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What effect reduces plastic waste most?
－The case of Japanese manufacturing－

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What effect reduces plastic waste most?
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Abstract

In recent years, increasing attention has been paid to plastic waste, but in most cases, only household plastic waste has received attention. Knowing that the amount of plastic waste from households and that from manufacturing are almost the same in Japan, we focus on the change in plastic waste emissions from manufacturing from 2004 to 2017. Following the novel method of Levinson (2015), we decompose the emissions of plastic waste into scale effects, composition effects and (in)direct technique effects. This first application of the method in waste generation shows that the composition effect accounts for half of the cleanup, which is a much larger figure than those of previous studies on environmental problems.

Keywords: plastic waste; decomposition; technique effect; composition effect

1 Introduction

Plastic is a material that keeps our modern economic activity efficient because it is lightweight, easy to shape and long-lasting. This long-lasting attribute casts the downside of plastics when a product made of plastic ends its life and becomes waste. When plastic waste is misplaced, it will remain there for a long time. Currently, attention to plastic waste has been increasing worldwide. The plastic waste issue has been discussed not only in the conferences

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of high-ranked government officials but also by the world's political leaders, such as at the G7 meeting. In 2018, the G7 meeting in Charlevoix, Canada, for example, adopted the "Ocean Plastic Charter", the primary aim of which is to prevent plastic waste from entering the ocean. In 2018, the European Union also adopted the "European Strategy for Plastics in a Circular Economy". This is the first plastic waste strategy at the European Union level, and the objective of the 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 agenda point 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, the estimate says that China alone accounts for approximately 30% of ocean waste, followed by Indonesia with 10% in 2010 (at the median level). As a result, China stopped importing postconsumer plastic waste at the beginning of 2018. Since China was the largest importer of plastic waste in the world, other importers, especially Southeast Asian countries, were surged by plastic waste in the following year. As a consequence, many Asian countries started regulating plastic waste imports. It is worth mentioning that developed countries export a large amount of plastic waste each year and contribute to ocean plastic waste generation indirectly through developing countries. To prevent plastic waste problems, including ocean plastic waste, it is important to alleviate plastic waste generation in developed countries.

It seems that the current policy movements, including the G7 charter and the EU's strategy, focus mostly on the control of postconsumer plastic waste. In addition, most of the

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

previous literature on plastic waste related to economic activity concerns the postconsumer plastic waste problem.

As Abbott and Sumaila (2019) elucidate, there is an increasing number of studies on postconsumer plastic waste[2]. 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 saved USD 29.5 million. In addition, Jang *et al.* (2014) found marine debris resulting in a 63% reduction in tourism industry income (approximately USD 37 million) on Geoje Island. Beaumont *et al.* (2019) covered the costs of marine plastic debris regarding global ecological, social and economic impacts. The study postulates that marine plastic debris causes an annual loss of 500 to $2,500$ billion due to reduced marine ecosystem services. Abate *et al.* (2020) and Crowly (2020) also investigated marine plastic waste at Svalbard in the Arctic and Northern Philippines, respectively. From a policy perspective, Wagner (2020) helped to identify potentially effective policies for alleviating plastic waste pollution.

According to the European Union[3], industrial waste accounts for five and one-half tons out of a total of six tons of waste generated by a person per year. Comparing the amount of waste, however, industrial waste usually accounts for a nonnegligible amount. In fact, according to the Plastic Waste Management Institute of Japan (2019), the plastic waste coming from the industry 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). While strengthening regulations on plastic use by consumers, ignoring the same amount of waste

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

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

from industries does not make sense. Very few studies discuss the relationship between plastic waste from industry and economic activity. The rare exception is Weerdt *et al.* (2020), which argued that waste treatment taxation and plastic-related legislation significantly contribute to plastic waste generation from industry and can increase the recycling rates of industrial plastic waste.

To address the lack of evidence on the rest of the plastic waste—that from industry—we concentrate on plastic waste reduction from the manufacturing sector in this paper. Our analysis relies on a novel method developed by Levinson (2015). As we discuss the definition in a later section, this method allows us to directly measure the technique effect. Levinson (2015; 2009) analyzed air pollution from US manufacturing and concluded that the technique effect was dominant for the reduction of US air pollution from the late 1990s and early 2000. Brunel (2017) applied a similar methodology to EU air pollution and derived the result 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, from 2003 to 2015. As you can imagine, the Chinese economy grew 6 times during this period, but Cole and Zhang (2019) found that the SO2 emissions from the manufacturing sector were only 1.5 times higher due to the extensive improvement of the technique effect. Bernard *et al.* (2020) and Holland *et al.* (2020) extended this method to different ways to analyze air and water pollution in the Canadian pulp industry and the US's electricity industry. However, none of these previous papers targeted waste generation. To the best of our knowledge, this is the first study to apply Levinson's method to waste management policy, which is possible due to the excellent dataset provided by the Japanese Ministry of Environment.

Section 2 explains the current situation of Japanese plastic use and its effort in handling plastic waste. Using a novel dataset of industrial plastic waste in Japan, Section 3 conducts the decomposition analysis and summarizes the findings, and Section 4 interprets the implications from the results. Section 5 provides concluding remarks.

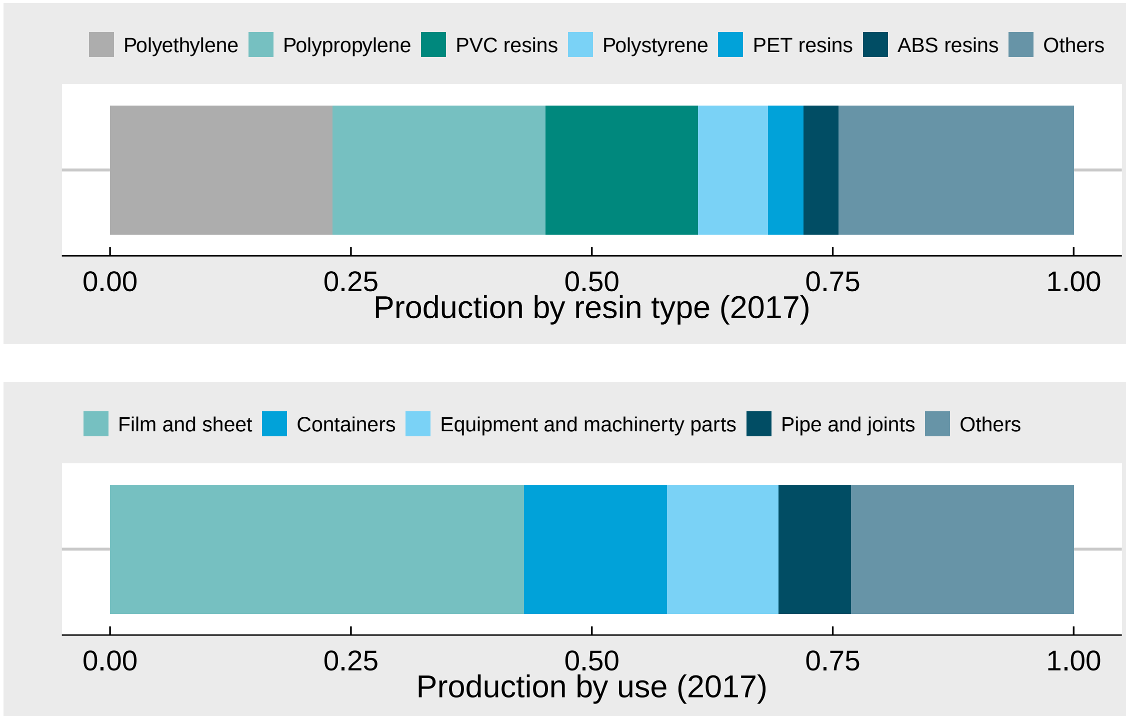
2 Japan's Efforts to Reduce Plastic Waste

In this section, we briefly introduce an overall picture of Japanese plastic use and efforts to reduce its waste. A recent report by the Plastic Waste Management Institute of Japan summarizes the current situation of Japan's plastic recycling and states that plastic production in Japan has stayed the same, at approximately 11.5 million tons per year, over the last 10 years, but production has decreased compared to approximately 14 million tons per year in the early 2000s. Figure 1 (above) is the share of resin type in Japanese plastic production. Almost half of the production is either polyethylene or polypropylene because approximately 40% of plastics are used for bags, packaging and sheeting (Figure 1, below).

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

During the same period of time, Japan's total industrial waste was at a steady level of approximately 400 million tons per year for the last 20 years, while its municipal waste

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



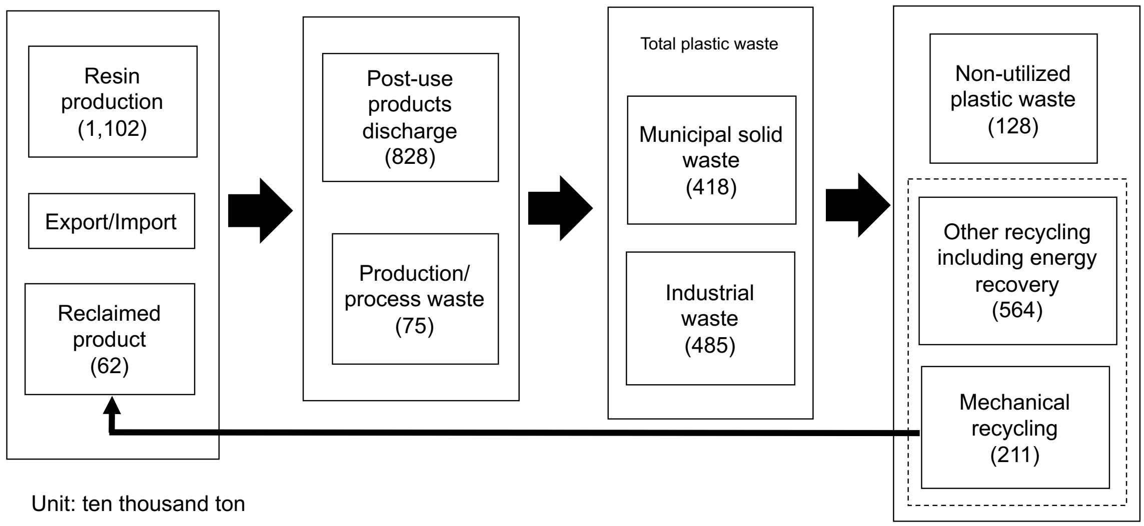
Source: Plastic Waste Management Institute of Japan (2019)

Figure 1: Plastic Production by Resin Type (Above) and Its Use (Below) in 2017

decreased from 55 million tons per year in 2001 to 42 million per year in 2017[5]. Of course, other sectors, such as the chemical sector or general-purpose machinery sector, also use plastics as their input, which results in the generation of plastic waste in these sectors. We will discuss further sector-specific issues when we explain the data definition.

Figure 2 is the Japanese material flow of plastics in 2017. The resin input was approximately 11.5 million tons, and this has not changed much over the last several years. After production and consumption, this input became 8.28 million tons of postuse 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.

[5]See the Annual Report of Environmental Statistics at http://www.env.go.jp/en/statistics/index.html for more details.



Source: Plastic Waste Management Institute of Japan (2019)

Figure 2: Material Flow of Plastic Products and Waste

The Japanese government introduced several laws to curve the generation of waste and promote recycling. In 2001, a new law, called "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. After 20 years, most of the laws are considered successful. In the following section, we would like to explore what enabled industries to be successful in reducing plastic waste in the past 20 years.

3 Decomposition of Plastic Waste from Manufacturing

3.1 Method

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

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

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

$$\hat{P}_t = V_t \sum_i \theta_{it} \overline{z}_i, \tag{2}$$

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

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

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

Totally differentiating the above equation, we have

$$dP = \boldsymbol{\theta}' \boldsymbol{z} dV + V \boldsymbol{z}' d\boldsymbol{\theta} + V \boldsymbol{\theta}' d\boldsymbol{z} \tag{4}$$

The first term in (4) is the scale effect, which explains the change in pollution when the size of the manufacturing sector increases. The second and third terms are the composition effect and technique effect, respectively. In the discrete expression, $P_t - \hat{P}_t$ corresponds to the left-hand side (LHS) of (4) minus the first and second terms of the right-hand side (RHS). This allows us to indirectly derive technique effects.

Rather than holding emission intensity constant, Levinson (2015) holds the composition of output fixed and shows how pollution per dollar of output has changed using the following indices. Given that the base year is 2004,

$$\text{Laspeyres index: } I_t^L = \frac{\sum_i z_{it} \times v_{i,2004}}{\sum_i z_{i,2004} \times v_{i,2004}} \tag{5}$$

$$\text{Paasche index: } I_t^P = \frac{\sum_i z_{it} \times v_{i,t}}{\sum_i z_{i,2004} \times v_{i,t}} \tag{6}$$

In addition to the conventional indirect technique index, we compute two indices above so that we can describe the reduction in plastic waste from various angles. As Levinson (2015) points out, the Laspeyres index would be smaller than the Paashe index if a subsetor with relatively smaller z_{it} grows 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) sector-specific output level, 2) generation of plastic waste by sector and 3) sector-specific deflators to convert our economic variable from nominal to real.

First, we obtain the data on manufacturing activity from *the Census of Manufacture*, published by the Ministry of Economy, Trade and Industry (METI) of Japan[6]. The census contains the annual output (monetary base) for each of the 24 subsectors of manufacturing. This nominal output value was converted to a real term by the GDP deflator (base year=2004).

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

This is enough information to define the total output of the manufacturing sector, $V_t = \sum_{i=1}^{24} v_i$, covering the periods from 2004 to 2017. The starting year of 2004 was chosen since 24 subsector-specific waste emissions levels ($\equiv p_{it}$) are available only from 2004 onward. This information on plastic waste is available at *State of Discharge and Treatment of Industrial Waste*, which is published yearly by the Ministry of Environment of Japan[7]. 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.

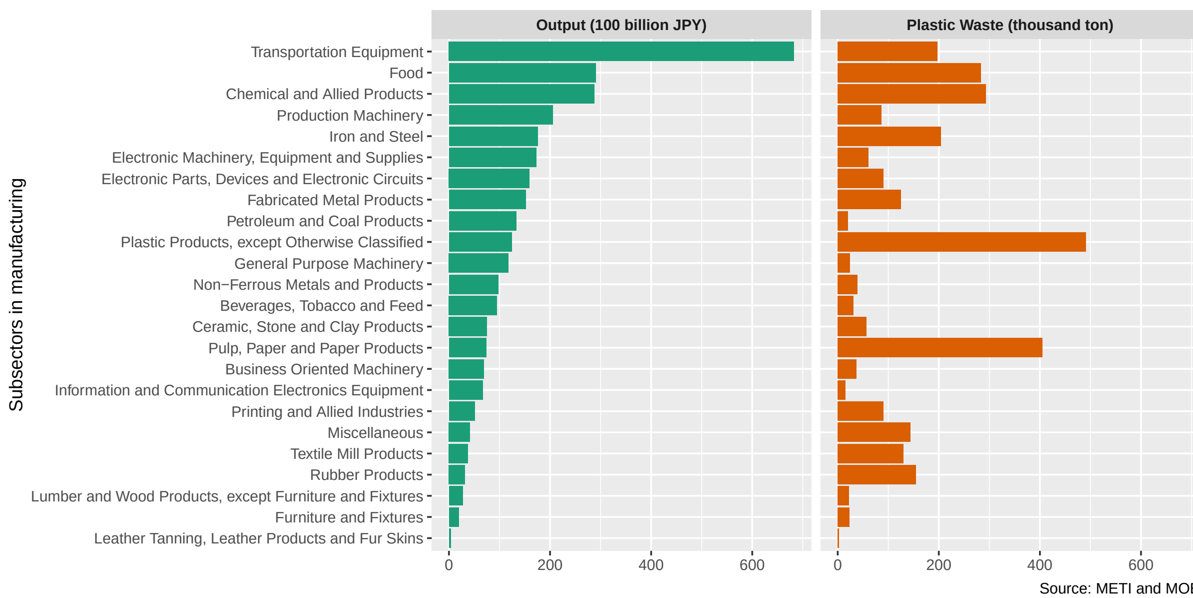


Figure 3: Output and Generation of Plastic Waste from Manufacturing in 2017

Figure 3 shows the comparison of the manufacturing output level and plastic waste generation by each of the 24 subsectors in 2017, which are $v_{i,2017}$ and $p_{i,2017}$ in our notation, respectively. The pillar of Japanese manufacturing is the automobile industry, most of which is included in the subsector of "Transportation Equipment". The production output (not

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

value added) of over 60 trillion in this subsector is outstanding in that it is larger than the second ("Food") and the third ("Chemical and Allied Product") combined. Plastic waste is generated most in the plastic product sector, followed by the pulp and chemical sectors.

Subsectors such as "Textile Product" and "Rubber Product" 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}, while "Transportation Equipment" and "Product Machinery" have very low levels of z_{it}. It is worth mentioning that in our analysis section, the more production shifts to lower z_{it} subsectors, the larger the composition effect is.

A small concern arises in regard to comparing z_{it} among each of the subsectors over time because there was a slight change in industry classification in 2008. Japan's official statistics must follow the *Japan Standard Industrial Classification*[8], but this was changed towards the end of 2007. As a result, there is no one-to-one correspondence among each of the subcategories before and after 2008. The definition of the manufacturing sector has not changed, and there was only a small rearrangement of subsectors within the manufacturing sector. Since we compare only aggregated results at the manufacturing sector level, keeping different classifications before and after 2008 does not bring about any problems in the following analysis.

3.3 Results

Figure 4 shows our main result. The first thing we note is the enormous decline from 2008 to 2009, which is completely due to the world financial crisis. As you can see in the figure, most of

[8] The whole classification is available at https://www.soumu.go.jp/english/dgpp_ss/seido/sangyo/index07.htm (last accessed on May 8, 2020)

the downward shift can be attributed to the change in scale effect (line 1), the real production output change. This change between 2008 and 2009 is quite significant, considering that there is no such significant scale effect, even after the Great East Japan Earthquake in March 2011. Although the impact itself is substantial, we will not consider the scale effect any further since the main reason for the change in scale effect is based on the economic business cycle in most cases[9].

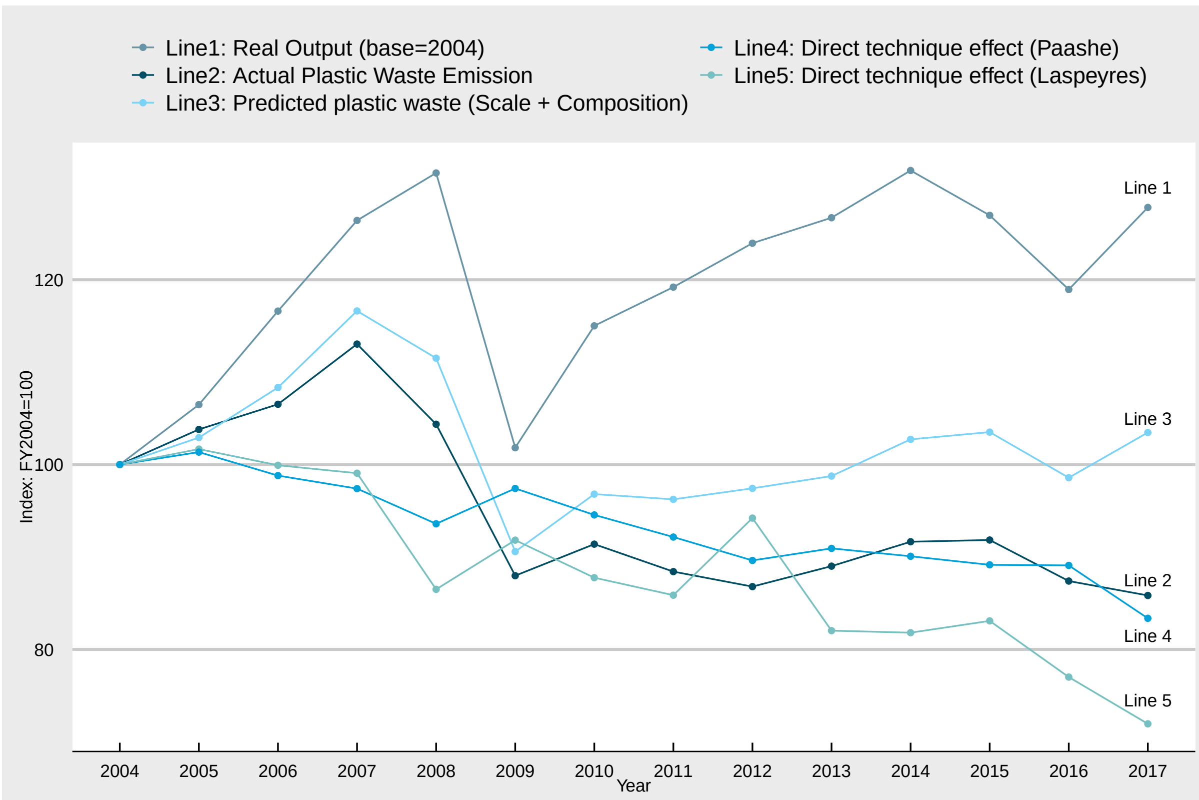


Figure 4: Changes in Scale, Composition and Technique Effects

Next, line 2 is the observed total plastic waste generation in each year, while line 3 is the plot of $\hat{P}_t$, which is a predicted plastic waste emissions. Note that $\hat{P}_t$ is defined as

[9] To check robustness, we have computed alternative indices with the base year of 2009, but the qualitative results are unchanged.

the combination of scale and composition effects. The difference between lines 1 and 3 is the composition effect. Since line 3 is constantly below the scale effect, we can say that the cooperation effect was negative from 2004 to 2017, which means that Japanese manufacturing is shifting its production to less pollution-intensive subsectors relative to the base year (= 2004). This negative result is much more intuitive than the results in Brunel (2017) and Cole and Zhang (2019), where the composition of EU and Chinese manufacturing became more pollution-intensive than less, respectively. This difference increased after the financial crisis and in most years since 2009. In 2017, the composition effect in Japan accounted for 57.8% of the 32.9% decline in plastic waste. Manufacturing increased by 27.8%, and predicted plastic waste generation (= $\hat{P}$) rose 3.5%. Given that the actual plastic waste generation declined by 14.2%, we derive

$$\frac{127.8 - 103.5}{127.8 - 85.8} = 0.578 \tag{7}$$

This means that more than one-half of the decline was caused by the change in composition. This approach does not consider the interactions among three different effects (scale, composition and technique effects). If there is any interaction among them, then it creates a bias on the residual, (indirect) technique effect. To check robustness, we explore another approach to compute the technique effect in the next section.

4 Discussion

Now, we know that 57.8% of the cleanup of plastic waste from Japanese manufacturing between 2004 and 2017 is accounted for by the composition effect under the framework with the indirect technique effect. Levinson (2015) called this effect indirect because it is derived as the residual. Graphically speaking, this is the difference between lines 2 and 3 in Figure 4. The differences have had an upward trend since 2009. It is interesting that the sum of indirect technique and composition effects was not large enough to erase the scale effect in the periods before the financial crisis. This means that the business transformation forced by the financial crisis led to cleaner plastic waste generation in Japanese manufacturing, while it seems that the 2011 great earthquake, which changed many aspects of Japanese society, did not place any similar pressure on the business.

Table 1: Plastic Waste Cleanup (Technique) in Japanese Manufacturing (2004-2017)

	(1) Clean-up of manufacturing (%)	(2) Technique effect (%)	(3) Technique share (%)
Indirect	-32.85	-13.86	42.2
Direct (Laspeyres)	-32.85	-28.06	85.4
Direct (Paasche)	-32.85	-16.64	50.7

Note: Column 1 is the difference between lines 1 and 2, that is, (127.8-85.8)/127.8 = 0.3285. The first row of Column 2 is Column 1 times -1.578, derived from equation (7). Column 3 is the ratio of Column 2 to Column 1.

Table 1 is the summary of technique effects including two direct technique effects defined by equations (5) and (6). The technique effects range from an approximately 14% to 28% decline, which accounts for 42% to 85% of the total cleanup in plastic waste from Japanese manufacturing. Where does this disparity come from? It is well known that the Lespeyres price index overstates inflation, while the Paashe price index understates inflation when we assume that people are rational in following relative prices during the inflation period.

Given the analogy of the inflation example, the Lespeyres index value would be smaller than the Paashe index value when a subsector of manufacturing produces less share of plastic waste and this subsector's pollution intensity is decreasing relatively fast. In other words, the Lespeyres index gives us a larger technique effect under such circumstances. Moreover, when a subsector lowering its pollution intensity relatively fast increases its share of plastic waste more during the targeted period of 2004 to 2017, the Lespeyres index value will be larger than the Paashe index value.

It is worth mentioning that a naive application of the price index analogy to this study is misleading when we discuss types of bias in the Laspeyres and Paashe indices. One can assume that a price increase usually has a consequence of decreasing quantity sold in the case of price index. Since the quantity share stays unchanged in Laspeyres price index from the base year, the price increase would be overstated. In our analysis, a price is replaced to pollution intensity and quantity is to output. Unlike price index's case, it is difficult to assume direct (positive or negative) relationship between the pollution intensity and the subsector's output. Our result in Table 1 shows relatively smaller Laspeyres index to Paashe index, which means subsectors with smaller share of waste generation compared to the base year happened to have pollution intensity decreasing relatively fast.

To show it more formal way, let us rewrite the Lespeyres index. Using $P_t = \sum_i p_{it} = \sum_i v_{it} z_{it}$,

$$I_t^L = \frac{\sum_i z_{it} v_{i\bar{t}}}{\sum_i z_{i\bar{t}} v_{i\bar{t}}} = \frac{1}{\sum_i z_{i\bar{t}} v_{i\bar{t}}} \sum_i (z_{i\bar{t}} v_{i\bar{t}}) \left(\frac{z_{it}}{z_{i\bar{t}}} \right) \tag{8}$$

$$= \frac{\sum_i \left(\frac{z_{it}}{z_{i\bar{t}}} \right) p_{i\bar{t}}}{P_{\bar{t}}}, \tag{9}$$

where $\bar{t}$ denote the base year, which is 2004 in our case. Thus the change in the Lespeyres index from $t-1$ to t is

$$\frac{I_t^L - I_{t-1}^L}{I_{t-1}^L} = \frac{\sum_{i=1} (\tilde{z}_{it} p_{i\bar{t}} - \tilde{z}_{i,t-1} p_{i\bar{t}})}{I_{t-1}^L P_{\bar{t}}} = \sum_{i=1} \frac{\tilde{z}_{it} - \tilde{z}_{i,t-1}}{I_{t-1}^L} \cdot \frac{p_{i\bar{t}}}{P_{\bar{t}}}, \tag{10}$$

where $\tilde{z}_{it} \equiv \frac{z_{it}}{z_{i\bar{t}}}$. The change described by (10) has a downword bias when the real share of plastic waste in 2017 become smaller compared to 2004 in subsectors with falling their pollution intensity.

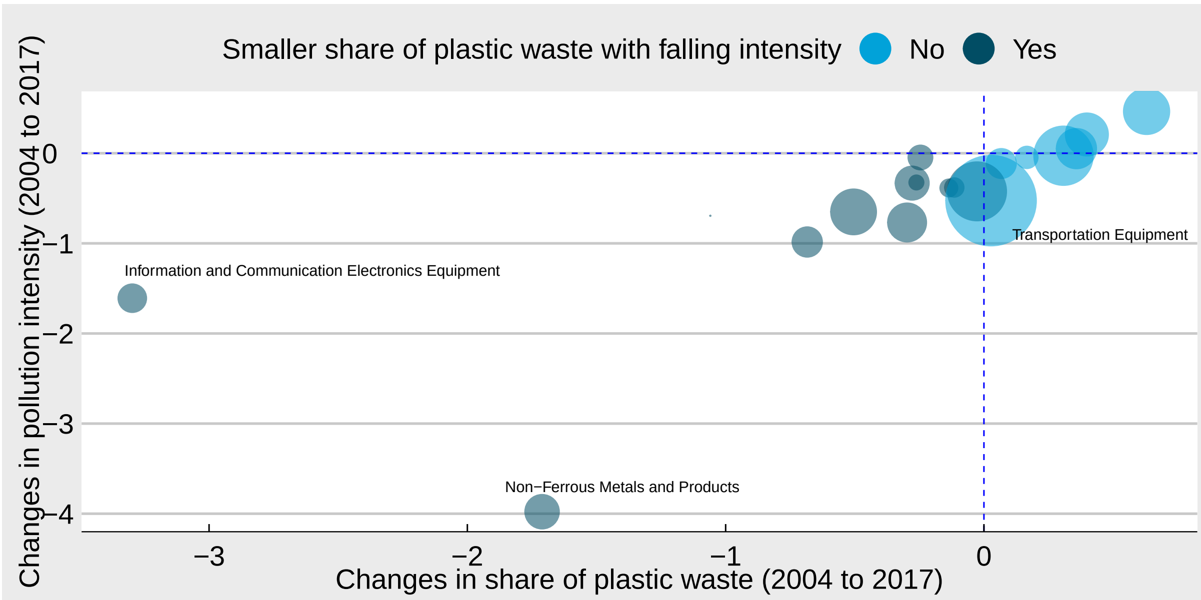


Figure 5: Changes in Pollution Intensity and share of Plastic waste

Figure 5 is a plot of the change in pollution intensity ($= z_{it}$) and the change in share of plastic waste generation ($= \frac{p_{it}}{P_t}$) from 2004 to 2017[10]. In Figure 5, the blue dotted lines categorize four quadrants. Our result in Table 1 shows a smaller Lespeyres index value. As we discussed above, less share subsectors with fast-falling intensity creates downward bias to

[10] As we discussed earlier, the official classification changed during this time period. Thus, we excluded five subsectors that were difficult to compare between 2004 and 2017. The production level of the remaining 19 subsectors combined amounted to 85% of the total production level.

the Lespeyres index. As you can see, the thrid quadrant has the large number of circles in Figure 5.

For example, the subsector of “Nonferrous Metals and Products”, which has the middle level of production among the 24 subsectors, recorded the largest decline in terms of pollution intensity. From the viewpoint of change in the share of plastic waste, “Information and Communication Electorics Equipment” contributed most. This subsector decreased the platics waste generation more than three times larger than its production decline.

The size of the circle in Figure 5 shows the production level. The largest circle is in the fourth quadrant and it is “Transportation Equipment”. The automobile industry, which is the pillar of the Japanese manufacturing, not only constantly increases its production level but also decreases pollution intensity. Since the change in the share of plastic waste generation increased very slightly (only 2%), this subsector would be neutral to any bias.

Together with the indirect technique effect being close to the Paashe index, it is more likely that the technique effect had a limited contribution compared to air pollution cleanup in the US. Levinson (2015) concluded that only 12% of the total cleanup of the US’s air pollution accounted for the composition effect. In our analysis, the composition and technique effects are able to split their contribution in half.

5 Conclusions

In this paper, we analyzed the determinants of the change in plastic waste in the Japanese manufacturing sector from 2004 to 2017. Using Levinson’s (2015) method, we decomposed the change into three different effects. To our knowledge, this is the first study to apply this novel decomposition analysis to waste management issues. Unlike the work of Levison and other air-pollution-related studies, we derived a larger contribution to the composition effect and less to the technique effect. This result revealed a new research question regarding whether having a smaller composition effect is true of waste issues in other countries. Uncovering this question contributes to more efficient sector-by-sector policy making to encourage waste cleanup.

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