The recycled content of plastic products: estimating the impact of a recycling law on the input mix

AUTHOR(S):

Kumamaru, Hirotaka; Takeuchi, Kenji

Environmental Economics and Policy Studies (2023) 25:355–376
https://doi.org/10.1007/s10018-023-00360-6

RESEARCH ARTICLE

The recycled content of plastic products: estimating the impact of a recycling law on the input mix

Hirotaka Kumamaru[1] · **Kenji Takeuchi**[2]

Received: 6 July 2022 / Accepted: 18 January 2023 / Published online: 3 February 2023

Abstract

The use of recycled material is a key building block for the circular economy. In this study, we explore the impact of recycling laws in Japan on the use of recycled materials in the production process of intermediate plastics. Using a difference-in-differences approach, we investigate whether the input share of recycled plastics in intermediate plastic products increased after the Container and Packaging Recycling Law (CPR Law) was enforced in 1997 in Japan. Results indicate that the input share of recycled plastics increased by 1 percentage point after the law's implementation. Meanwhile, the input share of virgin plastic materials, such as polyethylene, polypropylene, and vinyl chloride, per plastic product decreased by 3 percentage points on average. These results suggest that the CPR law helped shift inputs from virgin plastics to recycled plastic materials even though the impact size has been small. To further encourage the use of recycled plastic materials, policy interventions should directly incentivize producers to increase the use of recycled plastics.

Keywords Plastic waste · Recycling · Container and packaging · Japan

JEL Classifications C23 · K32 · L65 · Q53

1 Introduction

The global production of plastics increased from 2 million tons in 1950 to 380 million tons in 2015, and the cumulative generation of plastic waste amounted to 6.3 billion tons during this period (Geyer et al. 2017). The vast amount of plastic

✉ Hirotaka Kumamaru
kumamaru@ed.akita-u.ac.jp

[1] Faculty of Education and Human Studies, Akita University, 1-1, Tegata-Gakuenmachi, Akita 010-8502, Japan

[2] Graduate School of Global Environmental Studies/Graduate School of Economics, Kyoto University, Yoshida-Honmachi, Kyoto 606-8501, Japan

waste poses a serious threat to the environment, including marine litter and pollution (Carney Almroth and Eggert 2019; Navarre et al. 2022). In particular, plastic leakage from developed countries is contributing to these issues through global supply chains (Navarre et al. 2022). While the governments of many countries have implemented various policies to reduce plastic waste and promote recycling, the extent to which these policies have impacted the production process is not yet clear.

This study examines the impact of a recycling law in Japan on the use of recycled/virgin materials in the production process of intermediate plastics.[1] Recycling is beneficial in that it reduces disposal costs as well as the use of virgin material. Although the collection of recyclables temporarily avoids disposal, the latter benefit will not be realized unless the recycled material is used for production and substitutes for virgin material. To explore how the input share of recycled and virgin material has changed after the implementation of the recycling policy, we focus on the production of intermediate plastic products, such as film, sheets, plates, and containers. The Japanese recycling law for containers and packaging does not directly require producers to use recycled plastics, but the law may indirectly affect producer behavior by increasing the supply of recyclable materials. As the law increases the collection of used plastics, we expect the producers of intermediate products to find more opportunities to shift their input mix toward used plastics and increase the recycled content of products. For example, Hosoda (2004) documented that manufacturers began to increase the use of recycled plastics as inputs for various products after the law's implementation.

In this study, we capture the change in the input mix by utilizing data from the Monthly Report of Current Production Statistics Survey published by Japan's Ministry of Economy, Trade, and Industry. The report provides data on the monthly production of various categories of intermediate plastic products and the amounts of inputs used for their production. This allows us to investigate the changes in the input share of recycled plastics in each product category. Building on the assumption that the recycling law impacted only specific product categories, we examine the law's impact by the difference-in-differences (DID) method. To confirm the validity of the method, we run the estimation with a different definition of the treatment and the control group, as well as the test for parallel trend by event studies. We further discuss the effect of the export of plastic waste to describe the whole picture of the law's impact.

Results of this study indicate that the use of recycled plastics per product increased by 1 percentage point after the recycling law's implementation. Meanwhile, the use of virgin plastic materials, such as polyethylene, polypropylene, and vinyl chloride, per plastic product decreased by 3 percentage points on average. These results suggest that the law helped shift inputs from virgin plastics to recycled plastic materials even though the impact size has been small.

[1] The use of substitute materials, such as biomass plastics and biodegradable plastics, is an alternative response by producers. Because of limited data availability, this study does not explore the impact on the substitute materials.

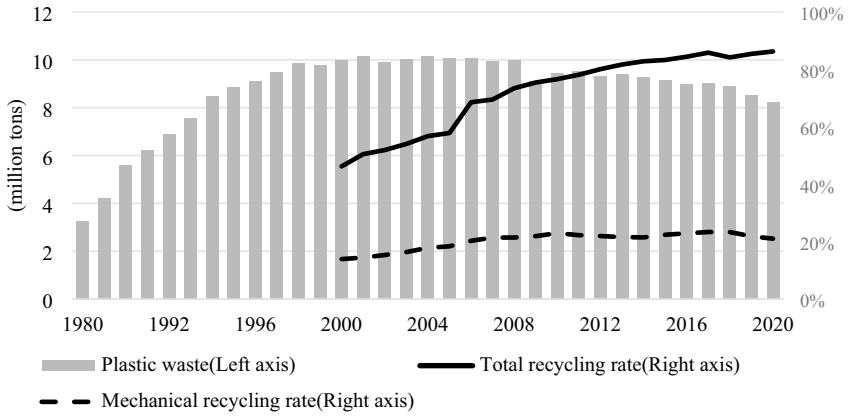
This study is related to several strands of literature on waste management and recycling. First, there are numerous empirical studies on the economics of recycling. Specifically, scholars have investigated the impact of recycling programs on households (Ek and Miliute-Plepiene 2018; Ishimura 2022), professional recyclers (Ashenmiller 2009), municipalities (Dijkgraaf and Gradus 2017, 2020; Ferreira et al. 2017), and technological innovation (Nicolli et al. 2012). These studies tend to focus on how much waste is collected and pay less attention to how much-collected waste is actually used. This study fills the research gap by focusing on the producer's role in the recycling system and examines how the collected waste affects demand for recycled/virgin materials by producers. As producers play a critical role in determining the total amount of material used in an economy, our study has significant implications for policies to establish a sustainable production process with lower environmental impacts. Second, while several studies have theoretically investigated the impact of various policies on extended producer responsibility (Calcott and Walls 2000; Ino 2011; Matsueda and Nagase 2012), empirical investigation of existing recycling programs remains scant. This study contributes to the literature by quantitatively examining the impact of recycling law on the change in inputs in the production process.

The remainder of this paper is organized as follows. Section 2 introduces the institutional background. Section 3 describes the data and our empirical model. Section 4 explains the main results. Section 5 discusses extensions of the analysis. Section 6 concludes. Supplemental figures are included in the Appendix.

2 Institutional Background

In Japan, the generation of plastic waste increased from 3.26 million tons in 1980 to more than 8.91 million tons in 2018, as shown in Fig. 1 (Plastic Waste Management Institute 2020a). Meanwhile, the mechanical recycling of the plastic waste in Japan increased from 1.39 million tons in 2000 to 2.08 million tons in 2018. One of the driving forces behind this increase is the Container a nd Packaging Recycling Law (CPR Law) enacted in 1995 and enforced in 1997.[2] The CPR Law aims to reduce household waste by collecting containers and packaging waste for recycling. It mandates consumers to separate packaging waste from garbage, municipalities to collect recyclable materials, and producers of packaging and packaged goods to pay the cost of recycling. Producers take partial financial responsibility for recycling by paying a recycling fee to the Japan Containers and Packaging Recycling Association, which contracts with recyclers. The collected waste is sent to these recyclers selected by public bidding for processing waste into recycled materials. The recycling fee provides an incentive for producers to reduce packaging waste, but they are not directly motivated to use recycled materials in their production process.

[2] Domestic demand for plastics for containers and packaging accounted for 40% of the total demand for plastics in 2015 (Nakatani et al. 2020).



Note: Total recycling rate is the sum of the mechanical recycling rate, energy recycling rate, and feedstock recycling rate.

Fig. 1 Plastic waste and recycling rate in Japan (1980–2020)

Although plastic recycling in Japan has advanced during the last two decades, it is not clear if it has led to a fundamental change in the production process. First, while mechanical recycling has increased, energy recovery by incineration has also increased, from 3.12 million tons in 2000 to 5.02 million tons in 2018 (Plastic Waste Management Institute, 2020a). This has led to a large discrepancy between the total recycling rate and the mechanical recycling rate shown in Fig. 1. Although the Japanese Ministry of the Environment includes energy recovery as a method of recycling, it is distinguished from recycling by definitions in other countries. Second, materially recycled plastics are not necessarily used in the domestic production of new plastic products. A substantial proportion of them is exported to other countries or disposed of as residuals during the recycling process. In 2018, Japan exported more than half the amount of materially recycled plastics (Plastic Waste Management Institute, 2020a). Exported plastic waste is not always managed properly, which causes pollution in destination countries (Kellenberg 2012; Jambeck et al. 2015).

Japan's CPR Law provides a unique opportunity to examine the potential impact of the recycling policy on producer behavior. The CPR Law promotes recycling mainly by increasing the municipality's collection of packaging waste. There is evidence of a considerable increase in the supply of recycled materials. According to Ishimura (2022), municipalities have increased their recycling of plastic waste by 3–4 kg per person. The separate collection of PET bottles increased from 21,000 tons in 1997 to 298,000 tons in 2016 (Ministry of the Environment 2018). The separate collection of plastic containers and packaging rose from 101,000 tons in 2000 to 739,000 in 2016. Yamakawa (2004) reported that the implementation of the CPR Law has led to the reduction of plastic containers and packaging and increased recycling of PET bottles but has not promoted the use of returnable containers. The collection rate of PET bottles increased from 9.8 to 93% between 1997 and 2019 while the recycling rate of PET bottles increased from 75 to 86% between 2006 and 2019

(Council for PET Bottle Recycling 2001, 2011, 2020). Meanwhile, the total production volume of PET bottles increased from 124,000 tons in 1993 to 593,000 tons in 2019, and waste volumes were larger than before the law's enforcement (Yasuda 2001; Council for PET Bottle Recycling 2020). While these findings suggest a potential effect of the CPR Law on the production process, a thorough empirical analysis has not been conducted to date.

3 Data and methodology

3.1 Data

We use a panel of monthly data for 11 categories of plastic products in Japan from January 1989 to July 2019.[3] Data on the amounts of materials used in plastic products were obtained from the Monthly Report of Current Production Statistics Survey (Ministry of Economy, Trade, and Industry, 1989–2019), which covers all establishments working with plastic products employing more than 50 people. We collected the monthly totals of various plastic products and inputs used in these establishments.

Table 1 reports the descriptive statistics. On average, recycled plastics used for plastic products amount to 1223 tons per month per category. The data reveal that in 2018 the total amount of recycled plastics used in our sample establishments was approximately 235,725 tons. This amount is smaller than the total amount of recycled plastics used in domestic production (760,000 tons in 2018), as reported by the Plastic Waste Management Institute (2020a). The gap can be attributed to the coverage of the dataset. First, our data do not include establishments with fewer than 50 employees. These establishments comprise 91% of the total number of establishments and account for 47% of the total number of employees (Statistics Bureau of Japan 2014). Because of the data constraints, we use only data from large companies to perform our analysis. The results of this study, therefore, might be biased upward if large companies are more flexible in using recycled materials than smaller companies. Second, recycled plastics refer to those purchased or provided by other firms and offices of the company and are directly used in the manufacturing process. It does not include plastic waste generated during the manufacturing process within the establishment. Furthermore, the amount of recycled plastics used in our analysis includes waste generated from the municipal and industrial sectors. Because the CPR Law matters only to the container and packaging waste emitted by the municipal sector, we may overestimate the impact of the law. However, an estimate by the Plastic Waste Management Institute (1996, 2020) indicates that mechanically recycled plastic waste emitted by the industrial sector increased marginally from 1.01 million tons in 1996 to 1.16 million tons in 2018, while that emitted from the municipal sector increased substantially from 0.02 million tons in 1996 to 0.7 million tons in 2018. Thus, the change during the treatment period can primarily be attributed to the increase in the municipal sector.

[3] Refer to Table 3 for the categories of plastic products.

Table 1 Descriptive statistics

Variables	Obs	Mean	Std. dev	Min	Max	Unit
Recycled plastics	4037	1223	1849	0	13,521	t
Input share of recycled plastics (recycled content)	4037	2.24	1.64	0	8.5	%
Input share of polystyrene	4037	12.83	18.73	0	73.5	%
Input share of polyethylene	4037	10.74	11.57	0	47.6	%
Input share of polypropylene	4037	14.83	16.48	0	63.8	%
Input share of vinyl chloride	4037	21.79	25.67	0	92.6	%
Input share of Other	4037	12.74	13.12	0.12	63.4	%
Oil price	4037	5055	2780	1326	14,519	Yen per gallon
1995–1997	4037	0.03	0.16	0	1	Dummy variable that equals 1 from June 1995 to March 1997
After 1997	4037	0.73	0.44	0	1	Dummy variable that equals 1 from April 1997 to July 2019
1997–2000	4037	0.01	0.3	0	1	Dummy variable that equals 1 from April 1997 to March 2000
After 2000	4037	0.63	0.48	0	1	Dummy variable that equals 1 from April 2000 to July 2019
2000–2017	4037	0.58	0.49	0	1	Dummy variable that equals 1 from April 2000 to December 2017
After 2018	4037	0.05	0.22	0	1	Dummy variable that equals 1 from January 2018 to July 2019

As a measure of the material used in the production process, we define the input share of recycled plastics as follows:

$$S_{kit} = \frac{Input_{kit}}{Production_{it}},$$

where S_{kit} represents the input share of material k used as the input for manufacturing product i in period t. In the context of recycled material, the input share is often called recycled content. It is calculated by dividing the input of recycled plastics by the production of plastic products. For example, if 1 ton of recycled plastic is used as an input for 100 tons of plastic products, the recycled content is 1%. The input share of recycled plastics in our dataset is 2.2% on average and 8.5% at the highest. It is much lower than the input share of virgin plastic materials, as the average input share of PE is 14.8%, that of PP is 12.8%, that of polystyrene (PS) is 10.7%, and that of VC is 21.7%.

Table 2 summarizes the characteristics of plastic materials used for production. PE, PP, PS, and VC are representative plastic materials made from crude oil. PE and PP are widely used in plastic products, such as plastic bags, plastic wraps, and product packaging. They are lighter than water, soft, water-resistant, and have excellent electrical insulation properties. PS is hard plastic and is used for rigid products, such as food packaging and disposable cutlery. It can also be converted into a foam material to protect packaging, such as single-use food containers. VC is the precursor to polyvinyl chloride (PVC), typically used in plastic parts for the construction and automotive industries.

The CPR Law was enacted in 1995, enforced in 1997 for glass and PET bottles, and expanded its scope in 2000 to include containers and packages made of paper and plastics. This study uses the following dummy variables to capture the stepwise impact of the CPR Law: After 1997, After 2000, After 2018, and three dummy variables that indicate the period between these timelines (1995–1997, 1997–2000, and 2000–2017). The dummy variable 1995–1997 represents the announcement effect of the CPR Law. After 1997 and After 2000 represent the partial and full enforcement of the law, respectively. After 2018 is used to capture the impact of China's import ban on waste plastics in December 2017. Before the ban, more than 50% of plastic waste exports from Japan were directed to China (Trade Statistics of Japan). After the import ban, the amount of domestically recycled plastics was expected to increase. We use WTI crude oil price to control the effect of oil price on the usage of recyclables and other plastic materials. The data are from the World Bank Commodity Price Data (Pink Sheet) and adjusted to real prices in 2015 using the consumer price index.

3.2 Empirical methodology

This subsection discusses the empirical methodology used to investigate the effect of the CPR Law on input share. The estimated model is expressed as follows:

$$S_{kit} = \beta_0 Treatment_i * Post_t + \beta_1 OilPrice_t + \delta_i + \lambda_t + \varepsilon_{it} \quad (1)$$

Table 2 Characteristics of plastic materials

Materials	Characteristics	References
Polyethylene (PE)	The attractive features of PE include its low price, excellent electrical insulation over a wide range of frequencies, excellent chemical resistance, good processability, toughness, flexibility, and—in thin films of certain grades—transparency. The ability to manufacture several variations allows producers to tailor resins for specific applications, such as packaging films, rigid containers, drums, and pipes	Patel (2016) Ronca (2017)
Polypropylene (PP)	Polypropylene has excellent strength, low surface energy, low gas, and liquid permeability, and the relative ease of processing makes it an attractive option for use in multilayer films. Polypropylene may be used to manufacture single-layer films or as a component in multilayer films via both cast and blown film processing	Calhoun (2016)
Polystyrene (PS)	Polystyrene is the simplest plastic based on styrene. Polystyrene is used as a packaging material for food and non-food applications, casings in the electric/electronic and communication industry, building insulation and liners in the refrigeration industry, and disposable medical ware	McKeen (2014) Niessner and Gausepohl (2003)
Vinyl chloride (VC)	Vinyl chloride is used primarily to manufacture polyvinyl chloride (PVC) resin, a common plastic used in the fabrication of pipes, packaging materials, and insulation. The worldwide production of PVC is extensive, estimated at 59 billion pounds in 2002	Gospe (2009)

Table 3 Treatment and control. Source: Monthly Report of Current Production Statistics Survey (Ministry of Economy, Trade, and Industry, 1989–2019)

Treatment group	Control group
Plastic film and sheets	Plastic plates
Plastic products for machine tools and parts	Plastic products for building materials
Plastic pipes and joints	Plastic synthetic leathers
Plastic containers	Plastic products for general goods
Other plastic products	Plastic foam products
Plastic film and sheets	Plastic reinforced products

where S_{kit} represents the input share of material k used for plastic product i in period t. $Treatment_i * Post_t$ represents the interaction term to measure the impact of the CPR Law, where $Treatment_i$ is the dummy variable for the product category that is strongly affected by the CPR law (see the next paragraph for details), and $Post_t$ is a dummy variable representing the implementation of the CPR Law, as defined in the previous subsection. $OilPrice_t$ denotes the log of oil prices in period t, δ_i represents the category of fixed effects, λ_t denotes the year-by-month or year and month-fixed effects, and ϵ_{it} represents the error term.

This study uses the DID method to examine the effect of the CPR Law on the use of recycled plastics in intermediate plastic products. It investigates the differential impact of a treatment on a treatment group versus a control group in a natural experiment. We calculate the effect of the treatment (i.e., an explanatory variable or an independent variable) on an outcome (i.e., a response variable or a dependent variable) by comparing the average change over time in the outcome variable for the treatment group to the average change for the control group (Abadie 2005; Bertrand et al. 2004; Angrist and Pischke 2008). We divide the 11 categories of plastic products into the treatment group or the control group. Table 3 presents the classification of the product categories. We hypothesize that the effect of the law on the product mix is more substantial in the treatment group because of the difference in product characteristics. Although the CPR Law might affect all categories of plastic products, the impact is expected to be small in the control group because of the technical difficulty in increasing inputs of recycled plastics.

The treatment group comprises five product categories: film and sheets, products for machine tools and parts, pipes and joints, containers, and other products. The control group contains the other product categories: plates, building materials, synthetic leathers, general goods, foam products, and reinforced products. It is more challenging to use recycled plastic materials in these product categories because of their durability and stability. Plastic plates are hard plastic products made of VC, acrylic resin, and other materials. Plastic products for building materials, such as rain gutters and floor tiles, are typically made of VC. Synthetic leathers are mainly made of VC and nylon. Plastic products for general goods, such as tableware and lunch boxes, are mainly made of PP. Plastic foam products are mainly made of PS, while plastic-reinforced products are formed by

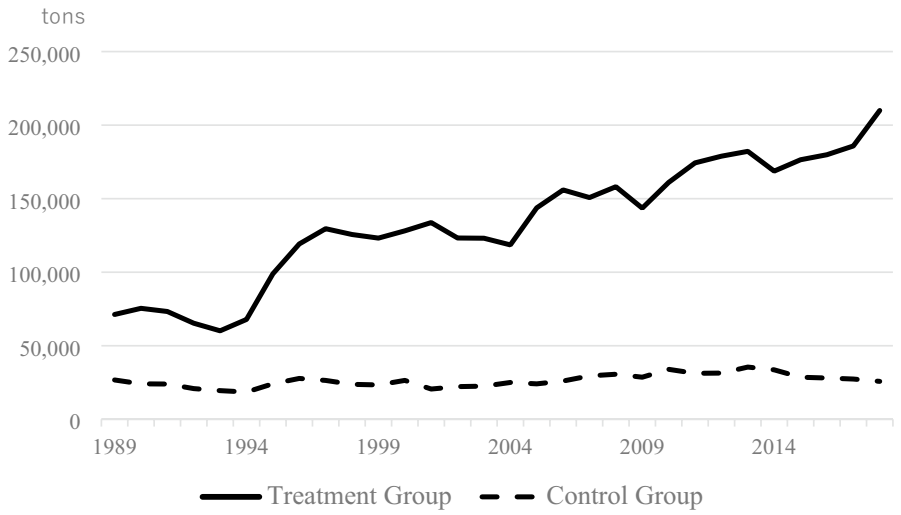


Fig. 2 Amount of recycled plastics used as inputs

adding glass and carbon fibers to plastic materials. The treatment group accounts for nearly 80% of the total amount of intermediate plastic products.

Figure 2 depicts the amount of recycled plastics used in the treatment and control groups during the study period. It suggests that recycled plastics used for the treatment group began to increase in the late 1990s, while the control group remained relatively stable. Throughout the study period, the total usage of recycled plastics was 133,533 tons on average for the treatment group and 26,340 tons on average for the control group. The above comparison, however, does not consider the increase in the total amount of plastic products. The increase in the amount of recycled materials used for production after implementing the CPR Law may be explained by the rise in the total amount of plastic production. As indicated in Figure A-1 in the Appendix, total plastic production in the treatment group began to increase in the late 1990s, while total plastic production of both groups remained relatively stable after the 2000s. To account for the increase in total plastic production, our DID analysis uses the change in the input share of recycled plastics as the outcome variable.

Figure 3 depicts the input share of recycled plastics of the treatment and control groups. When we divide the amount of recycled plastics by the total production, the contrast between the treatment and control groups becomes less clear. Nevertheless, Fig. 3 suggests that the input share in the treatment group increased in the late 1990s. We hypothesize that this shift was caused by the enforcement of the CPR Law, and we estimate a model that explains the change. We also investigate the change in the input share of virgin plastic materials after the CPR Law. For this purpose, we use the input share of virgin plastic materials as the dependent variable. Owing to the substitutability between recycled plastics and virgin plastic materials, the increase in the input share of recycled plastics is expected to reduce the input share of virgin materials. While our study period spans 1989 to 2019, it is more

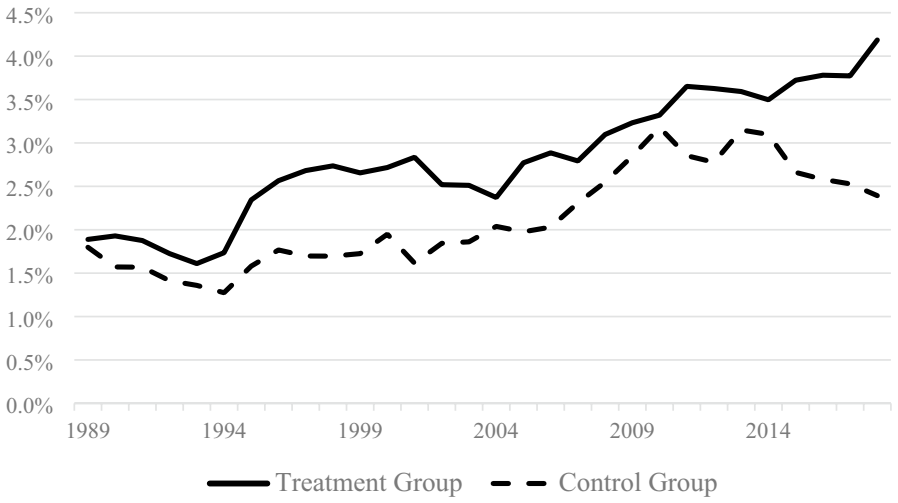


Fig. 3 The input share of recycled plastics

challenging to approximate the counterfactual trend in the later study period by the actual change in the control group. Therefore, the impact of China's import ban should not be interpreted as a reliable estimate of the causal relationship. Rather, it has been included as a control variable.

A potential threat to identification is that other recycling laws implemented during the 2000s might have impacted the use of recycled plastics: these include the Home Appliance Recycling Law in 2001, the Automobile Recycling Law in 2005, and the Small Home Appliance Recycling Law in 2013.[4] However, according to the Plastic Waste Management Institute (2020b), the amount of mechanical recycling in industrial waste has hardly changed since 1996, and the composition of automobiles and home appliances is mostly iron, aluminum, and glass. Thus, the impact of these recycling laws on recycled plastics seems to be small.

We define the treatment and the control group based on the technical feasibility of using recycled materials. According to the Council for PET Bottle Recycling (2020), collected PET bottles have been used domestically to produce PET bottles (24.3% of collected bottles); film and sheets (43.5%); synthetic fibers (20.7%); and products for logistics, construction, and offices (2.3%). Although these products roughly correspond to our treatment group (film and sheets, products for machine tools and parts, pipes and joints, containers, and other products), the assumption might be inappropriate for capturing the impact of the law. To examine the sensitivity of the results to this assumption, we estimate a model that uses an alternative definition of the treatment and the control group in SubSect. 4.2.

[4] In addition, the Green Purchasing Law was implemented in 2000 to promote the demand for environmentally friendly goods in administrative procurement. The law might have an effect of increasing the market share for products that use recycled material.

Table 4 Effect of CPR Law on recycled content

	Recycled content					
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment *1995–1997	0.0112***	0.0112***	0.0112***	0.0096***	0.0096***	0.0096***
	[0.0014]	[0.0014]	[0.0014]	[0.0012]	[0.0012]	[0.0012]
Treatment *After 1997	0.0101***			0.0099***		
	[0.0008]			[0.0007]		
Treatment *1997–2000		0.0108***	0.0108***		0.0105***	0.0105***
		[0.0012]	[0.0012]		[0.0011]	[0.0011]
Treatmen *After 2000		0.0100***			0.0097***	
		[0.0008]			[0.0007]	
Treatment *2000–2017			0.0099***			0.0096***
			[0.0008]			[0.0007]
Treatment *After 2018			0.0119***			0.0116***
			[0.0015]			[0.0014]
Oil price				−0.0008	−0.0008	−0.0008
				[0.0011]	[0.0011]	[0.0011]
Constant	0.0187***	0.0187***	0.0187***	0.0265***	0.0263***	0.0263***
	[0.0029]	[0.0029]	[0.0029]	[0.0090]	[0.0090]	[0.0090]
Year-by-Month FE	Yes	Yes	Yes	No	No	No
Year FE + Month FE	No	No	No	Yes	Yes	Yes
Category FE	Yes	Yes	Yes	Yes	Yes	Yes
Adj-R-squared	0.1277	0.1276	0.1279	0.1984	0.1985	0.1877
N	4037	4037	4037	4037	4037	4037

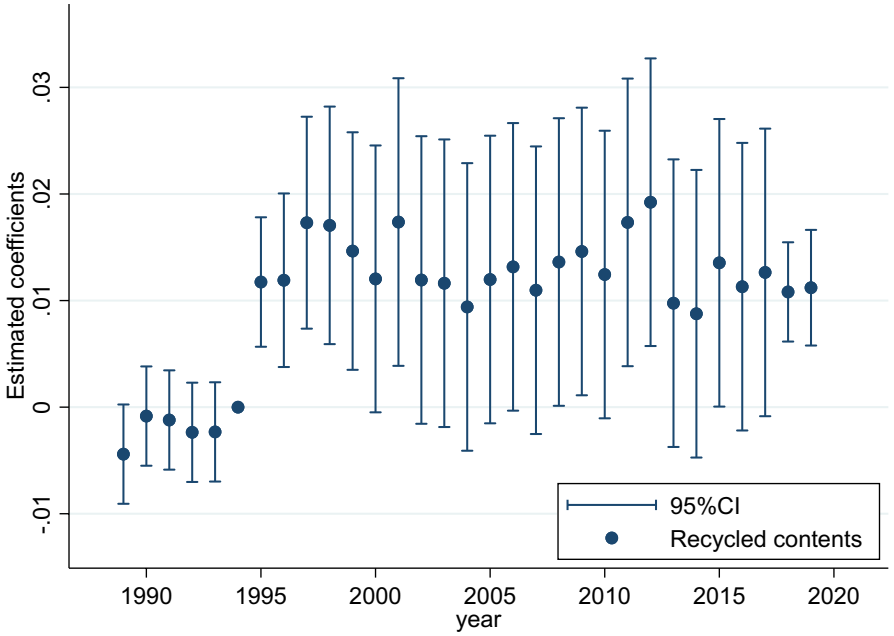
*$p<0.1$, **$p<0.05$, ***$p<0.01$. Standard errors are in parentheses

4 Main results

4.1 Effect of CPR Law on recycled content

Table 4 reports the estimation results for the recycled content. The interaction term between the treatment group and all policy dummies is positive and statistically significant. The results suggest that the recycled content increased after the implementation of the CPR Law. It implies that the share of recycled plastics increased by approximately 1 percentage point after the law. The estimated impact of the CPR Law is small: column (3) suggests the effect is 1.08 percentage points after the initial enforcement in 1997 and 0.99 percentage points after the complete enforcement in 2000. The impact of initial enforcement is similar to the full enforcement in this model. Finally, the effect of China's import ban is positive and statistically significant, as suggested by the interaction term between the treatment group and After 2018 (Treatment*After 2018).

These results imply that the CPR Law caused a slight increase in the recycled content in the production process (about 1 percentage point). Although the amount



Note: Dots represent the estimated coefficients for the interaction term between the treatment group and each year. The dashed lines indicate 95% confidence intervals for these coefficients.

Fig. 4 Event study plots: input share of recycled plastics

of recycled plastics used as inputs increased during this period, the increase in the total production of plastic products outweighed the effect.

To confirm the parallel trend during the baseline years, we also estimate a model that includes the interaction term between the treatment group dummy and year dummy, taking 1994 as the baseline year. Figure 4 presents the coefficients of the interaction term estimated by the event study. The results for recycled content indicate that all coefficients before 1995 have 95% confidence intervals that overlap with zero. Therefore, we can assume that the trends of recycled content were similar between the treatment and control groups before the enactment of the CPR Law. The figure for the input share of recycled plastics shows that many coefficients after 1995 are positive and statistically significant, suggesting an increase in the amount of recycled content in the treatment group, particularly after implementing the CPR Law.

4.2 Robustness check

To confirm the robustness of the main results, we consider a model with an alternative treatment group and a fractional-response model.

Table 5 Alternative treatment group (film and sheets, and containers)

	Recycled content
Treatment*1997–2000	0.0090***
	[0.0015]
Treatment*2000–2017	0.0057***
	[0.0009]
Treatment*after 2018	0.0269***
	[0.0019]
Oil price	0.001
	[0.0048]
Constant	0.0121
	[0.0337]
Year-by-month FE	Yes
Category FE	Yes
Adj-R-squared	0.1337
N	4037

*$p<0.1$, **$p<0.05$, ***$p<0.01$. Standard errors are in parentheses

As the alternative treatment group, we use "film and sheets" and "containers" while using the rest of the 11 product categories as the control group. Because two categories (film and sheets, and containers) are closely related to packaging and containers, we can regard the model as a conservative estimate of the impact of the CPR Law. Table 5 reports the estimation results. It shows that the effect of the CPR Law is positive and statistically significant, and the impacts are slightly smaller than those of the main results. Thus, the effect of the CPR Law is confirmed even with a conservative definition of the treatment group.

To account for the proportional value of the dependent variable, we also estimate Eq. (1) using the fractional-response logit model. Table 6 shows the results, including the marginal effects. The coefficients of the CPR Law are positive and statistically significant, and the input share of recycled plastics shows an increase of 1 percentage point. These results suggest that the main findings are robust to the choice of estimation model.

5 Discussion

5.1 Effect of CPR Law on virgin plastic materials

To consider the potential substitution between recycled materials and virgin plastic materials, this subsection investigates the impact of the CPR Law on the input share of virgin plastic materials. We focus on five materials: PE, PP, PS, VC, and other materials. According to the Plastic Waste Management Institute (2020a), the share of plastic materials in total plastic waste is 33% for PE, 22% for PP, and 12% for PS.

Table 6 Fractional-response model

	Recycled content	
	Fractional-response model	Marginal effects
Treatment*1997–2000	0.5361***	0.0116***
	[0.0533]	[0.0012]
Treatment*2000–2017	0.4414***	0.0096***
	[0.0373]	[0.0008]
Treatment*after 2018	0.5187***	0.0113***
	[0.0787]	[0.0017]
Constant	−3.7678***	
	[0.1571]	
Year-by-month FE	Yes	
Category FE	Yes	
N	4037	

*$p<0.1$, **$p<0.05$, ***$p<0.01$. Standard errors are in parentheses

Table 7 presents the estimation results for the input shares of these plastic materials.[5] In the case of PE, PP, and VC, the interaction between the treatment group and 1997–2000 (Treatment*1997–2000) is negative and statistically significant. The results suggest that the input shares of these materials decreased after the initial implementation of the CPR Law in 1997. The impact is also significantly negative after 2000. Thus, the input shares of these materials decreased after the CPR Law, while that of recycled content increased. However, we must be cautious about interpreting the results as indicating the substitution of petroleum-derived plastic materials, because the coefficients are much larger than those of recycled plastics.

Notably, the use of VC might be mainly driven by reasons other than the recycling policy. VC is considered an intermediate source of dioxin contamination and has been highlighted as a serious environmental issue in Japan in the late 1990s (Sekine 1997; Sakamoto 2020). This concern, coupled with social pressure (such as the Act on Special Measures against Dioxins) on the producers during the period may reduce the usage of the material, regardless of the CPR Law (Sakai 2007).

5.2 Export and domestic usage of recycled plastics

As noted in Sect. 2, a substantial part of collected plastics is exported to other countries as recyclable materials. The export of recyclables inevitably reduces the domestic use of recycled materials. Thus, it is necessary to consider the recycled plastics exported abroad to capture the whole picture of plastic recycling. Figure 5

[5] The parallel trend test results are reported in Figure A-2 in the Appendix. There appears to be no significant difference in trends between the treated and the control group before the CPR Law, as all the pre-treatment coefficients are statistically insignificant.

Table 7 Effect of CPR Law on input share of virgin plastic materials

	Polystyrene (PS)	Polyethylene (PE)	Polypropylene (PP)	Vinyl chloride (VC)	Other materials
Treatment *1995–1997	0.0057	−0.0130***	−0.0310***	−0.0082	0.0017
	[0.0049]	[0.0042]	[0.0049]	[0.0063]	[0.0061]
Treatment *1997–2000	0.0041	−0.0212***	−0.0365***	−0.0126**	0.0216***
	[0.0041]	[0.0035]	[0.0041]	[0.0053]	[0.0051]
Treatment *2000–2017	−0.0158***	−0.0405***	−0.0098***	−0.0214***	0.0524***
	[0.0027]	[0.0023]	[0.0027]	[0.0035]	[0.0034]
Treatment *after 2018	−0.0450***	−0.0337***	0.0112**	−0.0384***	0.0583***
	[0.0051]	[0.0044]	[0.0052]	[0.0067]	[0.0065]
Oil price	−0.0326*	−0.0001	0.0554***	−0.0492**	0.0357*
	[0.0168]	[0.0145]	[0.0169]	[0.0219]	[0.0211]
Constant	0.4110***	0.1202	−0.3144**	0.6457***	−0.1961
	[0.1392]	[0.1202]	[0.1400]	[0.1817]	[0.1752]
Category FE	Yes	Yes	Yes	Yes	Yes
Adj-R-squared	0.13	0.0709	0.2215	0.1585	0.2089
N	4037	4037	4037	4037	4037

*$p<0.1$, **$p<0.05$, ***$p<0.01$. Standard errors are in parentheses

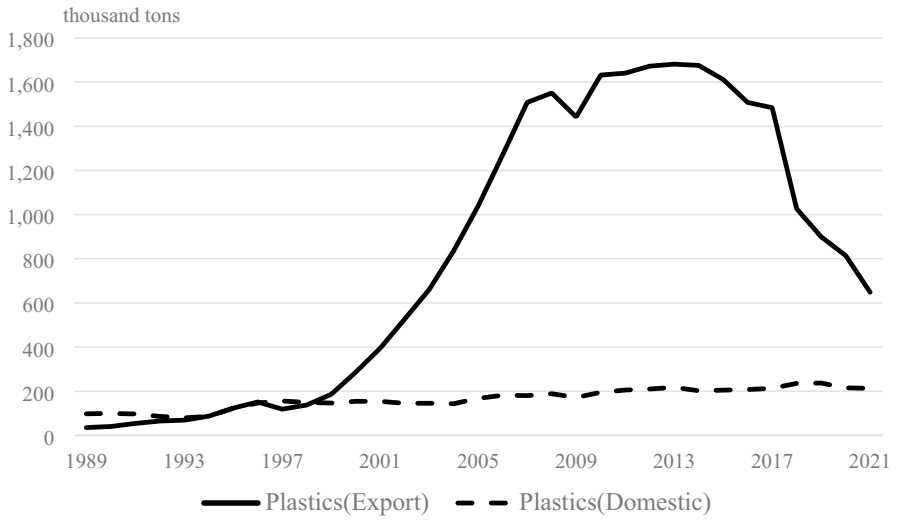


Fig. 5 Export volume and domestic usage volume of recycled plastics

presents the change in the export volume and domestic usage volume of recycled plastics.

The export volume of recycled plastics has been increasing substantially since the early 2000s. In 2013, it amounted to 1,680,000 tons, almost eight times larger than the domestic use of recycled plastics. Exports suddenly dropped as a result of China's import ban in December 2017, providing more opportunities for domestic usage of collected and recycled materials.

6 Conclusion

This study has investigated the impact of the CPR Law on the input share of recycled plastics. The findings can be summarized as follows. Our estimation results indicate that the input share of recycled plastics increased by 1 percentage point after the enforcement of the CPR Law in 1997. The results suggest that the CPR Law indirectly affected the proportion of recycled plastics used as inputs. Furthermore, the use of virgin plastic materials, such as polyethylene, polypropylene, and vinyl chloride, has significantly decreased since 1997. Irrespective of the small impact, the results are suggestive of a substitution between recycled plastics and virgin plastic materials. However, the estimated coefficients suggest that the decrease in these plastic materials has been more substantial than the increase in recycled plastics. The increase in exports of recycled plastics also suggests that a large portion of collected plastics are not utilized in domestic production.

The findings of this study indicate that policymakers should take into account policies that specifically impact the utilization of recycled plastics, such as implementing recycled content standards. For instance, the EU approved a directive

on single-use plastic products in 2019, mandating that plastic bottles must comprise 25% recycled plastic by 2025 and 30% by 2030. Japan has also pledged to decrease the usage of single-use plastics by 25% by 2030 through the Plastic Material Cycle Strategy. As our results imply a weak substitution between recycled plastics and virgin plastic materials, supplementary measures are necessary to shift inputs from virgin to recycled materials and achieve the objectives of a circular economy. One example of such additional measures could be the Plastic Resource Circulation Act in Japan, enacted in 2021, which aims to reduce single-use plastics and promote recycling.

A limitation of this study is that our analysis does not take into account biomass and biodegradable plastics in the production process. These newly developed plastic materials can substitute for conventional plastics and provide an alternative avenue for firms seeking to reduce their use of plastic materials. Furthermore, a more comprehensive examination of the energy usage of chemical and mechanical recycling of plastic waste is also necessary. Future research should comprehensively evaluate the cost and benefits of these various measures to reduce plastic waste.

Appendix

See Figs. 6 and 7.

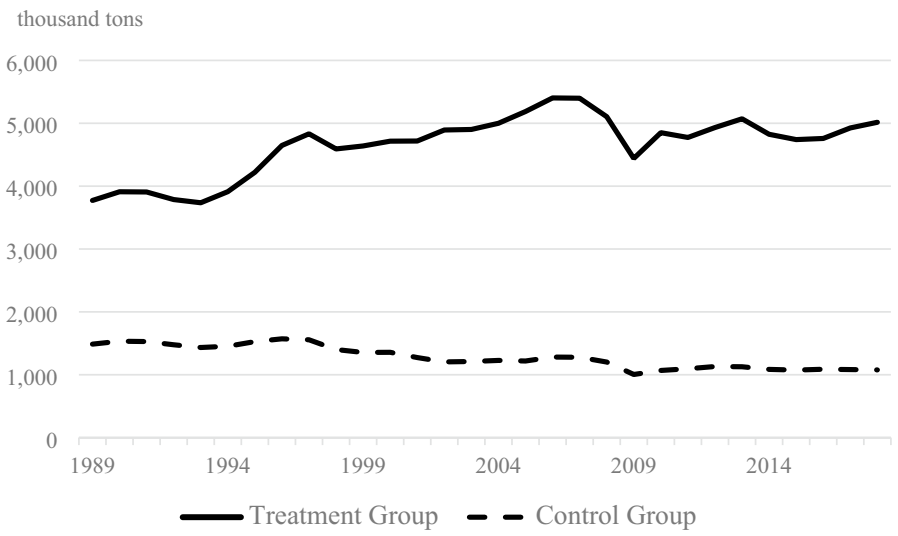


Fig. 6 Amount of total plastic production

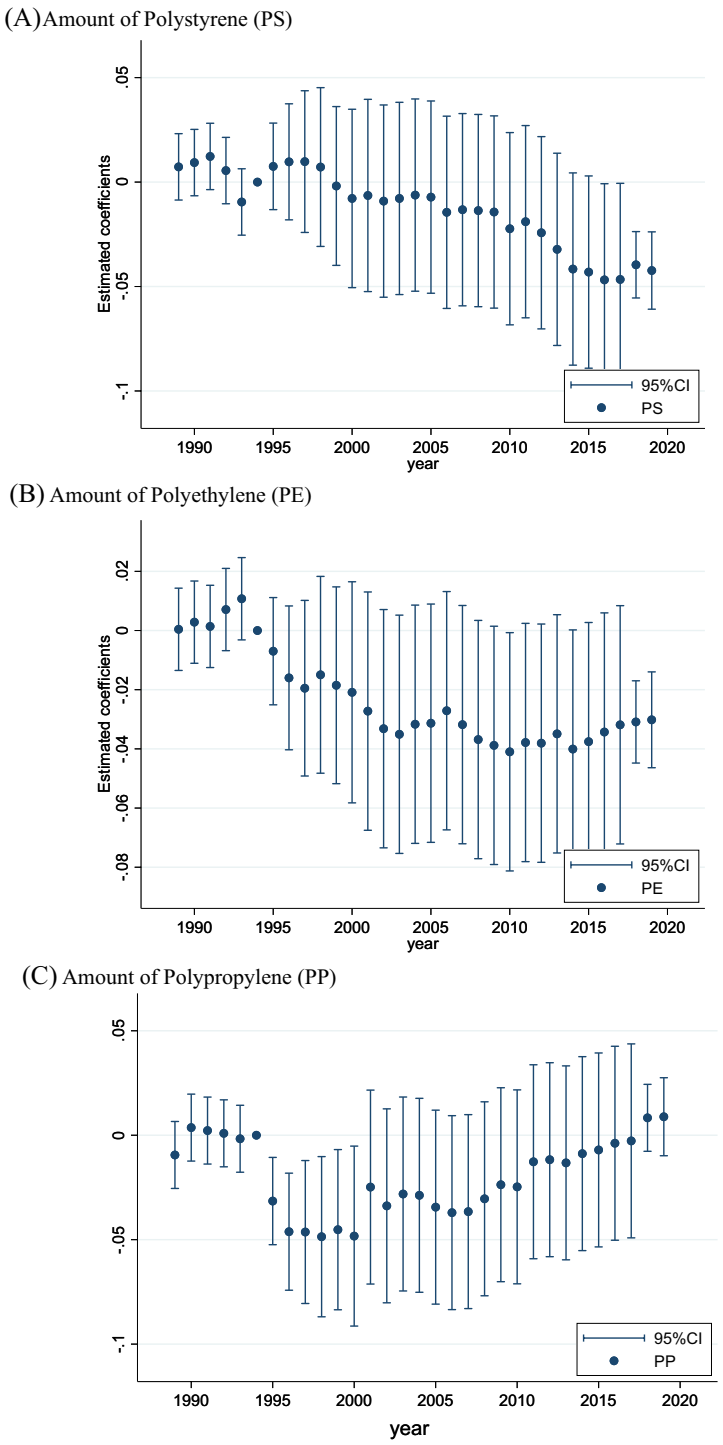
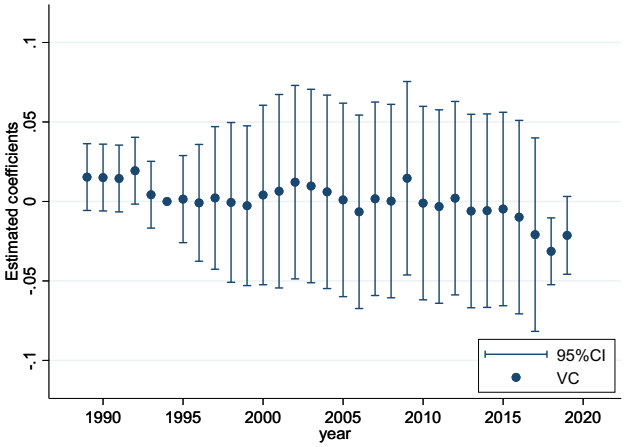
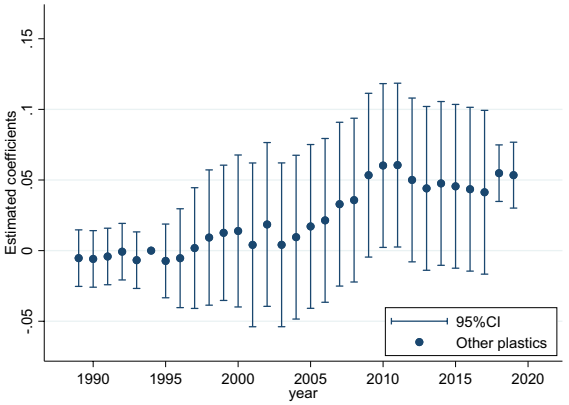


Fig. 7 Event study plots: virgin plastic materials

(D) Amount of Vinyl Chloride (VC)



(E) Other Plastics



Note: Dots represent the estimated coefficients for the interaction term between the treatment group and each year. The dashed lines indicate 95% confidence intervals for these coefficients.

Fig. 7 (continued)

Acknowledgements This research was supported by the Environment Research and Technology Development Fund (S-19-2: JPMEERF21S11920) of the Environmental Restoration and Conservation Agency of Japan. The authors thank helpful comments from Masashi Yamamoto, Daisuke Ichinose, Yuichi Ishimura, and the participants at the 25th Annual Conference of the Society for Environmental Economics and Policy Studies. Two anonymous reviewers have enormously contributed to the improvement of an early version.

Funding Environment Research and Technology Development Fund, S-19–2: JPMEERF21S11920, Kenji Takeuchi.

Data availability The data that support the findings of this study are openly available in *Mendeley Data* (2023).

References

Abadie A (2005) Semiparametric difference-in-differences estimators. Rev Econ Stud 72(1):1–19
Angrist JD, Pischke JS (2008) Mostly harmless econometrics. Princeton University Press
Ashenmiller B (2009) Cash recycling, waste disposal costs, and the incomes of the working poor: evidence from California. Land Econ 85(3):539–551
Bertrand M, Duflo E, Mullainathan S (2004) How much should we trust differences-in-differences estimates? Quarterly J Econ 119(1):249–275
Calcott P, Walls M (2000) Can downstream waste disposal policies encourage upstream "design for environment"? Am Econ Rev 90(2):233–237
Calhoun A (2016) Polypropylene. In: Wagner JR (ed) Multilayer flexible packaging. William Andrew Publishing, Norwish NY, pp 35–45
Carney Almroth B, Eggert H (2019) Marine plastic pollution: Sources, impacts, and policy issues. Rev Environ Econ Pol 13(2):317–326
Council for PET Bottle Recycling (2001) Annual report of PET bottle recycling 2001. https://www.petbottle-rec.gr.jp/. Accessed Nov 2021
Council for PET Bottle Recycling (2011) Annual report of PET bottle recycling 2011. https://www.petbottle-rec.gr.jp/. Accessed Nov 2021
Council for PET Bottle Recycling (2020) Annual report of PET bottle recycling 2020. https://www.petbottle-rec.gr.jp/. Accessed Nov 2021
Dijkgraaf E, Gradus R (2017) An EU recycling target: what does the Dutch evidence tell us? Environ Resource Econ 68(3):501–526
Dijkgraaf E, Gradus R (2020) Post-collection separation of plastic waste: better for the environment and lower collection costs? Environ Res Econ 77(1):127–142
Ek C, Miliute-Plepiene J (2018) Behavioral spillovers from food-waste collection in Swedish municipalities. J Environ Econ Manag 89:168–186
Ferreira S, Cabral M, da Cruz NF, Simões P, Marques RC (2017) The costs and benefits of packaging waste management systems in Europe: the perspective of local authorities. J Environ Plann Manag 60(5):773–791
Geyer R, Jambeck JR, Law KL (2017) Production, use, and fate of all plastics ever made. Sci Adv 3(7):25–29
Gospe Jr, SM (2009) Other organic chemicals. In: Dobbs MR (ed) Clinical neurotoxicology eBook: syndromes, substances, environments. Saunders Elsevier, Philadelphia, pp 415–420
Hosoda E (2004) Evaluation of EPR programs in Japan. In: Priya D (ed) Organization for economic co-operation and development. economic aspects of extended producer responsibility. OECD Publishing, UK, pp 151–192
Ino H (2011) Optimal environmental policy for waste disposal and recycling when firms are not compliant. J Environ Econ Manag 62(2):290–308
Plastic Waste Management Institute (2020a) An introduction to plastic recycling in Japan. https://www.pwmi.or.jp/pdf/panf1.pdf (in Japanese). Accessed May 2021
Ishimura Y (2022) The effects of the containers and packaging recycling law on the domestic recycling of plastic waste: Evidence from Japan. Ecol Econ 201:107535
Jambeck JR, Geyer R, Wilcox C, Siegler TR, Perryman M, Andrady A, Narayan R, Law KL (2015) Plastic waste inputs from land into the ocean. Science 347(6223):768–771
Kellenberg D (2012) Trading wastes. J Environ Econ Manag 64(1):68–87

Kumamaru, H., & Takeuchi, K. The Recycled content of plastic products: estimating the impact of japan's container and packaging recycling law. Discussion Paper No. 2119, Graduate School of Economics, Kobe University. Preprint at http://www.econ.kobe-u.ac.jp/RePEc/koe/wpaper/2021/2119.pdf (2021)

Matsueda N, Nagase Y (2012) An economic analysis of the packaging waste recovery note system in the UK. Res Energy Econ 34(4):669–679

McKeen LW (2014) The effect of temperature and other factors on plastics and elastomers. William Andrew Publishing, Norwish NY

Ministry of the Environment (2018) Report on the amount of recyclable materials collected by municipalities in 2016 under the Container and Packaging Recycling Law. https://www.env.go.jp/press/105234.html. Accessed Oct 2019

Nakatani J, Maruyama T, Moriguchi Y (2020) Revealing the intersectoral material flow of plastic containers and packaging in Japan. Proc Nat Acad Sci United States Am 117(33):19844–19853. https://doi.org/10.1073/PNAS.2001379117

Navarre N, Mogollón JM, Tukker A, Barbarossa V (2022) Recycled plastic packaging from the Dutch food sector pollutes Asian oceans. Res, Conserv Recycling 185:106508

Nicolli F, Johnstone N, Söderholm P (2012) Resolving failures in recycling markets: the role of technological innovation. Environ Econ Pol Stud 14(3):261–288

Niessner N, Gausepohl H (2003) Polystyrenes and Styrene Copolymers—An Overview. In: Scheirs J, Priddy DB (eds) modern styrenic polymers: polystyrenes and styrenic copolymers. John Wiley & Sons Ltd, New Jersey, pp 25–41

Patel RM (2016) Polyethylene. In: Wagner JR (ed) Multilayer flexible packaging. William Andrew Publishing, Norwish NY, pp 17–34

Plastic Waste Management Institute (1996) Material flow of plastics in Japan, 1996. https://www.pwmi.or.jp/flow_pdf/flow1996.pdf (in Japanese). Accessed Nov 2021

Plastic Waste Management Institute (2020b) Plastic products, plastic waste and resource recovery. https://www.pwmi.or.jp/pdf/panf2.pdf (in Japanese). Accessed Nov 2021

Ronca S (2017) Polyethylene. In: Gilbert M (ed) Brydson's plastics materials, 8th edn. Butterworth-Heinemann, Oxford, pp 247–278

Sakai Y (2007) Polyvinyl chloride. Nippon Gomu Kyokaishi Soc Rubber Sci Technol, Japan 80(8):309–314 ((**in Japanese**))

Sakamoto H (2020) The change of waste plastics recycling, treatment and disposal methods. Kanagawa Pref Environmen Sci Center Res Rep 43:8–17 ((**in Japanese**))

Sekine A (1997) Achieving zero dioxin. Japan Soc Mater Cycles Waste Manag 8(4):312–321 ((**in Japanese**))

Statistics Bureau of Japan (2014) Economic census for business frame. "Tabulation of establishments by status of an establishment." https://www.e-stat.go.jp/en/stat-search/files?page=1&layout=datalist&toukei=00200552&tstat=000001137226&cycle=0&tclass1=000001137228&tclass2=000001137229&tclass3val=0. Accessed Nov 2020

The dataset of recycled and virgin plastic materials in Japan (2023) *Mendeley Data*, 1, https://doi.org/10.17632/p4w45rcfgv.1

Trade Statistics of Japan. http://www.customs.go.jp/toukei/info/index.htm (in Japanese). Accessed Feb 2021

Ministry of Economy, Trade, and Industry. (1989–2019). Monthly report of current production statistics survey (in Japanese). https://www.meti.go.jp/statistics/tyo/seidou/result/ichiran/08_seidou.html.

World Bank commodity price data. "The Pink sheet" data. https://www.worldbank.org/en/research/commodity-markets

Yamakawa H (2004) The containers and packaging recycling law—cost accounting and impact on the packaging waste system. Japan Soc Mater Cycl Waste Manag 15(6):262–274 ((**in Japanese**))

Yasuda Y (2001) Evaluation and policy analysis on the recycling system of PET bottles. Japan Soc Mater Cycles Waste Manag 12(5):229–234 ((**in Japanese**))