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Country report

What activities reduce plastic waste the most? – The path to a circular economy for Japan's manufacturing industry

Masashi Yamamoto [a,*], Saifun Nahaer Eva [b]

[a] Department of Economics, School of Political Science and Economics, Tokai University, Kitakaname 4-1-1, Hiratsuka, Kanagawa 259-1292, Japan
[b] Center for Far Eastern Studies, University of Toyama, Japan

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ABSTRACT

In recent years, plastic waste has received increasing attention, though most studies on it have investigated only household plastic waste. In Japan, the amount of household plastic waste is approximately equal to that generated by the manufacturing process in Japan. Therefore, we focus on the change in plastic waste emissions from manufacturing from 2004 to 2018. Following the novel method of Levinson (2015), we decompose plastic waste emissions into scale effects, composition effects, and (in)direct technique effects. This first application of this method for waste generation shows that the technique effect contributes the most to reducing pollution emissions, whereas the composition effect has a very limited impact. These results contrast with those of previous studies (Brunel (2017) and Cole and Zhang (2019)) on CO_2 emissions and provide new insights into the characteristics of plastic waste generation. The reason for the increase in technique effect despite the absence of strict emission control regulations targeting industrial waste is that Japanese environmental policies are often promoted in a manner that involves all stakeholders, creating conditions for successful voluntary agreements through mutual monitoring.

1. Introduction

Plastic is a material that contributes to the efficiency of modern economic activity because it is light weight, easy to shape and long lasting (Ghayebzadeh et al., 2020; Rajmohan et al., 2019). This long-lasting attribute has a downside for products made of plastic due to their nondegradability (Geyer et al., 2017). When plastic waste is discarded, it can remain in place for many years. In recent years, plastic pollution has become a pervasive and pernicious environmental issue that has raised considerable attention throughout the world (Dilkes-Hoffman et al., 2019). For example, not only has the plastic waste issue been discussed at conferences attended by high-ranking government officials, but it also has been discussed by the world's political leaders, such as at G7 meetings. In 2018, the G7 meeting in Charlevoix, Canada, adopted the "Ocean Plastic Charter", the primary aim of which is to prevent plastic waste from entering the ocean. That same year, the European Union (EU) adopted the "European Strategy for Plastics in a Circular Economy" (European Commission, 2018), which is the first plastic waste strategy at the EU level. The objective of this strategy is to "transform the way plastic products are designed, used, produced and recycled in the EU"[1].

The plastic waste issue is an important policy item not only in developed countries but also in developing countries. According to Jambeck et al. (2015), ocean plastic waste is generated mostly in China and Southeast Asian countries. Surprisingly, their estimate concludes that in 2010, China alone accounted for approximately 30% of ocean waste, followed by Indonesia with 10% (at the median level). Although the importation of plastic waste has been economically beneficial for China, it has endangered people's health and damaged local ecological environments (Ren et al., 2020). As a result, China strictly banned the importation of all kinds of postconsumer plastic waste starting at the beginning of 2018.[2] Since China was the world's largest importer of plastic waste, other importers, especially Southeast Asian countries, received a surge of plastic waste in the following year.[3] Consequently, many Asian countries started regulating plastic waste imports. Developed countries export a large amount of plastic waste each year and

* Corresponding author.
E-mail address: yamamoto@tsc.u-tokai.ac.jp (M. Yamamoto).

[1] For more information on this strategy, please see the European Commission's environment website: https://ec.europa.eu/environment/waste/plastic waste.htm.

[2] We will explain the effect of the Chinese ban in the next section.

[3] EU countries experienced similar problems. For more details on the plastic waste trade from Europe, see D'Amato et al. (2019).

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indirectly contribute to ocean plastic waste generation through developing countries (Wang et al., 2020). To prevent plastic waste problems, including ocean plastic waste, it is important to reduce plastic waste generation in developed countries and to consider factors such as a lack of knowledge regarding recycling techniques and lax plastic waste pollution policies in developing countries (Alpizar et al., 2020). As noted by Abbott and Sumaila (2019), there is an increasing number of studies on postconsumer plastic waste.[4] For instance, Leggett et al. (2018) conducted an assessment of the economic impact of ocean plastic debris, showing that decreasing plastic waste on beaches by 25% would save USD 29.5 million. In addition, Jang et al. (2014) found that marine debris resulted in a 63% reduction in tourism industry income (approximately USD 37 million) on Geoje Island. Beaumont et al. (2019) examined the costs of marine plastic debris in terms of global ecological, social and economic impacts. Their study postulated that marine plastic debris causes an annual loss of USD 500–2500 billion due to reduced marine ecosystem services. Abate et al. (2020) and Crowley (2020) also investigated marine plastic waste at Svalbard in the Arctic and in the northern Philippines, respectively. From a policy perspective, Wagner (2020) helped to identify potentially effective policies for alleviating plastic waste pollution. It seems that the current policy movements, including the G7 charter and the EU's strategy, mostly focus on controlling postconsumer plastic waste. In addition, most of the previous literature on plastic waste related to economic activity has focused on the postconsumer plastic waste problem[5]. Industrial waste in the EU accounts for five and one-half tons out of a total of six tons of waste generated by a person per year.[6] According to the Plastic Waste Management Institute of Japan (2019), the plastic waste coming from the industrial sector in Japan is 485 million tons per year, which is slightly higher than the total amount of postconsumer plastic waste (418 million tons per year). Strengthening regulations on plastic use by consumers while ignoring the same amount of waste from industries does not make sense. Very few studies, however, discuss the relationship between plastic waste from industrial and economic activity. The rare exception is Weerdt et al. (2020), who argued that waste treatment taxation and plastic-related legislation significantly contribute to reductions in plastic waste generation from industry and can increase the rates of industrial plastic waste recycling.

In this paper, we concentrate on reducing plastic waste from the manufacturing sector. Our analysis relies on a novel method developed by Levinson (2015). This method allows us to directly measure the technique effect, which we define in a section below. Levinson (2015,2009) analyzed air pollution from US manufacturing and concluded that the technique effect dominated the reduction in US air pollution from the late 1990s to the early 2000s. Brunel (2017) applied a similar methodology to EU air pollution and found that the EU has become more pollution intensive in terms of its manufacturing composition. Cole and Zhang (2019) were the first to apply this method to a developing country, China, for the 2003–2015 period. The Chinese economy grew 6-fold during this period, but Cole and Zhang (2019) found that the SO_2 emissions from the manufacturing sector were only 1.5 times higher due to the extensive improvement in the technique effect. Bernard et al. (2020) and Holland et al. (2020) extended this method to different ways of analyzing air and water pollution in the Canadian pulp industry and the US electricity industry. However, none of these previous papers targeted waste generation. To the best of our knowledge, this study is the first to apply Levinson's method to waste management policy, which is possible due to the excellent dataset provided by the Japanese Ministry of the Environment.

Another contribution of this paper is to point to Japan's waste plastics reduction efforts as an example of how voluntary agreements can work, as pioneering studies such as Segerson and Miceli (1998) have shown. As Arimura et al (2019) argue, in Japan, laws are often proposed after detailed discussions between the government and the private companies that expect to be regulated. This increases the potential for voluntary agreements[7] to succeed.

Section 2 explains the current situation of Japanese plastic use and Japan's efforts to handle plastic waste. Using a novel dataset on industrial plastic waste in Japan, Section 3 conducts a decomposition analysis and summarizes the findings, and Section 4 discusses a possible explanation, rooted in economic analysis, for the observation that Japan has experienced industrial plastic waste reduction without policy regulations. Section 5 provides concluding remarks.

2. Policy background

2.1. Japan's efforts to reduce plastic waste

In this section, we provide a brief overview of plastic use in Japan and the country's efforts to reduce its waste. A recent report by the Plastic Waste Management Institute of Japan summarizes the current situation of plastic recycling. It states that plastic production in Japan has remained the same, at approximately 11.5 million tons per year, over the last 10 years. However, plastic production has decreased by approximately 14 million tons per year compared to that in the early 2000s. Fig. 1 (top) illustrates the share of resin-type plastic in Japanese plastic production. Almost half of Japan's plastic production is either polyethylene or polypropylene because approximately 40% of plastics are used for bags, packaging and sheeting (Fig. 1, bottom).

Fig. 2 presents the Japanese material flow of plastics in 2017. The resin input was approximately 11.5 million tons, and this amount has not changed considerably over the last several years. After production and consumption, this input became 8.28 million tons of post-use waste and 750 thousand tons of production and processing loss. A total of 4.18 million tons originated from households, while industry generated 4.85 million tons. Out of 9.03 million tons of total plastic waste, 2.11 million tons is classified as mechanical recycling, while more than half of the amount goes to energy recovery. In the plastic industry of Japan, only 620 thousand tons out of approximately 11 million tons of resin input is a reclaimed product of plastic waste (only 5.6%). As shown in Fig. 2, the amount of plastic waste originating from industry exceeds that originating from households. However, among previous studies, few papers have analyzed plastic waste as industrial waste, which led us to conduct this study.

According to the Census of Manufacture in 2017, published by the Ministry of Economy, Trade and Industry (METI) of Japan,[8] the output (monetary base) of the plastic product sector in Japanese manufacturing was JPY 1.24 trillion (or USD 1.13 billion). The share of the plastic product sector in Japan's 24 manufacturing subsectors remained almost the same, in the range of 3.6–4%, between 2004 and 2017.

During the same period, Japan's total industrial waste remained at a steady level of approximately 400 million tons per year for the last 20 years, while its municipal waste decreased from 55 million tons per year in 2001 to 42 million tons per year in 2017.[9] Of course, other sectors, such as the chemical sector and general-purpose machinery sector, also

[4] Almroth and Eggert (2019) provide a useful summary of current research on ocean plastics, among others.

[5] UNEP (2018) also warns about the increase in single-use plastics at household level.

[6] https://ec.europa.eu/environment/waste/index.htm.

[7] Note that Fleckinger and Glachant (2011) mentioned "In Europe and Japan, VAs are mostly negotiated agreements in which the firms and the regulator jointly define the commitments through bargaining"(p41). We follow this definition of voluntary agreement in this paper.

[8] The data are available at https://www.meti.go.jp/english/statistics/tyo/kougyo/index.html.

[9] For more details, see the Annual Report of Environmental Statistics at https://www.env.go.jp/en/statistics/index.html.

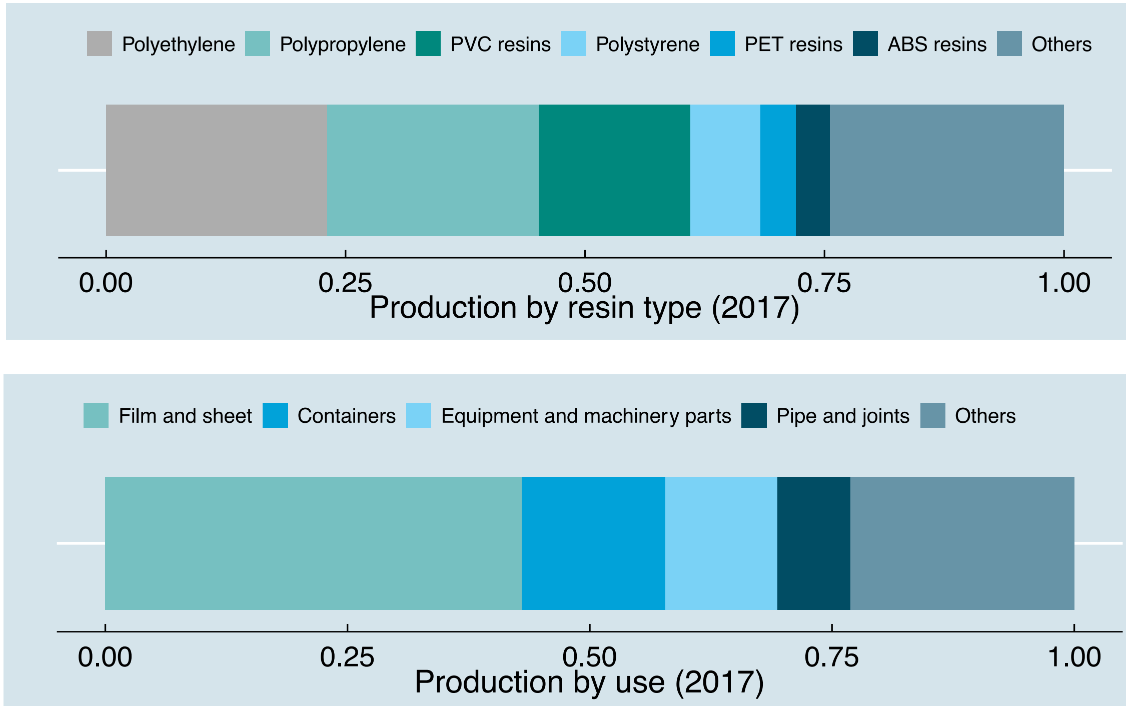

Fig. 1. Plastic Production by Resin Type (Top) and Its Use (Bottom) in 2017.
Source: Plastic Waste Management Institute of Japan (2019)

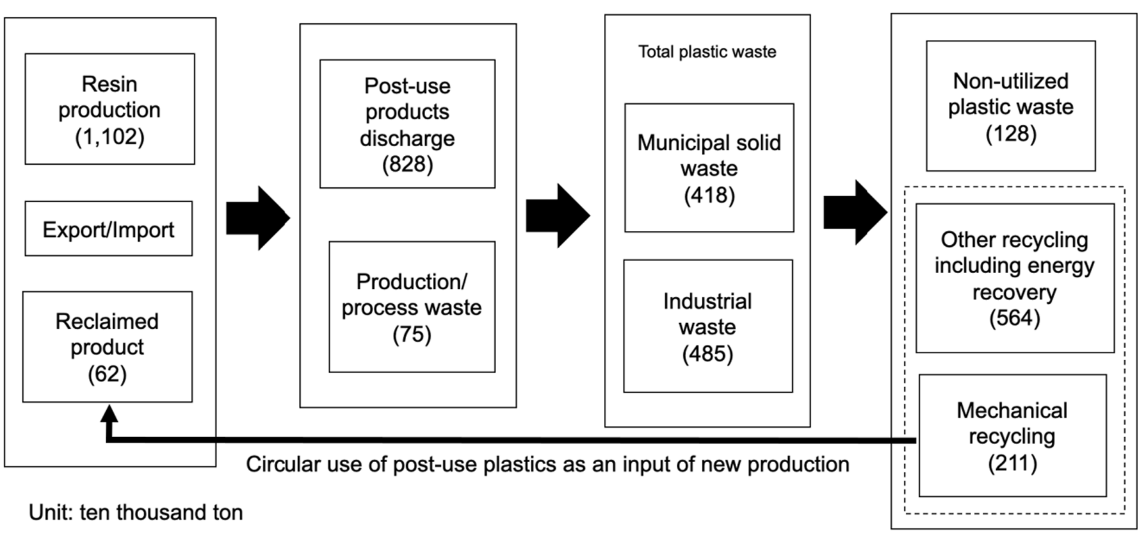

Fig. 2. Material Flow of Plastic Products and Waste. Source: Plastic Waste Management Institute of Japan (2019).

use plastics as their input, resulting in the generation of plastic waste in these sectors. We will discuss further sector-specific issues when we describe the data.

The Japanese government has introduced several laws to curb the generation of waste and promote recycling. In 2001, a new law, called the "Fundamental Law for Establishing a Sound Material-Cycle Society", was put into effect. This law works as a basic framework in the field of waste management and recycling. Following this law, six related laws for specific products were enacted: laws for containers and packaging, home appliances, food waste, construction waste, end-of-life vehicles and small home appliances. To analyze plastic waste from industry, there are two critical laws among the six laws above: the Containers and Packaging Recycling Law and the Home Appliance Recycling Law. The former obliges companies that conduct business using containers and packaging to bear the cost of recycling based on the volume of their shipments. The latter imposes an obligation on home appliance manufacturers to collect and recycle the four types of home appliances (refrigerators, washing machines, televisions, and air conditioners) they have sold through retailers using the recycling fees collected from consumers. The Containers and Packaging Recycling Law has resulted in beverage manufacturers reducing the weight of polyethylene terephthalate (PET) bottles. In addition, the Home Appliance Recycling Law, which requires home appliance manufacturers to recycle their own products, has led to the design of products that are easier to disassemble and recycle, resulting in a decrease in the amount of plastic used.

In 2019, the Japanese Ministry of the Environment released the *Resource Circulation Strategy for Plastics*. Unlike the previous recycling-related laws regulating final products (not material), this strategy focuses on plastic as a material (not a specific final product). The main objectives of this strategy are to establish (1) the "3Rs + Renewable" as a basic principle, (2) a mandatory charge for a plastic bag and (3) ambitious "milestones". The first objective mentions the importance of renewable plastic for the first time in Japanese legislative documents. Through the second objective, Japan began charging for a plastic bag nationwide. Although the amount of plastics reduced is not quite large, the announcement itself contributed to changing consumers' attitudes toward plastic waste. According to the Japan Chain Stores Association, the plastic bag refusal rate became 75.3% after the policy introduced a mandatory charge on a plastic bag, while the average refusal rate in the seven years prior to the introduction of this charge was 53%.[10] The third objective includes six milestones, including over 60% reuse or recycling of containers and packages by 2030 and 100% reuse or recycling of plastic waste by 2035. This strategy obviously affects the manufacturing industries using plastic as an input.[11]

In summary, the regulations on plastic waste control that Japan has introduced thus far have targeted households, and few policy systems have been designed to curb corporate behavior. The important question of what has led to the suppression of plastic waste will be discussed further in Section 4.

2.2. China's import ban

Since the 1980s, China has been importing large quantities of resource waste, such as plastic waste, and has used paper from Japan, the EU, the US, and other countries to sort, process, and reuse it as raw material for new products in China. In 2016, approximately 9 million tons of plastic waste was generated in Japan, of which over one million tons was exported to China. However, in July 2017, the Chinese government announced that it was amending the Imported Waste Management Catalogue. As a result, China banned the export of plastic waste, unsorted paper, and fiber waste starting in January 2018. Fig. 3 shows the changes in the export of plastic waste (HS code: 3915) from Japan, the EU28, and the US. Exports to China started declining immediately after China's announcement of the import ban. Once the ban took effect, exports to China dropped to almost zero in all the cases in the figure. Notably, the weight of exports from Japan to the rest of the world is slightly increasing, while the weight of exports from the EU28 and the US shows a decreasing trend after the ban.

In response to China's import restrictions, some of Japan's waste plastics were exported to Southeast Asia. Western countries have similarly shifted their export destinations to the countries in this region. As a result, each country's recycling and processing capacity has been unable to cope with the rapid increase in the amount of waste plastic imported.[12] This situation has become a global problem, leading to the adoption of a draft amendment to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes in May 2019. Through this amendment, the Basel Convention adds plastic waste to the list of items subject to regulation.

3. Decomposition of plastic waste from manufacturing

3.1. Method

The use of decomposition to break down in index into scale, composition and technique effects has been a popular method among economists. The scale effect is the change in pollution caused by total economic growth or manufacturing output in a given year. The composition effect is the shift in economic structure or the mix of different sectors comprising the economy. The technique effect reflects changes in production methods, advanced technologies and innovations such as a mix of input substitutions and process changes that usually reduce emissions per unit output.

Let p_{it} be pollution from industry i in year t. We also define v_{it} as output (or value added) by industry i in year t, and we define its share as $\theta_{it}\left(=\frac{v_{it}}{\sum_i v_{it}}\equiv\frac{v_{it}}{V_t}\right)$. Based on the share by industry i and pollution per dollar of output $\left(=\frac{p_{it}}{v_{it}}\equiv z_{it}\right)$, total pollution from manufacturing in given year t can be calculated as follows:

$$P_t=\sum_i p_{it}=\sum_i v_{it}z_{it}=V_t\sum_i\theta_{it}z_{it} \tag{1}$$

If we assume that the emission intensity, z_{it}, is constant over time and denote it as $\bar{z}_i$, then the total emission at year t,

$$\widehat{P}_t=V_t\sum_i\theta_{it}\bar{z}_i \tag{2}$$

is determined by economic growth ($=V_t$), known as the scale effect, and changes in composition ($=\theta_t$), called the composition effect. Furthermore, we measure the technique effect by subtracting $\widehat{P}_t$ from the actual observation of P_t. Since the technique effect is defined by what cannot be explained by the scale effect or the composition effect, Levinson (2015) called it the indirect technique effect.

In vector form notation, Eq. (1) becomes the following:

$$P=V\theta' z \tag{3}$$

Totally differentiating the above equation, we have the following:

$$dP=\theta' zdV+Vz' d\theta+V\theta' dz \tag{4}$$

The first term in Eq. (4) is the scale effect, which explains the change in pollution when the size of the manufacturing sector increases, holding the composition of industries and their pollution intensities fixed. The middle term is the composition effect, which accounts for the changing mix of industries while holding their scale and pollution intensities constant. The last term is the technique effect, which captures changes in pollution intensities while holding scale and composition fixed. In the discrete expression, $Pt-\widehat{P}t$ corresponds to the left-hand side (LHS) of Eq. (4) minus the first and second terms of the right-hand side (RHS). This process allows us to indirectly derive technique effects.

In contrast to the above-mentioned indirect technique effect, Levinson (2015) proposed two indices of direct technique effects, i.e., the Laspeyres index (IL) and the Paasche index (IP). The IL and IP are widely used price indices. The IP is a price index that uses the current quantity of goods as weights, and it allows us to see how much consumption has changed between the current year and the base year, assuming the same quantity of consumption as in the current year. In contrast, the IL is a price index that uses the number of goods in the base year as weights, and it shows how much consumption in the current year will change compared to the base year. Levinson (2015) proposed a new method to apply this index to decomposition.

Rather than holding emission intensity constant, these indices hold the composition of output fixed and show how pollution per dollar of output has changed. Given that the base year is 2004,

$$\text{Laspeyres index}:\ I_t^L=\frac{\sum_i z_{it}\times v_{i,2004}}{\sum_i z_{i,2004}\times v_{i,2004}}$$

$$\text{Paasche index}:\ I_t^P=\frac{\sum_i z_{it}\times v_{i,t}}{\sum_i z_{i,2004}\times v_{i,t}}$$

In addition to the conventional indirect technique index, we compute the two indices above to describe the reduction in plastic waste from

[10] https://www.jcsa.gr.jp/topics/environment/approach.html (available only in Japanese; last accessed on July 25, 2021).

[11] Our data were gathered from the period before the implementation of this strategy (2004–2018).

[12] Eventually, countries in Southeast Asia also strengthened their regulation of the export of plastic waste.

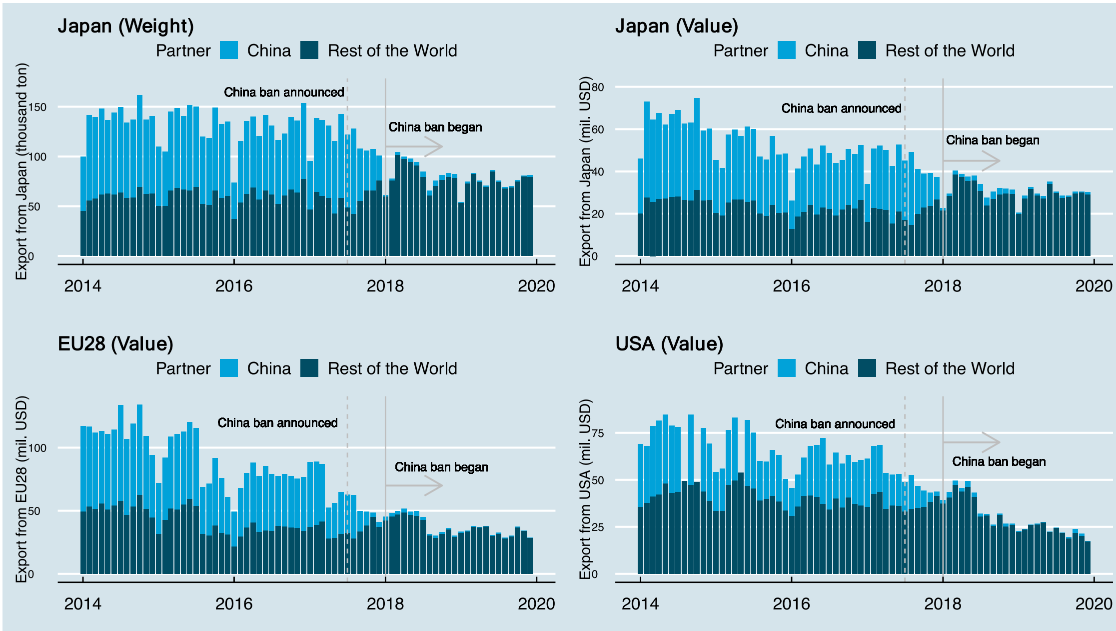

Fig. 3. Changes in Plastic Waste in China and Other Countries. Source: UN Comtrade.

various perspectives. As Levinson (2015) points out, the IL will be smaller than the IP if a subsector with smaller z_{it} increases its production output more rapidly during the targeted time period and vice versa.

3.2. Data

To compute the indices introduced above, we need three types of information: (1) the sector-specific output level, (2) the plastic waste generated by sector and (3) sector-specific deflators to convert our economic variable from nominal to real.

First, we obtain manufacturing activity data from *the Census of Manufacture*, published by the METI of Japan.[13] This census contains the annual output (monetary base) for each of 24 manufacturing subsectors. This nominal output value was converted into real value by the GDP deflator (base year = 2008), which is available for 14 categories in the manufacturing sector.[14] This information is sufficient to define the total output of the manufacturing sector, $V_t = \sum_{i=1}^{24} v_i$, covering the period from 2004 to 2018.[15] Note that the data that Levinson (2015) analyzed included over 400 manufacturing categories. If two different categories in the data with 400 categories are in the same category in the data with 24 categories, a potential composition effect between these two categories is erased. Having a smaller number of manufacturing categories is likely to underestimate a composition effect. As Cole et al. (2010) indicate, industry output is available for over 500 categories, but the industrial waste data in Japan is not available at such a detailed level. In order to understand the changes in waste plastic emissions in more comprehensive manner, it is necessary to refer to analyses using more detailed data sets potentially available in other countries.

Information on plastic waste is available from the *State of Discharge and Treatment of Industrial Waste*, which is published yearly by the Ministry of the Environment of Japan[16]. Dividing plastic waste emissions (p_{it}) by the output value shipped for each industry (v_{it}), we can obtain subsector-specific pollution intensities ($\equiv z_{it}$) for each year.

Fig. 4 shows the comparison of the manufacturing output level and plastic waste generation of each of the 24 subsectors in 2018, which are $v_{i,2018}$ and $p_{i,2018}$ in our notation, respectively. The pillar of Japanese manufacturing is the automobile industry, most of which is included in the "Transportation Equipment" subsector. The production output (not value added) of over JPY 58 trillion of this subsector is outstanding in that it almost equals that of the second-ranked ("Chemical and Allied Product") and the third-ranked ("Food") subsectors combined. The most plastic waste is generated by the plastic product sector, followed by the pulp and chemical sectors.

Subsectors such as "Lumber and Wood Products" and "Rubber Products" are problematic because of the relatively high level of plastic waste generation compared to production output. These subsectors are typical high-pollution-intensity sectors with high z_{it}. Although they are not labeled in the figure, "Petroleum and Coal Products" and "Information and Communication Electronics Equipment" have very low levels of z_{it} (located at the left-bottom corner). Notably, in our analysis section, the greater the extent to which production shifts to subsectors with lower z_{it}, the larger the composition effect is.

3.3. Results

Fig. 5 shows our main results with inflation-adjusted indices set to FY2004 = 100. As the figure shows, most of the upward shift can be attributed to the change in the scale effect (Line 1), which increases 31% compared to the base year. The largest decline in the scale effect occurred between 2008 and 2009, which is explained by the global financial crisis. There was no such significant scale effect after the Great East Japan Earthquake in March 2011. Although the impact itself was substantial, we will not consider the scale effect further since the change in the scale effect is based on the economic business cycle in most cases.

Line 2 in Fig. 4 is the observed total plastic waste generation in each year. It shows that actual plastic waste generation decreased 18.1% in 2018 compared to 2004. Note that this 18.1% decline was due to the combination of scale, composition and technique effects. The line exceeded 100 in the first two years, with a maximum of 113.1, while Line 2 has never been over 100 since the global financial crisis. These

[13] For more details, see the following site: https://www.meti.go.jp/english/statistics/tyo/kougyo/index.html (last accessed on May 1, 2020).

[14] We use the most similar subcategory to cover all of the 24 subsectors in manufacturing.

[15] The data for 2018 are preliminary and subject to change in the future.

[16] All the data used are available at https://www.env.go.jp/recycle/waste/sangyo.html (in Japanese, last accessed on May 7, 2020).

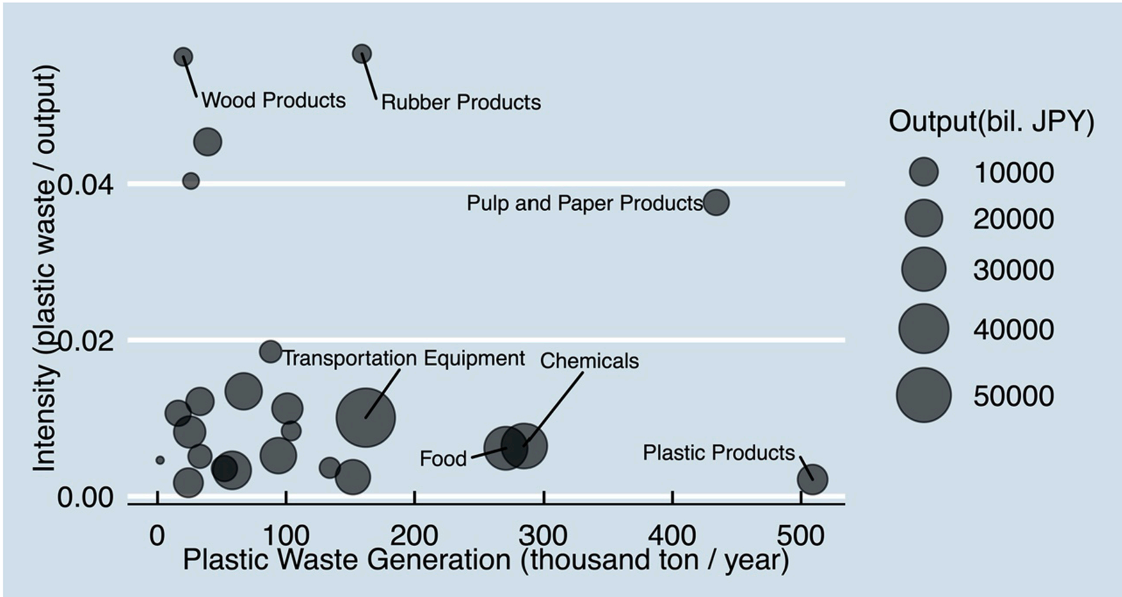

Fig. 4. Plot of $p_{i,2018}$ and $v_{i,2018}$ with the Size of Outputs. Source: Author's calculation from *the Census of Manufacture* and *State of Discharge and Treatment of Industrial Waste.*

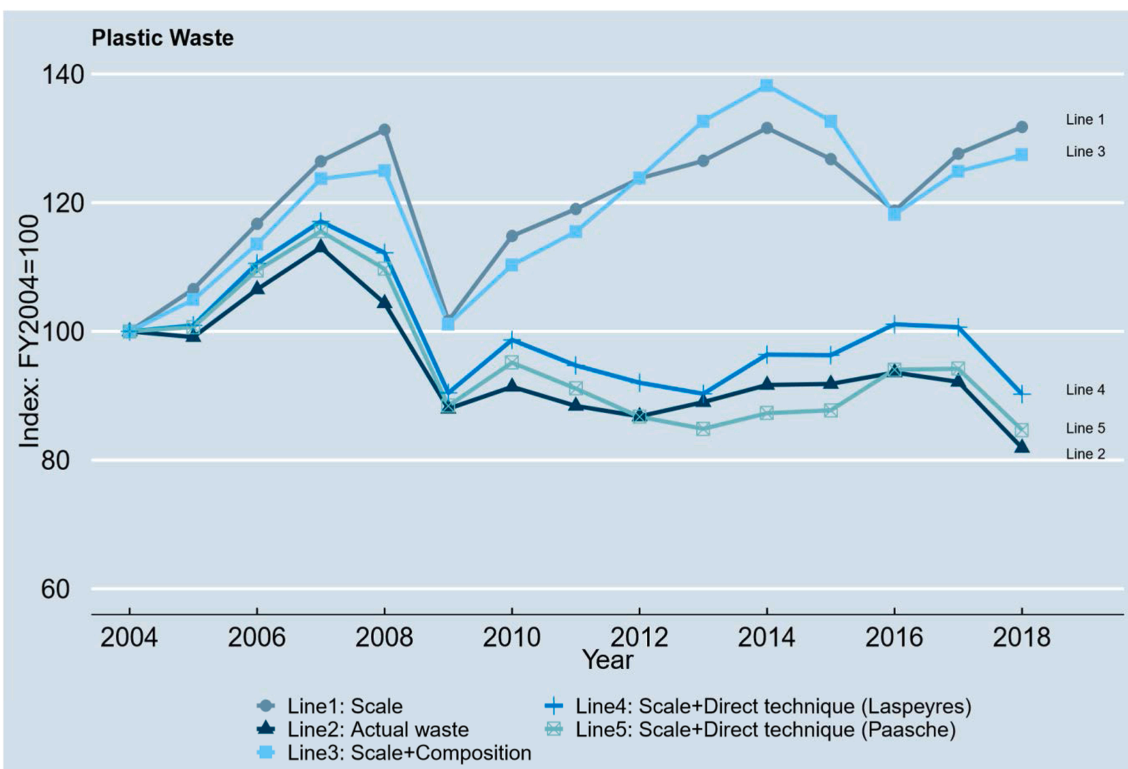

Fig. 5. Scale, composition and technique effects on plastic waste. **Source**: Author's calculation. **Note**: The total real manufacturing output of each year was multiplied by the Laspeyres index and Paasche index to plot Lines 4 and 5, respectively.

findings reflect not only the scale of the economy but also its composition.

Line 3 is the plot of $\widehat{P}_t$, which is the predicted waste plastic emission defined by Eq. (2). Note that $\widehat{P}_t$ is a combination of scale and composition effects, with a 27% increase in 2018 from the base year for plastic waste. The vertical distance between Line 1 and Line 3 reveals the composition effect alone, that is,

$$\frac{\text{Scale }[131.77] - (\text{Scale } + \text{ Composition }[127.42])}{\text{Scale }[131.77] - (\text{Scale } + \text{ Composition } + \text{ Technique }[81.89])} = 0.087 \tag{7}$$

The composition effect accounts for only 8.7% of the plastic waste reduction in this approach.

Table 1 summarizes the results for plastic waste and total industrial

Table 1
Comparison of the technique effect.

	(1) Cleanup of manufacturing (%)	(2) Technique effect (%)	(3) Technique share (%)
Plastic waste			
Indirect	−37.84	−34.55	91.3
Direct (Laspeyres)	−37.84	−31.52	83.3
Direct (Paasche)	−37.84	−35.73	94.4

Note: Column (1) is the difference between Lines 1 and 2, that is, [(Scale) − (Scale + Composition + Technique)/(Scale)]. The first row of Column (2) is derived by multiplying Column (1) and Eq. (7). For example, in the case of plastic waste, [−37.84 × (1–0.087) = −34.55]. Column (3) is simply the ratio of Column (2) to Column (1).

waste. The calculation method is identical in the two cases. Column (1) is the ratio of reduction (caused by the composition and indirect technique effects combined) to the scale effect. The first row is based on an indirect method, while the technique effect is directly calculated in the second and third rows.

The remaining 91.3% reduction is attributed to the technique effect. Levinson (2015) called this effect the indirect technique effect. Although the impact is not especially high, Japan's industrial composition has been shifting to less pollution-intensive subsectors relative to the base year (i.e., 2004). This finding contrasts with the results reported by Brunel (2017) and Cole and Zhang (2019), who, using the same method as that in the present study, concluded that the composition of EU and Chinese manufacturing became more pollution intensive, rather than less so. However, they analyzed air pollution and CO_2 emissions, not plastic waste.[17]

Notably, this approach does not consider the interactions among the three different effects (scale, composition and technique). If there is any interaction among them, it creates bias on the residual, and in this analysis, we simply assume that there is no interaction. The other concern is that the (indirect) technique effect is defined as a residual, which might contain other systematic bias. Following Levinson (2015), we explore the same decomposition from the other side. That is, we simply calculate the technique effect first given a constant composition effect. Using the indices defined in Eqs. (5) and (6), we calculate the technique effect directly. The result is shown in Line 4 and Line 5 in Fig. 4.

The difference between Line 2 and Line 4 represents the impact of the direct technique effect. That is,

$$\frac{\text{Scale}\,[131.77] - (\text{Scale} + \text{Technique}\,(\text{Laspeyres})\,[90.24])}{\text{Scale}\,[131.77] - (\text{Scale} + \text{Composition} + \text{Technique}\,[81.89])} = 0.833 \quad (8)$$

in the case of the IL. A similar calculation concludes that 94.4% of the reduction is attributable to the technique effect in the case of the IP. These results indicate that a large part of the reduction in plastic waste from manufacturing in Japan is associated with the technique effect, which ranges from 83.3% to 94.4%, depending on different calculation methods. Fig. 4 shows that the magnitude of the technique effect has been expanding since 2017, which corresponds to the timing of China's import ban on plastic waste and the subsequent trend of increasing capital investment, as made by recycling firms, and subsidies, as provided by regulatory authorities.

[17] In fact, the composition effect contributed to increasing waste generation in Japan from 2013 to 2015. However, this period represents only 3 out of the 15 years under study, while the results in the EU and China constantly exceeded the scale effect with greater impact.

4. Discussion

In the previous section, we noted that the technique effect is the main reduction factor for waste plastics in Japan. It is obvious that the technique effect needs to be supported by innovation. It is well known that Porter (1991) has led to a number of previous studies on the relationship between environmental regulation and innovation. Theoretical studies have not consistently concluded whether strict environmental policies stimulate the domestic economy. Therefore, empirical studies such as those by Jaffe and Palmer (1997), Greenstone (2002), and Johnstone et al (2010) have been accrued. In a recent study, Brunel (2019) highlighted Japan, Germany and the United States, as historically innovative economies, and showed empirically that such countries respond strongly to the implementation of environmental policies that drive innovation.

As we have seen, however, most of Japan's policies on waste plastic management target households, and very few (except for safety regulations) regulate the generation of industrial waste from corporate production activities. Nonetheless, our analysis above shows that Japan's waste plastic continues to decline due to technique effects that usually require significant innovation efforts. Why is it the case that Japan's industrial waste, especially waste plastic, is on the decline? To pursue a further reduction in waste plastics, understanding the driver of the reduction is very important and meaningful.

We believe that one of the reasons lies in the unique circumstances of the policy-making process in Japan. As shown by Arimura et al. (2019), the involvement of all stakeholder groups in the early stages characterizes the decision-making process of environmental policy in Japan. This involvement means that polluters can also express their opinions on how policy should be designed. Polluting firms have an incentive to prevent an official legislative implementation of emission controls by being willing to take voluntary actions by themselves.

From the perspective of policy makers, either price-based or quantity-based controls are options for achieving the social optimum. The former include emission taxes, while the latter are represented by emission trading schemes and usually include (an optimal level of) voluntary pollution reduction by polluting firms. Under different policies, the resulting pollution level is the same, but the profits of firms are not equivalent. An efficient level of pollution can be achieved either way, but polluting firms are not indifferent to these policies and prefer voluntary quantity controls over other price controls.

Let *MB* denote a marginal benefit to firms and *MEC* denote the social marginal cost of plastic waste. Without any regulation, firms maximize their benefits by setting $MB = 0$, while the optimal emission is where MB and MEC intersects; in Fig. 6, they are represented by q_0 and q^*, respectively. Under a price control policy such as a tax on plastic waste,

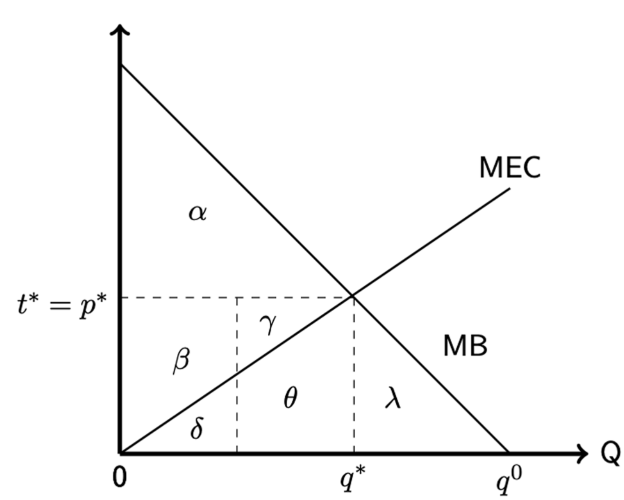

Fig. 6. Welfare Comparison.
Source: Arimura et al. (2019).

the regulator can choose a fee, t^*, which leads to an optimal level of quantity, q^*.

The benefits reaped by firms under the tax are the area α, but profits can be the entire area below the *MB* curve represented by $\alpha+\beta+\gamma+\delta+\theta$ if firms promise to voluntarily reduce their plastic waste until q^*. In this case, firms lose only λ from the profit-maximizing equilibrium. Once polluting firms understand that they now face the threat of a new tax burden from the regulator and have no choice but to relinquish a portion of the maximum profit, they have an incentive to lobby for voluntary action to avoid paying fees such as a carbon tax.

We strongly believe that this type of voluntary action has played an essential role in reducing plastic waste in Japan. Japan's leading player in this voluntary action has been *KEIDANREN* (Japan Business Federation). *KEIDANREN* is Japan's largest lobbying organization, with more than 1,400 members, mostly leading Japanese companies. In addition to political issues and economic policy, *KEIDANREN* often coordinates with government agencies on environmental issues, serves as a consensus builder among industries, and greatly influences Japanese policy in general.[18] In 1997, *KEIDANREN* established the "Voluntary Action Plan on the Environment", which included a section on waste management that set targets for each industry and promoted reduction as a voluntary initiative.

Remember that the plastic waste emission in Fig. 5 shows a decreasing trend since 2016. The voluntary plan established by *KEIDANREN* has been extensively revised since 2016. For example, since 2016, the section on waste management in the "Voluntary Action Plan on the Environment" has been separated and made independent as a single plan. The new plan sets a 2020 target of reducing final disposal by 70% from the 2000 level. The steady decline in plastic waste since 2016 must have been affected by the introduction of this new plan, which is another example of a well-established relationship between regulatory authorities and industry.

Finally, we discuss the challenges that voluntary agreements face[19]. Segerson and Miceli (1998), in a pioneering studies on voluntary agreements, found that when a company voluntarily reduces pollution at a lower cost, a voluntary agreement can be a win–win for both the regulator and the polluting company under certain conditions. Dawson and Segerson (2008) extended this model into one-to-many voluntary agreements where a certain regulator faces many companies in the same industry. This model fits more in our waste plastic reduction voluntary action in Japan. The priority is to avoid free riders. The challenge is how to avoid companies that have joined *KEIDANREN* but do not actually reduce waste plastics.

To prevent this problem, *KEIDANREN*'s Voluntary Action Plan was prepared for each industry, which makes comparisons with each other relatively easy, when compared to a single reduction target for each industry. As a result, 45 voluntary action plans have been formulated. We believe this policy has helped to maintain a substantial number of participating firms. Decision-making in Japan is known to be heavily influenced by one's neighbors (e.g. Ichinose et al., 2015). Companies in the same industry that belong to *KEIDANREN* have regular opportunities to exchange ideas and information on various business issues (including environmental issues). If one company in the same industry has achieved a significant reduction in plastic waste, this type of information is instantly known by other members of *KEIDANREN*. Other companies in the same industry with relatively similar manufacturing processes will try to achieve the same level of reduction. It is unacceptable for a company's management to fall behind its "neighbors" in reduction targets. This is another key to the functioning of the *KEIDANREN* framework.

The problem is, however, that the voluntary agreement does not necessarily achieve the optimal level of reduction for society. In other words, the pollution reduction level that is agreed upon through voluntary action cannot assure the cost minimized reduction allocation for the society.[20] To verify whether the reductions are at a level desirable from the social welfare perspective is our future research challenge.

5. Conclusions

In this paper, we analyzed the determinants of the change in plastic waste in the Japanese manufacturing sector from 2004 to 2018. Using Levinson's (2015) method, we decomposed the change into three different effects. To the best of our knowledge, this study is the first to apply this novel decomposition analysis to waste management issues. Unlike the work of Levison, we derived a larger contribution of the technique effect and a smaller contribution of the composition effect. Our results suggest that compositional changes in the Japanese manufacturing sector have made a limited contribution to plastic emissions. Changes in pollution from Japanese manufacturing subsectors were accelerated by improvements in production techniques. Considering the lack of legislation to reduce plastics in industrial wastes, we believe that the smooth relationship between the government and industry associations, such as *KEIDANREN*, has been a major reason for the technological innovation. However, whether the reduction level is cost-effective or not is a research question that remains as another research opportunity. Our research findings may also raise a further question, namely, whether the smaller composition effect on plastic waste is universal among other countries. Although we are unable to collect worldwide data to pursue answering this research question, addressing it would contribute to more efficient sector-by-sector policymaking to promote waste cleanup worldwide.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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[18] For example, *KEIDANREN* is the counterpart of the World Business Council of Sustainable Development (WBCSD) in Japan. For more details on *KEIDANREN*, see https://www.keidanren.or.jp/en/.

[19] Note that we discuss only part of the issues with voluntary agreements but not all of it. See Segerson (2018) for more details.

[20] This point is also mentioned by Proposition 5 in Dawson and Segerson (2008).

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