into category (a), including Chiyoda-ku and Minato-ku, collect plastic products in a mixed manner with plastic packaging waste for recycling, and Shibuya-ku has also fallen into this category since 2023. As the collection of plastic product waste is considered to have no direct effect on the use and disposal of plastic shopping bags, we did not segregate the above-mentioned municipalities from other category (a) municipalities.

Survey details

Questions regarding the use and disposal of plastic shopping bags in the 2016, 2021, 2022, and 2023 surveys are shown in Tables 2 and 3, in which the number of bags was surveyed not for households but for individuals. Before the questions, the definition of single-use plastic shopping bags targeted in the survey, that is, shopping bags made from plastics available at retail stores for carrying products, was provided to respondents.

In terms of the use of plastic shopping bags, a participant was asked to note the number of bags that he/she had taken to carry items home in the preceding week from each type of store. We did not ask whether the plastic shopping bags were paid for or free of charge in the 2016 survey (before the charging for plastic shopping bags was introduced). In Japan, even after charges for plastic shopping bags were introduced, when certain conditions (ratio of biomass material is 25% or higher, the ratio of marine-biodegradable plastic is 100%, or film thickness is 0.05 mm or higher) were met, bags could be distributed free of charge. Therefore, in the 2021–2023 surveys, a participant was asked to note the number of bags obtained with and without a fee separately (the type of store was noted only for bags with a fee). In terms of the use of plastic shopping bags, the questions remained the same regardless of municipality classification. A participant was asked to record the number of plastic shopping bags that he/she obtained each day over a one-week survey in a dedicated form shown in Appendix 1 and subsequently fill in the total number for the entire week in the response box at the end of the survey period. The aforementioned definition of single-use plastic shopping bags was also presented on the form as a reminder for respondents.

In terms of the disposal of plastic shopping bags, a participant was asked to note the number of bags that he/she had disposed or reused at home in the preceding week for each manner of disposal and reuse in the 2016, 2021, 2022,

Table 1 Classification of municipalities based on the implementation of waste policies

Waste policy category	Designated trash bag	Separate collection of plastic waste	Corresponding municipalities (2016 survey)	Corresponding municipalities (2021 and 2022 surveys)	Corresponding municipalities (2023 survey)
(a)	No	Yes	Chiyoda-ku, Chuo-ku, Minato-ku, Shinjuku-ku, Koto-ku, Shinagawa-ku, Meguro-ku, Nakano-ku, Suginami-ku, Nerima-ku, Katsushika-ku, Edogawa-ku, Musashimurayama-shi, Kodaira-shi, Kunitachi-shi, Higashikurume-shi	Chiyoda-ku, Chuo-ku, Minato-ku, Shinjuku-ku, Koto-ku, Shinagawa-ku, Meguro-ku, Suginami-ku, Nerima-ku, Katsushika-ku, Edogawa-ku, Musashimurayama-shi	Chiyoda-ku, Chuo-ku, Minato-ku, Shinjuku-ku, Koto-ku, Shinagawa-ku, Meguro-ku, Nakano-ku, Suginami-ku, Nerima-ku, Katsushika-ku, Edogawa-ku, Shibuya-ku, Kita-ku (Takinogawa district)
(b)	No	No	Bunkyo-ku, Taito-ku, Sumida-ku, Ota-ku, Setagaya-ku, Toshima-ku, Arakawa-ku, Itabashi-ku, Adachi-ku, Shibuya-ku, Kita-ku	Bunkyo-ku, Taito-ku, Sumida-ku, Ota-ku, Setagaya-ku, Toshima-ku, Arakawa-ku, Itabashi-ku, Adachi-ku, Shibuya-ku, Kita-ku	Bunkyo-ku, Taito-ku, Sumida-ku, Ota-ku, Setagaya-ku, Toshima-ku, Arakawa-ku, Itabashi-ku, Adachi-ku, Kita-ku (excl. Takinogawa district)
(c)	Yes	Yes	Hachioji-shi, Tachikawa-shi, Musashino-shi, Mitaka-shi, Ome-shi, Fuchu-shi, Akishima-shi, Chofu-shi, Koganei-shi, Higashimurayama-shi, Kokubunji-shi, Fussa-shi, Higashiyamato-shi, Kiyose-shi, Tama-shi, Hamura-shi, Nishitokyo-shi	Hachioji-shi, Tachikawa-shi, Musashino-shi, Mitaka-shi, Ome-shi, Fuchu-shi, Akishima-shi, Chofu-shi, Koganei-shi, Higashimurayama-shi, Kokubunji-shi, Fussa-shi, Higashiyamato-shi, Kiyose-shi, Tama-shi, Hamura-shi, Nishitokyo-shi, Kodaira-shi, Kunitachi-shi, Higashikurume-shi, Hino-shi, Machida-shi, (southern district)	Hachioji-shi, Tachikawa-shi, Musashino-shi, Mitaka-shi, Ome-shi, Fuchu-shi, Akishima-shi, Chofu-shi, Koganei-shi, Higashimurayama-shi, Kokubunji-shi, Fussa-shi, Higashiyamato-shi, Kiyose-shi, Tama-shi, Hamura-shi, Nishitokyo-shi, Kodaira-shi, Kunitachi-shi, Higashikurume-shi, Hino-shi, Machida-shi (southern district), Musashimurayama-shi
(d)	Yes	No	Komae-shi, Inagi-shi, Akiruno-shi, Hino-shi, Machida-shi	Komae-shi, Inagi-shi, Akiruno-shi, Machida-shi (excl. southern district)	Komae-shi, Inagi-shi, Akiruno-shi, Machida-shi (excl. southern district)

Underline indicates the municipalities whose classification changed in the 2021, 2022, and 2023 surveys compared to the 2016 survey

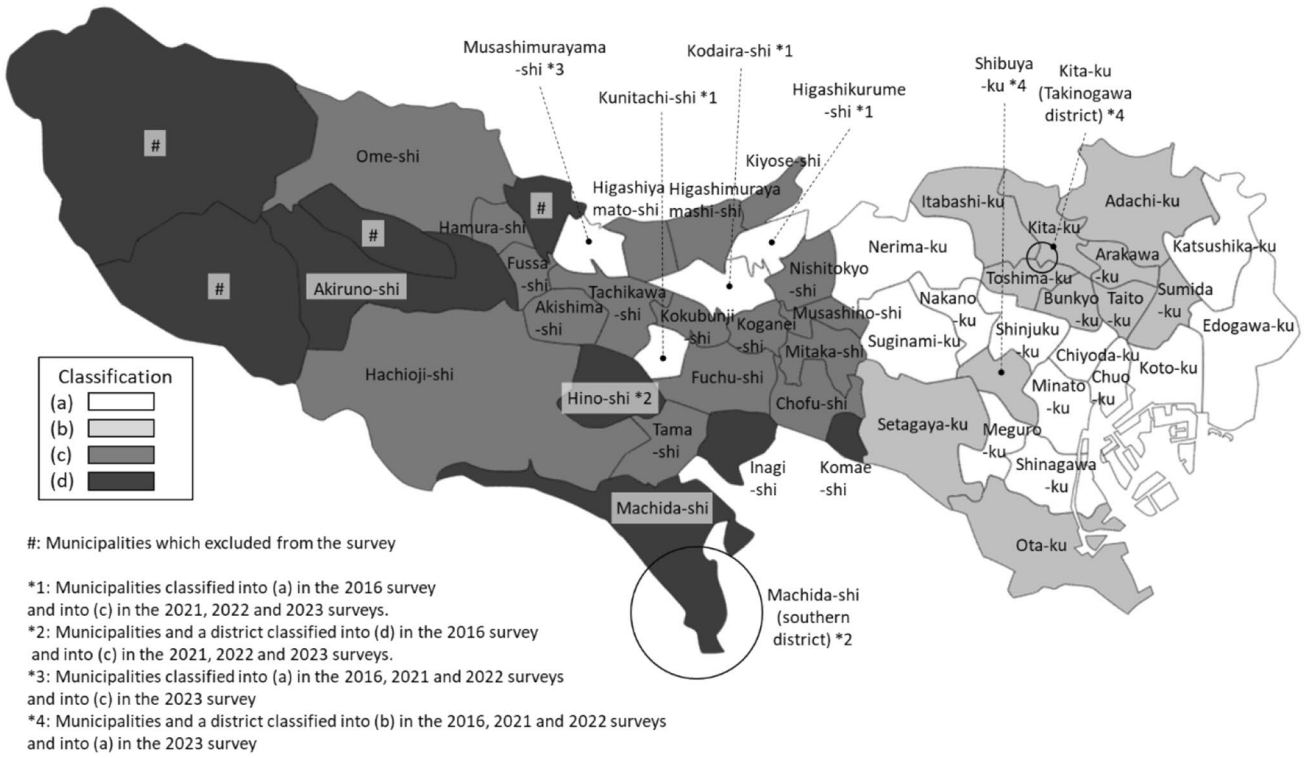

Fig. 1 Map of municipalities in Tokyo and their classification based on the implementation of waste policies

Table 2 Questions on the use of plastic shopping bags

Question		Notes
The number of plastic shopping bags taken during shopping and brought home in the preceding week	Supermarket	Inquired in the 2016 survey
	Convenience stores	
	Drug stores	
	Butcher/seafood store/greengrocer	
	Bakery/side dish store/confectioner	
	Other retail stores	
The number of plastic shopping bags purchased to carry items home in the preceding week	Supermarket	Inquired in the 2021, 2022, and 2023 surveys
	Convenience stores	
	Drug stores	
	Butcher/seafood store/greengrocer	
	Bakery/side dish store/confectioner	
	Other retail stores	
The number of plastic shopping bags that were provided free of charge and brought home in the preceding week		Inquired in the 2021, 2022, and 2023 surveys

and 2023 surveys. As with the number of plastic shopping bags obtained, a participant was asked to record the number of bags that he/she discarded each day using the form shown in Appendix 1 and subsequently fill in the total number for the entire week in the response box at the end of the survey period. The common disposal and reuse options for the municipality classifications (a)–(d) were "disposed as combustible waste," "disposed as incombustible waste," and "reused for other purposes." Only municipalities with waste policy categories (a) and (c) with separate collection of plastic waste had the option of "disposed as recyclable waste (plastic waste)." Category (a) and (b) municipalities without designated trash bags had the option of "reused as a trash bag," and category (c) and (d) municipalities with

Table 3 Questions on the disposal of plastic shopping bags by municipality classification

Question	Municipality classification			
	(a)	(b)	(c)	(d)
The number of plastic shopping bags that were disposed or reused at home in the preceding week				
Disposed as combustible waste	✓	✓	✓	✓
Disposed as incombustible waste	✓	✓	✓	✓
Disposed as recyclable waste (plastic waste)	✓		✓	
Reused as a trash bag	✓	✓		
Reused to sort trash in a trash bag			✓	✓
Reused with other methods	✓	✓	✓	✓

Table 4 Overview of survey implementation

Survey year	Period	Number of requests	Number of valid responses		
2016	February 15–17	3769	3015	(a)	1142
				(b)	965
				(c)	712
				(d)	196
2021	February 15–17	5308	4325	(a)	1550
				(b)	1410
				(c)	1157
				(d)	208
2022	February 14–16	5122	4385	(a)	1571
				(b)	1453
				(c)	1156
				(d)	205
2023	February 14–16	4624	3924	(a)	1417
				(b)	1241
				(c)	1076
				(d)	190

designated trash bags had the option of "reused to sort trash in a trash bag."

Survey implementation

Table 4 shows the survey periods and the number of respondents who participated in the surveys. The survey format was an online questionnaire. The survey was sent to a number of people proportional to the population of each municipality in terms of sex and age group (i.e., 20s and 30s, 40s and 50s, and 60 and older) in Tokyo [28] who were registered with a survey company. As the valid response rates were not 100% (80–86% depending on the survey years), the compositions of sex and age groups within the valid responses were not necessarily proportional to the demographics. Towns and villages in the islands and western areas of Tokyo that were excluded from the survey constituted merely 0.6% of the population of Tokyo; thus, excluding these towns and villages had a limited impact on the study. Samples with more than 50 obtained or discarded bags were considered excessive for 1 week and were treated as invalid responses.

Statistical analysis

Two-way ANOVA was conducted to evaluate the effects of the survey years (2016, 2021, 2022, and 2023) and the municipality classifications based on the waste policy implementations on the number of plastic shopping bags obtained and discarded to understand the characteristics of these numbers. As for the survey year, only 2016 was the year before the charge for plastic shopping bags came into effect; thus, we performed the two-way ANOVA considering all 4 years (2016, 2021, 2022, and 2023) as a factor for examining the effect of charging and performed another analysis to examine the persistence of the charging policy effect with only the years after charging (2021, 2022, and 2023) as the factor. In all analyses, the significance level was set at 5%. In cases where the survey years or the municipality classification had a significant effect on the number of bags taken or discarded, multiple comparisons were performed using Tukey's HSD test to understand the difference in the average values between the survey years and the municipality classifications.

Results

Number of plastic shopping bags taken

Figure 2 shows the number of bags taken per person per week in Tokyo, and Fig. 3 shows the number of bags taken per person per week in relation to the municipality classifications (a–d) (Appendix 2 for the number of bags taken for each year and each municipality). Table 5 shows the result of the two-way ANOVA on the number of bags taken. The result shows that the interactions between the survey year and municipality classification were significant in the years before and after implementing the plastic bag charges (2016, 2021, 2022, and 2023). These interactions are shown in Fig. 4. However, in the years after the charging came into effect (2021, 2022, and 2023), as the main effects of the survey year and interactions between the survey year and municipality classification were not significant, the result of the multiple comparisons of the municipality classification using Tukey's HSD test is shown in Table 6.

As shown in Fig. 2, the number of plastic shopping bags taken per person per week was 5.8 before the introduction

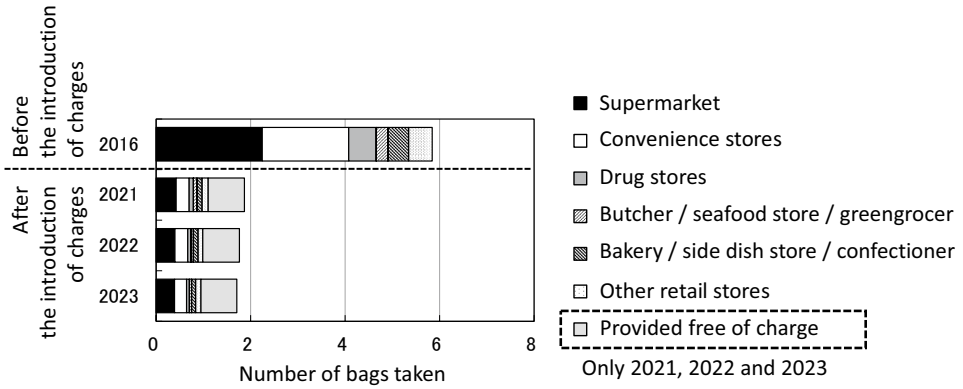

Fig. 2 Number of plastic shopping bags taken by consumers in Tokyo

of charging in the 2016 survey but decreased to approximately 30% (1.9) after the implementation of charging in the 2021 survey. The two-way ANOVA result (Table 5) also confirmed a significant reduction in the number of plastic shopping bags taken due to the implementation of charging. The numbers of plastic shopping bags taken were 1.8 and 1.7 in the surveys conducted 1.5 and 2.5 years after the introduction of the charging in 2022 and 2023, respectively. Although there was a slight decreasing trend with each year, the results of the two-way ANOVA (Table 5) showed no significant difference. As life without plastic shopping bags became the norm, there was no increasing trend in the effect of the charging policy; however, there was at least no trend where the charging policy effect decreased due to complacency. Regarding the number of plastic shopping bags taken (with fees) after the charging came into effect, the proportions of store types where the bags were obtained did not change significantly compared with those before the charging. In the 2021–2023 surveys after the charging came into effect, the plastic shopping bags provided free of charge accounted for approximately 40% of all plastic shopping bags. This could be vital for further reduction in the use of single-use plastic shopping bags.

Figure 3 shows that, in all survey years, the number of plastic shopping bags taken was the highest in category (a) municipalities, in which the designated trash bags are not introduced but plastic wastes are collected separately, followed by category (b) municipalities, in which the designated trash bags are not introduced and plastic wastes are not collected separately. However, the error bars also indicate that variations among the municipalities within each category cannot be ignored. In addition, there was a notable difference between categories (a) and (b) and categories (c) and (d) before the charging, but the difference decreased after the charging came into effect.

Changes in the number of bags taken with the charging

The two-way ANOVA that included the 2016 survey (Table 5) showed that the *F*-statistics of the main effect of the survey year, the main effect of municipality classification, and their interaction were larger than their criterion for rejecting the null hypothesis (2.60, 2.60, and 1.88, respectively). This means that the survey year and municipality classification influenced the number of plastic shopping bags taken and that there were interactions between the survey year and municipality classification. The interaction between the survey year and municipality classification (Fig. 4) shows that the number of plastic shopping bags taken in the 2016 survey before the plastic shopping bag charge was 6.2 in categories (a) and (b) municipalities, while it was 1.3 fewer, i.e., 4.9, in category (c) and (d) municipalities. Municipalities classified as categories (c) and (d) have introduced designated trash bags, which might have suppressed the use of plastic shopping bags. Between the 2016 and 2021 surveys, which are before and after the introduction of the plastic shopping bag charge, the number of plastic shopping bags taken declined by 4.4, 4.5, 3.3, and 3.6 in categories (a), (b), (c), and (d), respectively. The reduction was less in categories (c) and (d). Since categories (c) and (d) municipalities had a suppressed use of plastic shopping bags even before the introduction of the plastic shopping bag charge, the impact of the plastic shopping bag charge was not prominent.

The simple main effect of the survey year for each municipality classification (Appendix 4) indicates that only the average numbers of bags taken in 2016 were significantly different from those in the other survey years in all municipality classifications and that there was no significant difference in those among 2021, 2022, and 2023. The simple main effect of each municipality classification in each survey year (Appendix 5) indicates that

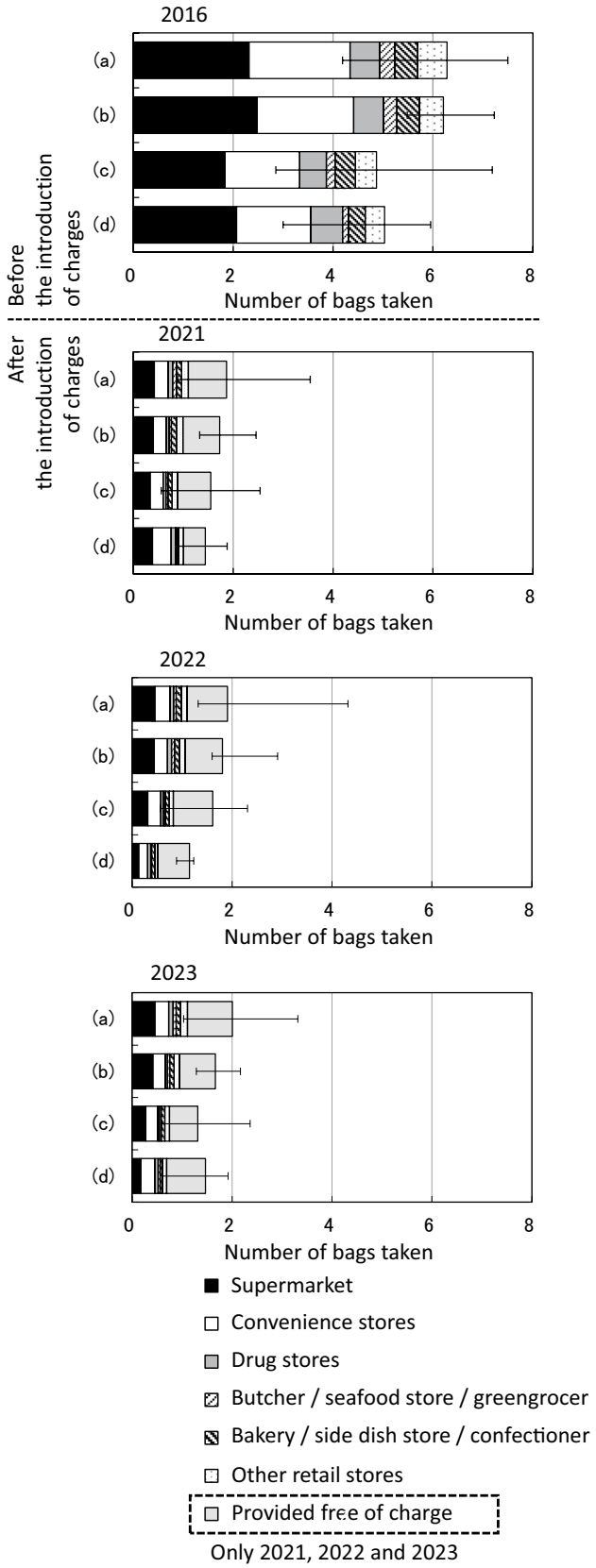

Fig. 3 Number of plastic shopping bags taken in Tokyo by municipality classification. (Error bars indicate the range of average values for each municipality included in each category)

Table 5 Results of the two-way ANOVA on the number of plastic shopping bags taken

Variable	Comparison among 2016, 2021, 2022, and 2023	Comparison among 2021, 2022, and 2023
Survey year	437.96***	0.04
Municipality classification	23.80***	9.79***
Interaction	3.76***	0.90

Note: *F*-statistics are shown (*** 1% significance; ** 5% significance; * 10% significance)

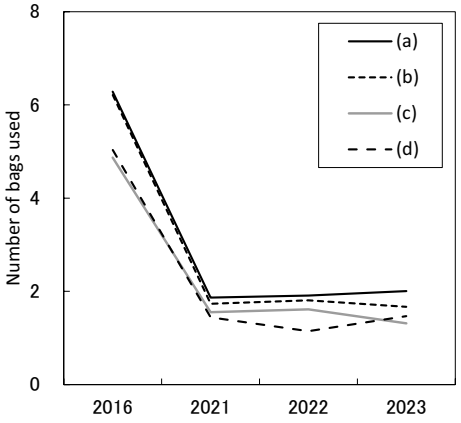

Fig. 4 Interaction between the survey years and municipality classification related to the number of plastic shopping bags taken before and after the introduction of charging

Table 6 Results of the multiple comparisons (Tukey's HSD test) of municipality classification in terms of the number of bags taken after the plastic shopping bag charges were implemented (2021, 2022, and 2023)

Municipality classification	Municipality classification		
	(a)	(b)	(c)
(b)	0.103	–	–
(c)	0.000 ***	0.045 **	–
(d)	0.004 ***	0.117	0.842

p-statistics are shown (*** 1% significance; ** 5% significance; * 10% significance)

a significant difference between categories (a) and (b) and categories (c) and (d) before the charging but no significant difference between (a) and (b) and between (c) and (d). After the introduction of the charging, significant differences were found only between (a) and (c) in 2023, and there was no significant difference in the average number of bags taken in most combinations of municipality classifications. Therefore, it can be said that the charging has

weakened the relationship between municipality waste policies (especially the introduction of designated trash bags) and the number of plastic shopping bags taken in each municipality.

Changes in the number of bags taken over the years after the introduction of the charging

The two-way ANOVA that did not include the 2016 survey (Table 5) showed that the *F*-statistics of the main effect of the survey year and interaction with the municipality were smaller than their criterion for rejecting the null hypothesis (3.00 and 2.10, respectively); however, the *F*-statistic of the main effect of municipality classification was larger than the criterion for rejecting the null hypothesis (2.60). This means that only municipality classification had a significant effect on the number of bags taken; the survey year did not.

The results of the multiple comparisons among municipality classifications (Table 6) show no significant difference in the mean number of bags taken between categories (a) and (b), but there was a significant difference between categories (a) and (c) and between categories (a) and (d). Furthermore, there was no significant difference between categories (b) and (d) or between categories (c) and (d). However, there was a significant difference between categories (b) and (c). As such, differences caused by municipality classification were detected in the analysis that excluded the year before charging. Combinations that did not present a significant difference in the number of bags taken were categories (a) and (b) without designated trash bags, (c) and (d) with designated trash bags, and (b) and (d) without separate collection of plastic waste; thus, there was commonality in the waste policies between municipality classifications that exhibited similar trends in the use of plastic shopping bags.

Number of plastic shopping bags discarded

Figure 5 shows the number of plastic shopping bags discarded per person per week in Tokyo, and Fig. 6 shows the number of bags discarded per person per week in the municipality classification of categories (a)–(d) (Appendix 2 for the number of bags discarded for each survey year and each municipality). The result of the two-way ANOVA on the number of bags discarded is shown in Table 7. This result shows that the main effect of the survey year and that of municipality classification were significant before and after the charging (2016, 2021, 2022, and 2023), as well as after the charging (2021, 2022, and 2023); however, the interaction between them was not significant. Therefore, the multiple comparisons of survey year and municipality classification were performed using Tukey's HSD test before and after the charging (Tables 8 and 9). In addition, the results of the multiple comparisons of survey year and municipality classification after the charging are shown in Tables 10 and 11.

Figure 5 shows that the number of plastic shopping bags discarded per person per week was 6.2 before the charging in the 2016 survey and decreased to 3.4 after the charging in the 2021 survey. The ratio of decrease was small compared to the number of bags taken; it was approximately half of that of the number of bags taken. The total number of plastic shopping bags disposed of as combustible, incombustible, and recyclable waste decreased from 1.8 in 2016 to 1.1 in 2021. The total number of plastic shopping bags reused as trash bags, sorting bags, and for other purposes also decreased from 4.3 to 2.3. Moreover, the numbers of bags discarded in the 2022 and 2023 surveys were 3.1 and 3.0, respectively, and the two-way ANOVA (Table 7) also confirmed the decreasing trend.

The difference between the number of bags taken (5.8) and the number of them discarded was not large before the introduction of the charging, but after the introduction of the charging, the deviation from the number of bags taken (1.9 in the 2021 survey) is not negligible. One hypothesis is that the plastic shopping bags stocked in households for reuse before the charging came into effect may have been reused as trash bags after the charging came into effect. In particular, given that Fig. 5 also shows a decrease in the number of bags reused as trash bags, the gap between the number of bags taken and the number of bags discarded

Fig. 5 Number of plastic shopping bags discarded in Tokyo

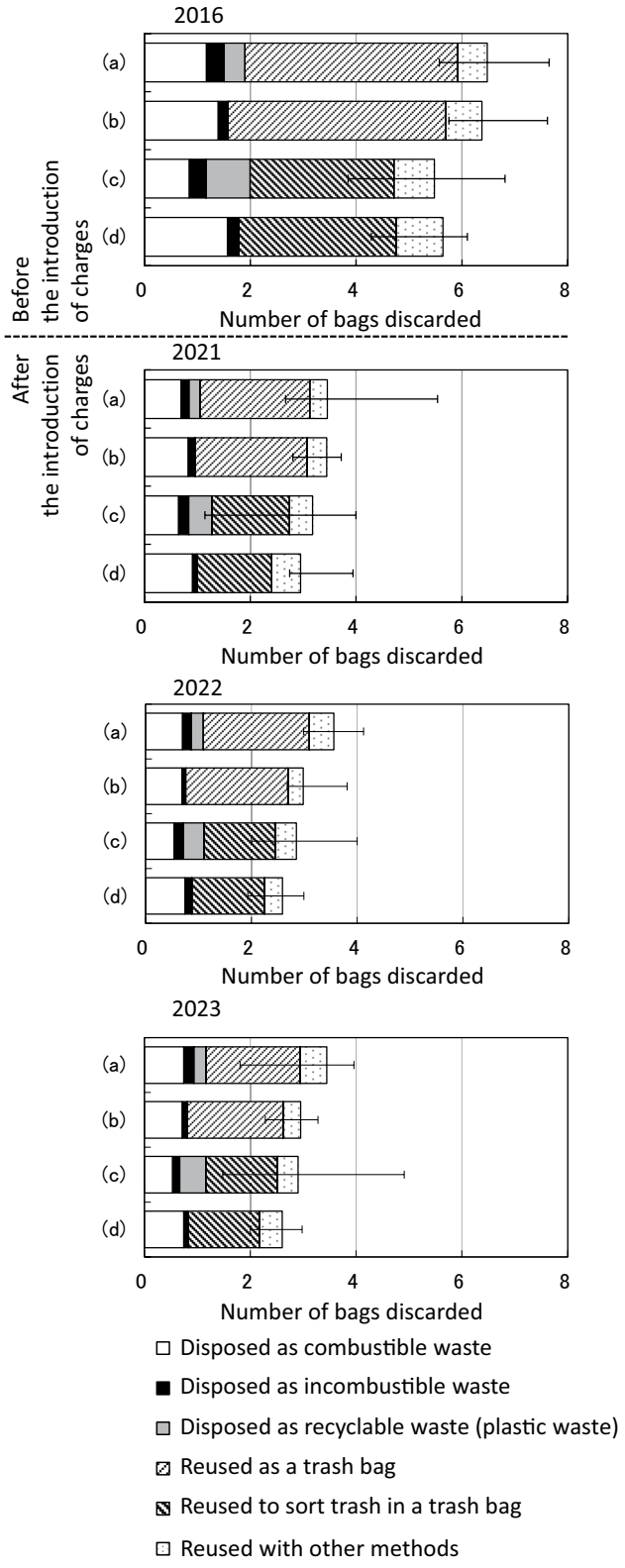

Fig. 6 Number of plastic shopping bags discarded in Tokyo by municipality classification (Error bars indicate the range of average values for each municipality included in each category)

Table 7 Results of the two-way ANOVA on the number of plastic shopping bag discarded

Variable	Comparison among 2016, 2021, 2022, and 2023	Comparison among 2021, 2022, and 2023
Survey year	241.92***	5.08***
Municipality classification	15.97***	9.77***
Interaction	1.73*	0.79

F-statistics are shown (*** 1% significance; ** 5% significance; * 10% significance)

Table 8 Results of the multiple comparisons (Tukey's HSD test) of survey year in terms of the number of bags discarded before and after the plastic shopping bag charges (2016, 2021, 2022, and 2023)

Survey year	Survey year		
	2016	2021	2022
2021	0.000***	–	–
2022	0.000***	0.011**	–
2023	0.000***	0.003***	0.966

p-statistics are shown (*** 1% significance; ** 5% significance; * 10% significance)

Table 9 Results of the multiple comparisons (Tukey's HSD test) of municipality classification regarding the number of bags discarded before and after the implementation of the plastic shopping bag charges (2016, 2021, 2022, and 2023)

Municipality classification	Municipality classification		
	(a)	(b)	(c)
(b)	0.013**	–	–
(c)	0.000***	0.001***	–
(d)	0.003***	0.208	0.999

p-statistics are shown (*** 1% significance; ** 5% significance; * 10% significance)

Table 10 Results of the multiple comparisons (Tukey's HSD test) of survey year regarding the number of bags discarded after the implementation of the plastic shopping bag charges (2021, 2022, and 2023)

Survey year	Survey year	
	2021	2022
2022	0.002 ***	–
2023	0.000 ***	0.865

p-statistics are shown (*** 1% significance; ** 5% significance; * 10% significance)

Table 11 Results of the multiple comparisons (Tukey's HSD test) of municipality classification regarding the number of bags discarded after the implementation of the plastic shopping bag charges (2021, 2022, and 2023)

Municipality classification	Municipality classification		
	(a)	(b)	(c)
(b)	0.019 **	–	–
(c)	0.000 ***	0.326	–
(d)	0.001 ***	0.066 *	0.415

p-statistics are shown (*** 1% significance; ** 5% significance; * 10% significance)

could be reduced in the future. Moreover, the use and disposal of plastic shopping bags could depend on roles of individuals in their households, which might affect the numbers of bags taken and disposed. Further investigation is needed to determine the cause of this gap.

Figure 6 shows that in the 2016 survey (before the plastic shopping bag charge), the number of bags discarded in the municipalities in categories (c) and (d) was approximately one bag fewer than in categories (a) and (b), showing a similar trend to the number of bags taken. The designated trash bag is not introduced in categories (a) and (b), where plastic shopping bags can be reused as trash bags. In contrast, in categories (c) and (d), since designated trash bags are introduced, the reuse of plastic shopping bags is limited to sorting trash. We compared the number of bags discarded in municipality classifications with the same plastic waste collection situations and found that the number of bags discarded was one bag fewer for category (c) than category (a) and category (d) than category (b), indicating that the introduction of the designated trash bag suppressed discarding the plastic shopping bags. We then compared categories (a) and (c) where plastic waste is being separately collected and found that category (c) with designated trash bags had approximately 0.4 more plastic shopping bags disposed as recyclable waste, while approximately 0.4 fewer plastic shopping bags were disposed as combustible waste.

Figure 6 shows that the number of plastic shopping bags discarded decreased by 3.0, 3.0, 2.3, and 2.6 for categories (a), (b), (c), and (d), respectively, between the 2016 survey (before the charging) and the 2021 survey (after the charging). The municipalities in categories (c) and (d) are the ones that have introduced the designated trash bags, which might have suppressed discarding the plastic shopping bags even before the introduction of the charging, thereby diminishing the impact of the charging, as in the case of the number of bags taken.

Change in the number of bags discarded with the charging

The two-way ANOVA that included the 2016 survey showed that the *F*-statistics of the main effect of the survey year and that of the municipality classification (Table 7) were larger than the respective criterion for rejecting the null hypothesis (2.60 and 2.60), whereas the *F*-statistic of the interaction (Table 7) was smaller than the criterion for rejecting the null hypothesis (1.88). This means that while the survey year and the municipality classification had impacts on the number of plastic shopping bags discarded, there was no interaction between the survey year and municipality classification.

The multiple comparisons among survey years (Table 8) show significant differences between the average number of bags discarded in 2016 and those in other survey years and between that in 2021 and those in other survey years; however, there was no significant difference between those in 2022 and 2023. The multiple comparisons among municipality classifications (Table 9) show that there were significant differences between the average number of bags discarded in category (a) and those in other municipality classifications and between categories (b) and (c); however, there were no significant differences between categories (b) and (d) or between categories (c) and (d). Similar to the case of the number of bags taken, the combinations with no significant differences were categories (c) and (d), which had the designated trash bag, and categories (b) and (d) without separate collection of plastic waste. As such, municipalities with no significant differences had certain similarities in their waste policies.

Changes in the number of bags discarded over time after the charging came into effect

The two-way ANOVA that did not include the 2016 survey (Table 7) showed that the *F*-statistics of the main effects of the survey year and the municipality classification were larger than their respective criterion for rejecting the null hypothesis (3.00 and 2.60). However, the *F*-statistic of the interaction between the two (Table 7) was smaller than its criterion for rejecting the null hypothesis (2.10). This means that the survey year and municipality classification influenced the number of bags discarded, but the interaction between the survey year and municipality classification did not.

The results of the multiple comparisons of the survey year (Table 10) show a significant difference between the average

number of bags discarded in 2021 and those in other survey years, while there was no significant difference between those in 2022 and 2023. Similar results were also found in Table 8, which shows that at the time of the 2021 survey, which was only 6 months after the implementation of the plastic bag charge, the number of plastic shopping bags discarded had not yet fully decreased, but after 2022, more than a year after the implantation of the policy, the decrease in the number of bags discarded has converged. The result of the multiple comparisons of the municipality classification (Table 11) shows that the average number of bags discarded in category (a) was significantly different from that of other categories, but there were no differences among categories (b), (c), and (d) at the significance level of 5%.

Discussion

As described in the Introduction section, the persistence of the policy effect after the charging implementation has not been studied so far in Japan. This study identified that, unlike in the cases of South Africa [19] and Nepal [20], the number of bags taken after the implementation of charging remained the same, as shown in Fig. 2. Moreover, there was a significant decrease in the number of bags discarded between 6 months and 1.5 years after implementing the charge, as shown in Fig. 5 and Table 10. This finding indicates the possibility of plastic shopping bags stocked at home being discarded after the charging came into effect for reuse. Compared to the number of bags taken, the number of bags discarded had a slight delay in the policy effect becoming apparent. These results indicate the need for follow-up surveys after the implementation of policies at least in the short–to–medium term, as done in this study. Moreover, continuous surveys are necessary to confirm the absence of long-term rebound effects.

Important implications were also identified regarding the relationship between plastic bag disposal behaviors and other waste policies in the municipalities. In all survey years, 66–68% and 14–15% of unreused plastic shopping bags were disposed as combustibles and incombustibles, respectively (Fig. 6); even in municipalities that introduced separate collection of plastic waste, only 27–29% were disposed as recyclable waste [categories (a) and (c) in Fig. 5]. As such, although neither synergy nor offsetting were observed between the separate collection and implementation of the plastic bag charge, this finding conversely indicates that there is room for improvement in the recycling rate of plastic shopping bag. Previous studies on sorting and LCA of recycling of plastic packaging waste showed that non-composite films made from polyethylene (PE) could efficiently be sorted for recycling [29] and that both material and feedstock recycling of PE reduced climate change impacts compared with incineration [30]. As a complementary measure for plastic bag use which persists even after the charging was implemented, separate collection and recycling of plastic packaging waste should further be encouraged.

Although a significant relationship was not confirmed between the number of plastic shopping bags taken and discarded and the implementation of separate collection of plastic waste, there was a clear relationship between the introduction of designated trash bags and the number of plastic shopping bags taken and discarded, as presented in Tables 6 and 9, respectively. This means that in municipalities that have introduced designated trash bags, the number of plastic shopping bags taken and discarded was fewer than the number in other municipalities even before the charging was introduced. In other words, waste policy for the introduction of designated trash bags contributed to reducing plastic shopping bags by removing the option of reusing plastic bags as trash bags. In contrast, the policy effect of the plastic shopping bag charge alone (reduction in the number of bags taken and discarded after the implementation of the charge) was smaller than that in municipalities in which the number of plastic shopping bags taken and discarded was high. This finding indicates that when introducing policies to reduce not only plastic shopping bags but other single-use plastics, the relationship with existing waste policies must be analyzed to predict their effect. That is, introduction of a new waste policy could have a larger effect in municipalities where other policies that share the same goal have not been implemented.

Conclusion

In this study, we analyzed the changes in the number of plastic shopping bags taken and discarded by consumers residing in Tokyo before and after the charging came into effect and the changes over time after the charging came into effect by focusing on the differences in the waste policies of each municipality, such as the introduction of designated trash bags and separate collection of plastic waste. The result showed that the number of plastic shopping bags taken decreased to approximately 30% after the charging was implemented, and the number of bags discarded decreased by approximately 50%. According to the questionnaire survey of consumers conducted by the Ministry of the Environment in Japan [23], the percentage of consumers who did not take any plastic shopping bags in the week preceding the survey increased from 30.4 to 71.9% after the charging, whereas the percentage of consumers who took at least one plastic shopping bag decreased from 69.6 to 28.1% (down by approximately 40%). While the target of the survey was

different between Tokyo and the country of Japan, considering the reduction in the number of bags taken to approximately 30%, even consumers who took at least one plastic shopping bag earlier took fewer bags after the charging was implemented. This finding indicates that compared with the conventional estimate of the policy effect (approximately 60% reduction), the actual reduction based on the number of bags (approximately 70%) was larger.

Other key findings of this study are summarized as follows.

- *Persistence of the policy effect*: The number of bags taken was not significantly changed in the surveys conducted 6 months, 1.5 years, and 2.5 years after the charging came into effect, and the rebound effect was not confirmed. On the other hand, there was a significant decrease in the number of bags discarded was observed between 6 months and 1.5 years after the charging came into effect, which suggested a slight delay in the policy effect becoming apparent.
- *Relationship with other waste policies*: The number of plastic shopping bags taken and discarded was comparably low even before the introduction of charging in municipalities that had introduced designated trash bags because the option of reusing plastic bags as trash bags was removed. Therefore, the policy effect of the plastic shopping bag charges alone was found to be larger in municipalities where designated trash bags were not introduced.

A limitation of this study is that it depends on self-reported data of participants in the surveys. While we tried to minimize the uncertainty associated with irresponsible responses by asking respondents to record the numbers of bags they obtained and discarded each day over a one-week survey in a dedicated form, the results need to be verified by other objective data. For example, verification using the amount of plastic shopping bags distributed at retail stores located in each municipality and those contained in municipal solid waste, which could be estimated from waste composition data in each municipality, would enhance the reliability of the survey results.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10163-023-01856-9.

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