Analysis of the Correlation and Regional Distribution of Plastic Waste Pollution

Jia Xu¹, Zixuan Wu¹, Yazhi Zhao¹, and Jingsan Yang²,*

¹Nanjing University of Finance and Economics, Applied Mathematics Department, China
¹Nanjing University of Finance and Economics, Economics and Finance Department, China
¹Nanjing University of Finance and Economics, Information Engineering Department, China
²Nanjing University of Finance and Economics, Applied Mathematics Department, China

Abstract. Plastic has brought great convenience to people's lives, but it has also brought severe environmental pollution to the world. It is almost impossible to break down entirely in nature, and plastic waste, whether in rivers, oceans, or on land, can persist in the environment for centuries. The problem of plastic waste disposal has caused worldwide concern. It is necessary to reduce the production of plastic products through global cooperation effectively. However, achieving this goal will also involve some unexpected issues, such as controlling the adverse economic impact of plastics, and the rationality and fairness of the distribution of responsibilities between different countries. This paper collects massive data and takes China as an example to study the impact of plastic output reduction on China's Express industry and the plastics manufacturing industry using multivariate regression. This paper summarizes the positive and negative effects of plastic waste reduction. Given the distribution and management of national and regional plastic waste responsibilities, the global carbon emission rights distribution method is used for reference. The comprehensive index allocation method is used to deal with the problem of both fairness and efficiency relatively. What is more, based on the conclusions, this paper also provides suggestions for a global joint response to plastic waste.

1 Introduction

Since the 1950s, the manufacturing of plastics has grown exponentially because of its variety of uses, such as food packaging, consumer products, medical devices, and construction. While there are significant benefits, the negative implications associated with increased production of plastics are concerning[1]. Effects can be seen by the approximately 4 to 12 million tons of plastic waste that enter the oceans each year[1,2]. Plastic waste has severe environmental consequences and it is predicted that if our current trends continue, the oceans will be filled with more plastic than fish by 2050[2]. The effect on marine life has been studied[3], but the effects on human health are not yet completely understood[4]. The rise of single-use and disposable plastic products results in entire industries dedicated to creating plastic waste. It also suggests that the amount of time the product is useful is significantly shorter than the time it takes to properly mitigate the plastic waste. Consequently, to solve the plastic waste problem, we need to slowdown the flow of plastic production and improve how we manage plastic waste.

Ideally, we want to reduce the level of global waste of single-use or disposable plastic products as much as possible, but it will have a lot of impacts on different industries. Taking the Express and Manufacturing industries as examples, we used multivariate regression model to analyze the correlation between the impacts and plastic waste. While this is a global issue, the responsibilities are not equally distributed across nations or regions. Therefore, we discuss the equity issues that arise from this crisis of plastic pollution and propose the suggestion of a plastic quota for this global crisis.

2 Correlation analysis

The disposable plastics waste came from different industries, the primary packaging, textile, consumer and institutional products, and transportation and construction industries. Restricting the production of plastics will restrict the development of many industries. Take China, a manufacturing power, for example. According to THE NEW PLASTICS ECONOMY GLOBAL COMMITMENT 2019 PROGRESS REPORT[5] and Generation characteristics and management status of Express packaging waste in China, given the domestic reality, in terms of plastics pollution, China's express industry and plastic production industry are highly dependent on plastics and cannot find alternatives in time, which will lead some organizations seeking economic development to sacrifice environmental protection for the sake of profits. The following in Table 1. are selected to represent the number of plastics demanded and the
amount of plastic used in the specific industry, the number of recycled plastics, and the value of the sector and the cost of disposing of plastics waste[6]. Starting from the two selected industries, the express industry is related to the human lifestyle, and the reduction of the output of plastics products has a specific impact on the development of the plastic manufacturing industry.

We obtained data on the total volume of express delivery services in China from 2010 to 2018 from local and State Post Bureau of The People's Republic of China and converted into units. Data on the use of plastic films, the output of plastic products, and the cumulative import of plastic products were obtained from the National Bureau of Statistics.

Table 1. Variables

| Symbol | Description |
|--------|-------------|
| $\alpha_i$ | The weight of the i-th index for the first and second constraints |
| $\beta_i$ | The weight of the i-th index for the third and fourth constraints |
| $PB$ | Plastics film usage / 10,000 tons |
| $EB$ | Express delivery volume / 1 billion pieces |
| $GC$ | Garbage collection and transportation cost / 100 million yuan |
| $P$ | Plastics output / 10,000 tons |
| $MI$ | Main business revenue / 100 million yuan |
| $MRW$ | Main recycled waste plastics resources recovery volume/ton |
| $Pro$ | Total profit / 100 million yuan |
| $Pimp$ | Cumulative import quantity/ton of plastics products |

2.1. The express industry

The rise and development of the express industry in China have led to an increase in the use of plastics, which has made it more challenging to deal with various types of plastics waste. According to the research report "Generation characteristics and management status of Express packaging waste in China," the packaging used by China's express industry mainly consists of corrugated cartons and plastic bags, which account for about 33.5% of the total. As shown in Figure 1, the graph shows the trend chart of express delivery plastics film usage $PB$ (in tons), express delivery volume $EB$ (in billions of pieces), and garbage collection cost $GC$ (in billions of yuan) from 2010 to 2018. We found out that the use of plastics films is still increasing year by year, and the demand is not decreasing, but the increase rate is at a steady upward trend. Meanwhile, by 2018, due to the rapid development of e-commerce platforms in recent years, the express delivery business has increased rapidly, which has driven up the cost of garbage disposal.

There is a specific correlation between the factors as shown in Figure 2. According to the calculation, the use of express plastics film has a high positive correlation with the volume of express business and waste disposal cost. There is a strong positive correlation between the size of express delivery and the waste treatment cost, as shown in the figure below. The darker the color, the stronger the correlation.

2.2 Plastics manufacturing industry

Plastics is one of the necessary materials needed for the development of modern society, so the development of plastics manufacturing plays a vital role in the national economy. The Figure 3 shows the plastics output from 2010 to 2018 $P$ (unit: 10,000 tons), primary business revenue $MI$ (unit: 100 million yuan), recycling volume of waste plastics from primary renewable resources $MRW$ (unit: 10,000 tons), total profit $Pro$ (unit: 100 million yuan), cumulative import volume of plastics products $Pimp$ (unit: ton). Therefore, we found that in recent years, the recycling amount of waste plastics from renewable resources and the cumulative quantity of plastics products import changed little, and the trend of increasing plastics output $P$ was not evident[7]. However, the change in primary business income was relatively noticeable, and the primary business income was relatively the highest in 2016.
The development of plastics manufacturing industry in recent years

Secondly, after computing the correlation among various factors, in Figure 4, the plastics output has a moderate positive correlation with the recycling amount of waste plastics from primary renewable resources and a negative correlation with the total profit. The primary business revenue and total profit is a moderate positive correlation. The total profit is negatively correlated with the cumulative import quantity of plastic products, as shown in the following figure:

\[
\begin{align*}
\beta_0, \beta_1, \beta_2, \sigma^2 \text{ are all unknown parameters} \\
\text{independent of } X_1, X_2. \\
X = \begin{bmatrix}
x_{11} \cdots x_{1m} \\
\vdots \\
x_{n1} \cdots x_{nm}
\end{bmatrix}, \\
Y = \begin{bmatrix}
y_1 \\
\vdots \\
y_n
\end{bmatrix}, \\
\epsilon = \begin{bmatrix}
\epsilon_1, \ldots, \epsilon_n
\end{bmatrix}^T, \\
\beta = \begin{bmatrix}
\beta_0, \beta_1, \ldots, \beta_m
\end{bmatrix}^T
\end{align*}
\]

(2)

According to the existing independent observation data, it can be obtained from (1) that:

\[
\begin{align*}
\begin{cases}
Y = X\beta + \epsilon \\
\epsilon \sim N(0, \sigma^2, \mathbf{I}_n)
\end{cases}
\end{align*}
\]

(3)

The parameter estimation uses the least square method (LSM) so that \( \hat{\beta}_j \) and \( \beta_j \) are equal, that is, the sum of the squared of errors (SSE)

\[
Q = \sum_{i=1}^{n} \epsilon_i^2 = \sum_{i=1}^{n} (y_i - \beta_0 - \beta_1x_{i1} - \ldots - \beta_mx_{im})^2
\]

(4)

is minimized.

2.3.1 The express industry

We built multivariate regression models of plastic film usage (10,000 tons), garbage collection, and transportation cost (100 million yuan) and express business volume (1 billion pieces). It can be seen that the impact of plastic film usage in the express industry on garbage collection and transportation cost is tremendous, which is significantly correlated with express business volume. Assuming no new "plastic ban" is issued, each reduction in the use of 10,000 tons of express plastic film will reduce the collection cost of waste 335 million yuan and the delivery volume of 134 million yuan.

2.3.2 Plastics manufacturing industry

Set up the regression equation for plastic production (10,000 tons), primary business income (one hundred million yuan), primary recycling waste plastic resources (10,000 tons), total profits (one hundred million yuan), and cumulative import quantity of plastic products (tons). Under the premise of not change in the current policy, if the plastic output decreases by 10,000 tons, the primary recycling waste plastic resources will decrease by 8,748 tons and the cumulative import quantity of plastic products will increase by 20,000 tons. The principal business income will increase by 856 million yuan.

2.4 Test of the model

For the model test, the normality visualization was shown in the figure, Adjusted R-squared = 0.996, and the predictive variables explained the variance of the express plastics film by 99.6%. The model has a remarkable
effect, passing the F test, and the intercept term and coefficient have also passed the T-test.

From Figure 5, it can be seen that almost all the scatter points are near the line and fall within the confidence interval, which indicates that the normal assumption is relatively consistent, with two points that deviate significantly from the dotted interval, namely 4 and 5.

Fig. 5. QQ diagram and residual diagram

Similarly, for the model test, Adjusted $R^2$ = 0.7695, then the prediction variable could explain 76.95% of the variance of the express plastics film. All the scatter points were near the line and within the confidence interval.

3 Global equity distribution analysis

3.1 Factors

According to comprehensive index allocation method, the following indicators in Table 2 are chosen.

| Indicator | Description | Number of countries |
|-----------|-------------|---------------------|
| HDI       | Human development index (%) | 194                 |
| GDPC      | Gross domestic product per capita (Billion/$) | 194                 |
| GDP       | Gross domestic product (Billion/$) | 194                 |
| PWC       | Plastic waste per capita (MT) | 194                 |

The chart shows the plastics waste generate rate per person versus gross domestic product (GDP) per capita. In general, although there are conspicuous changes across countries at all levels of development -- plastics waste generation tends to increase as people get wealthier. Plastics waste per capita at low incomes tends to be notably smaller.

Whilst per capita plastics waste generation tends to increase with income (see above), this general relation does not hold considering mismanaged plastics waste. Figure 6 reflects the mismanaged per capita plastics waste generation rate versus GDP per capita.

Fig. 6. Mismanaged plastic waste per capita vs. GDP per capita

Mismanaged waste generation tends to be low at very low incomes (since per capita waste is small). It then rises towards middle incomes and then falls again at higher incomes[8].

Countries around the middle of the global income spectrum therefore tend to have the highest per capita mismanaged plastics rates. This has typically occurred in countries that have rapidly industrialized, but failed to make progress in waste management at the same speed.

The development of effective waste management infrastructure, particularly in middle-income countries, is therefore crucial to make progress against plastics pollution.

Fig. 7. World map representing Human Development Index categories in 2019

As shown in Figure 7 and Table 3, the more developed countries, the higher the HDI[9], the greater the contribution they can make to the global problem of disposable plastic waste.

Table 3. The top 10 regions in the 2018 HDI

| Region         | HDI   |
|----------------|-------|
| Norway         | 0.954 |
| Switzerland    | 0.946 |
| Ireland        | 0.942 |
| Germany        | 0.939 |
| Hong Kong      | 0.939 |
| Iceland        | 0.938 |
| Australia      | 0.938 |
| Sweden         | 0.937 |
| Singapore      | 0.935 |
| Netherlands    | 0.933 |
3.2 Suggestions

The disposal of plastic waste is a global problem. Scientific and reasonable distribution of plastic waste management responsibility is of considerable significance to protect the global ecological environment. Efficiency and equity need to be balanced, and the interests of different countries need to be addressed. Therefore, it is better to combine many principles and methods to form a consensus plan. In the specific plan, we can refer to the current carbon emission rights allocation, and make improvements. That is, establishing the maximum value of plastic waste treatment can limit or allocate the amount of plastic waste produced in each country. Adopt the multi-index factor method, such as GDP and HDI, to consider the problem more comprehensively.

Plastic waste disposal is still the result of the global allocation of resources by the market economy. Developed countries are more advanced in the field of plastic waste technology, but because of the high cost of waste disposal, they often choose to send plastic waste abroad in large quantities to developing countries[10]. Developing countries have limited capacity to deal with plastic waste, resulting in waste accumulation and environmental pollution. It is clear that the more developed countries, which are top ranked in terms of indicators, need to be constrained to assume their due responsibilities.

To solve single-use plastic waste equitably, countries should give full play to the effectiveness of the Basel convention and find room for improvement on this basis. The Basel Convention and its amendments stipulate that the state parties to the convention enjoy the right to treat marine plastic waste and the direct basis for the treatment of marine plastic waste[11] which has a significant impact on the global prevention and control of marine plastic waste pollution. In terms of effectiveness, more member states should be encouraged to abide by their commitments and participate deeply. In particular, the principles of waste minimization and the principle of proximity. It is relatively fair and efficient to prevent the cross-border transfer of plastic waste to countries that do not have waste disposal capacity. Besides, if these effective methods implemented more widely, corresponding measures should be taken at the level of international law, which is conducive to the realization of equity and efficiency under the joint supervision of the international community.

4 Conclusion

China’s express industry is highly dependent on plastics, and industries such as the plastics manufacturing industry cannot find substitutes in time. Suppose plastics' output is not reduced with the industry development. In that case, the cost of garbage cleaning, transportation, and the cost of recycling waste plastics from primary renewable resources will increase, which will lead to the sacrifice of environmental protection to benefit some organizations seeking economic development. Secondly, although many countries are aware of plastic waste pollution's seriousness, they have introduced relevant policies. However, there are still many defects in the formulation and implementation of these policies. For example, the limited objects are not broad enough, and the supervision is not strict enough. Nowadays, this problem has attracted wide attention all over the world, which urgently needs to find a scientific way to minimize the production of plastic products through global cooperation.

References

1. Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. Science Advances, 3(7), e1700782.
2. Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., … & Law, K. L. (2015). Plastic waste inputs from land into the ocean. Science, 347(6223), 768-771.
3. Li, W. C., Tse, H. F., & Fok, L. (2016). Plastic waste in the marine environment: A review of sources, occurrence and effects. Science of the Total Environment, 566, 333-349.
4. Galloway T.S. Micro- and Nano-plastics and Human Health. In: Bergmann M., Gutow L., Klages M. (eds) Marine Anthropogenic Litter.(2015)
5. N. E. W. P. Economy, G. Commitment, and P. Report, THE NEW PLASTICS ECONOMY 2019 PROGRESS REPORT Lead Philanthropic partner, no. October, 2019.
6. R. Geyer, J. R. Jambeck, and K. L. Law, Production, use, and fate of all plastics ever made, Sci. Adv., vol. 3, no. 7, pp. 25–29, 2017, doi: 10.1126/sciadv.1700782.
7. Hannah Ritchie (2018) - Plastic Pollution. Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/plastic-pollution’ [Online Resource]
8. R. Meys, F. Frick, S. Westhues, A. Sternberg, J. Klankermayer, and A. Bardow, Towards a circular economy for plastic packaging wastes – the environmental potential of chemical recycling, Resour. Conserv. Recycl., vol. 162, p. 105010, 2020, doi: https://doi.org/10.1016/j.resconrec.2020.105010.
9. S. Morse and S. Morse, Human Development Index, Rise Rise Indic., pp. 61–81, 2019, doi: 10.4324/9781315226675-3.
10. EPA, Advancing Sustainable Materials Management: Facts and Figures Report, United States Environ. Prot. Agency, no. November, 2019.
11. C. Sonam, Y. B. Prasad, S. N. Anwar, and C. S. Kumar, Mathematical modelling and analysis of plastic waste pollution and its impact on the ocean surface, J. Ocean Eng. Sci., pp. 0–44, 2019, doi: 10.1016/j.joes.2019.09.005