Data Open Championship 2021

An Empirical Analysis On the Impact of China’s Plastic Waste Import Ban

Team 2

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General Background

Much of plastics is made into one-time products and has generated considerable plastic waste each year. The poor degradability of plastics has **prompted concerns about its heavy toll** on the environment and many countries like China have already imposed stricter regulations on plastic waste importation. We are motivated to explore and validate the actual effect of plastic waste trade restrictions on export-import dynamics as well as on plastic waste pollution. Furthermore, we are interested in **investigating the country attributions that cause the disparity of plastic waste management capacity between countries and accordingly giving recommendations for future policy.**

Key Findings

Inspired by the heated discussion around the impact of China's 2017 import ban on plastic wastes, we conducted **a synthetic control method analysis** as an effort to establish causality between the policy and its effect on the plastic waste trade flows of China's top 20 importing partners, including the United States, Japan, Canada, Australia, Korea, etc.

Our results suggest that for countries that have largely relied on exporting plastic wastes to China in the past, the import ban **produced a downsizing effect on their net plastic waste exports by 10 times**. We also validate a negative correlation between the policy's effect margin and the volume of mismanaged plastic waste. Finally, we performed back attribution with decision tree, identified the factors that result in disparate effects among the countries, and arrived at the following insights:

Observation 1: China played a crucial role in the plastic economy as a major importer of plastic waste for the past two decades. **The import ban not only resulted in a direct decrease of China's import but also changed the plastic waste trade flow in pattern and quantity under the global context**.

Observation 2: We are able to validate **an annual decrease of 7141K metric tons in the net exports of plastic wastes** on average. This result is obtained by comparing with the non-intervention trajectory for the synthetic control unit.

Observation 3: There exists disparity in the magnitude of export margin for different countries. The decrease is sharp for some countries while being relatively moderate for others. Apparently, countries with different capabilities of waste management have taken distinctive approaches to deal with the consequence of China's import ban.

Observation 4: There exists a negative relationship between net export margin and the level of plastic pollution. A closer inspection of the net export trends of treatment and control countries suggests that countries **with greater decrease in net exports** after the ban are more prone to plastic pollution.

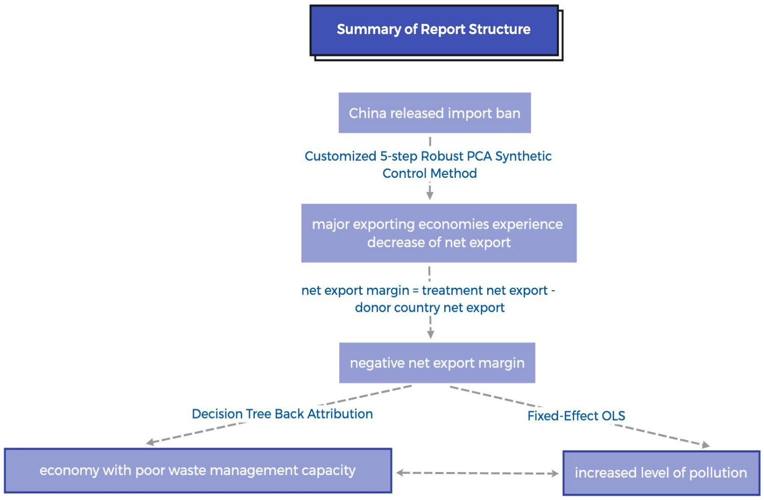
Observation 5: Countries with better waste management capacity depend less on plastic waste export as a way to cope with the domestic plastic pollution, and are consequently less impacted by China's plastic waste import ban. As a result, such countries are more capable of handling domestic plastic pollution when trade restrictions arise.

Recommendation

With China's plastic waste import ban in place, many countries around the world need to find other mechanisms to deal with the accumulation of plastic wastes. If not properly recycled or disposed of, these excessive wastes could **cause global pollution due to the lack of strong management facilities** for many regions.

Recommendation 1: Based on our results, we would recommend the most seriously affected countries, such as the US, Japan, and Korea to increase their **treatment capabilities of processing wastes** in their own countries or source to other regions to replace China. This can be achieved by mechanisms like facilitating higher waste collection and recycling rates, so that wastes could be captured and managed before contaminating the environment.

Recommendation 2: Countries could achieve better waste management through change in product design to reduce plastic wastes. Shifting towards the use of alternative materials such as biodegradable plastics could greatly mitigate the negative environmental impacts.



Background

Properly managing plastic waste has been one of the most heated topics since plastic production skyrocketed in the 1990s. Many countries have decided to export unmanageable plastic waste to other countries as a way to reduce domestic plastic pollution. Exporting countries export the plastic waste beyond their current management capacity and importing countries deal with those plastic waste, either by eco-friendly recycling and composting or by simple landfill and incineration. **It is worth noticing that plastic waste trade is not a final solution that truly "manages" the plastic waste**; it is more like exporters transferring the responsibility of plastic waste management and risk of plastic pollution to importers despite importers receiving some financial profits from the trade.

Since the 20th century, **China has imported almost half of the world's waste plastic in the past two decades** because it had a wealth of cheap labor to recycle plastics. In fact, **China was the main importing country of plastic waste and the largest plastic producer in the world.** However, Chinese annual imports of plastic waste reached 8.95 million metric tons, with as much as 74.3% buried or even mismanaged, triggering a series of environmental problems. To mitigate this situation, on July 27, 2017, China's State Council released the Implementation Plan on Banning Entry of Foreign Garbage and Reforming the Administrative System of Solid Waste Importation ("the China ban"), banning its import of 24 types of solid waste including plastic waste.

Our Story & Analytical Approach Summary

While past literature has posed the underlying mechanism of the impact of China's plastic waste import ban on the global waste import network, there currently lacks research **investigating the causality between China's policy and the trend in plastic waste trade flow from a quantitative perspective**. Thus, we believe it is crucial for us to carry out a synthetic control analysis of the long-term effects of the import ban on the dynamics of plastic waste trade. This technique utilizes a data-driven approach to choose comparative units and is an ideal model for analyzing the aggregate effect of policy interventions like the one we are interested in. If we can infer solid causality, we could then **quantify the policy's marginal effect** on the plastic waste trade flow of top exporters such as the United States and Japan.

Secondly, few existing works incorporate an understanding of how China's import ban posed a challenge to **the waste management capabilities of the developed economies**, thus leading to more serious plastic pollution over the years. Therefore, we decided to conduct a hypothesis testing on the relationship between the policy's effect and the level of plastic waste pollution following its passage. The result would provide us with insights into how the change in plastic waste trade flow would raise environmental concerns for the target countries.

Furthermore, we are interested in **factors that contributed to individual differences in the policy's effect** among countries. From there, we would propose several policy recommendations for these countries to better cope with the post-intervention scenario and establish a more resilient waste management system in the long run.

Exploratory Data Analysis

We utilized given datasets and sourced several external datasets to perform preliminary graphical analysis.

Datasets Descriptions & Data Cleaning

To perform our country-level analysis, we needed time series data on plastic waste trade & pollution indicators for different countries impacted by the China ban. We started with the provided Merchandise Trade Matrix and Plastic Trade by Partner data, which we hypothesized contained relevant data revealing the change of trade trends. We focused on the trade activities of plastic waste as this is the category directly affected by China's import ban. For waste management data on countries,we sourced the internet and used the 2014 measurement of countries' waste management capacity (e.g. Waste Recycle Rate, % Incineration with energy recovery) in our modelling.

For the plastic pollution measurement, due to sparsity and inconsistency of the current data, we combined data on several dimensions to approximate the level of pollution. Firstly, we used the panel data of waste management from the OECD statistics, aggregating the 'Landfill', 'Incineration without energy recovery', 'Total Incineration', 'Other disposal' waste as total waste pollution. Then, we multiplied total waste pollution by the percentage of plastic waste to approximate the total plastic pollution by country by year. Finally, to account for different scales of economic activities, we divided the total plastic pollution of each country by the population to get the final measurement of plastic pollution per millions of people. Figure 1 shows the plastic pollution per millions of people of top five countries in the world from 2016 to 2018.

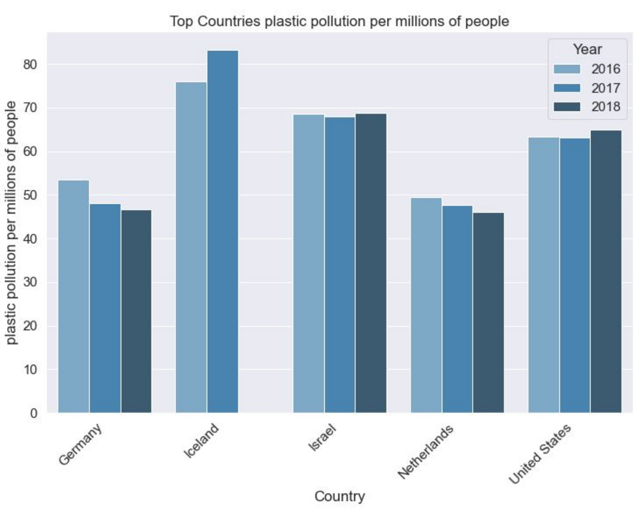


Figure 1: Top Countries of Plastic Pollution

China's Import Ban and Its Impacts

The import ban of plastic trades considerably **affects global plastic waste trade flow patterns as well as plastic waste treatment systems and mechanisms** of many countries in both short and long run. In the short term, countries relying on exporting plastic waste to China will need to seek temporary alternative solutions such as dumping plastic waste to other countries or increasing their domestic managing waste capacity. From Figure 2, we can see that **in 2017, China's import value of plastic was still the highest in the world, accounting for around 35% of the total imports in the world.** However, **from figure 3, we observe that since 2018, Chinese imports have rapidly decreased to near 0.** It motivates us to investigate the resulting environmental impacts and quantitatively assess the impacts of "the China's Import Ban".

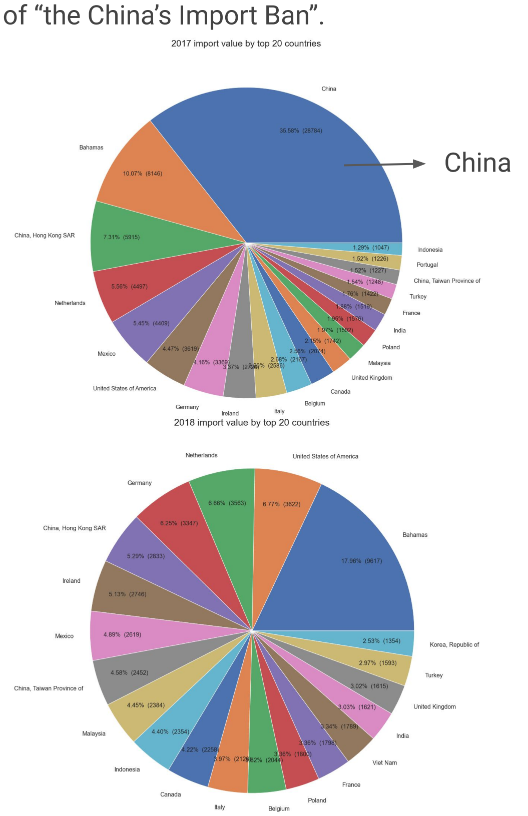


Figure 2: Total Import Values for Top 20 Countries 2017 vs. 2018

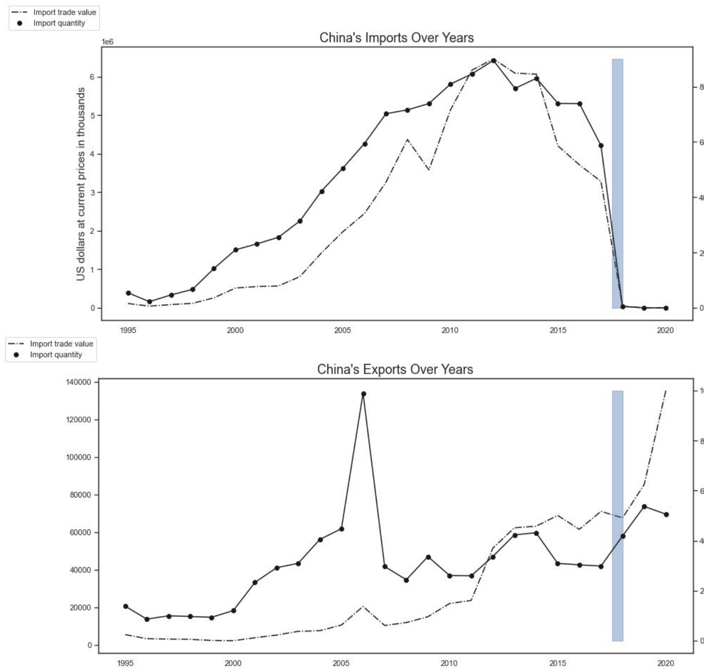


Figure 3: Year Trend of China's Imports vs. Exports of Plastic Wastes

Plastic Waste Trade Flow Before & After China's Import Ban

We would like to visualize the plastic waste trade flow before and after China's import ban on plastic waste to motivate future modelling. By selecting the Top 20 exporting economies in 2017 and 2018, we construct alluvial plots Figure 4 and Figure 5 that trace the flow of plastic waste from major exporters to importers. In both plots, we observed that most of the top 20 exporting economies are developed economies, such as Germany, United States, and United Kingdom, while on the side of importing economies, a lot of developing economies such as China, Malaysia, and India appear. **It showcases that plastic waste is more likely to flow from developed economies to developing economies.** Secondly, In 2017, the amount of plastic waste imported by China from the top 20 exporters largely exceeded the rest of importers, indicating a significant trade flow of plastic waste from exporters to China. After China's import ban on plastic waste came into effect, the pattern of plastic waste trade flow changed distinctively in 2018. Southeast Asian economies such as Malaysia and Thailand surpassed China and became the major destination of plastic waste. **Hence, China played a crucial role in "receiving" and managing plastic waste, and China's import ban posed an obvious impact on the pattern of plastic waste trade flow.** Last but not least, the trade quantity of the top 20 exporters represented by the vertical column "Export" reveals an overarching

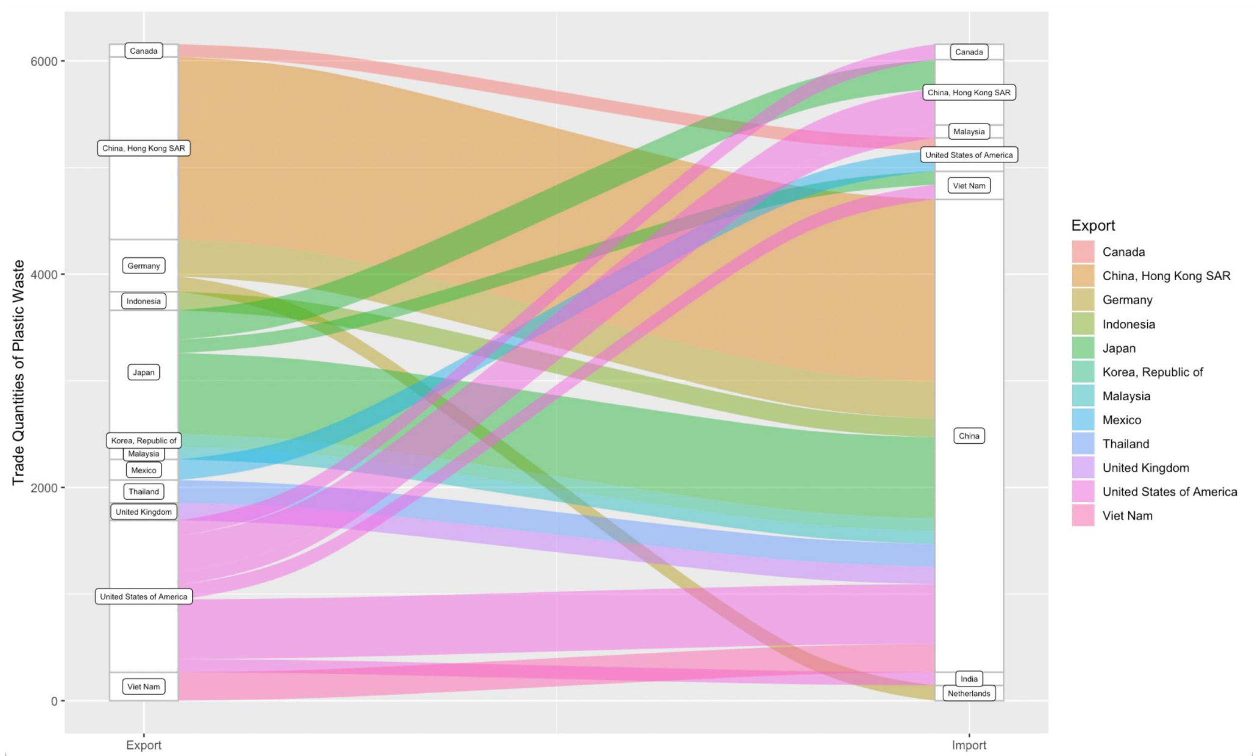


Figure 4: Flow of Global Plastic Waste Trade in 2017

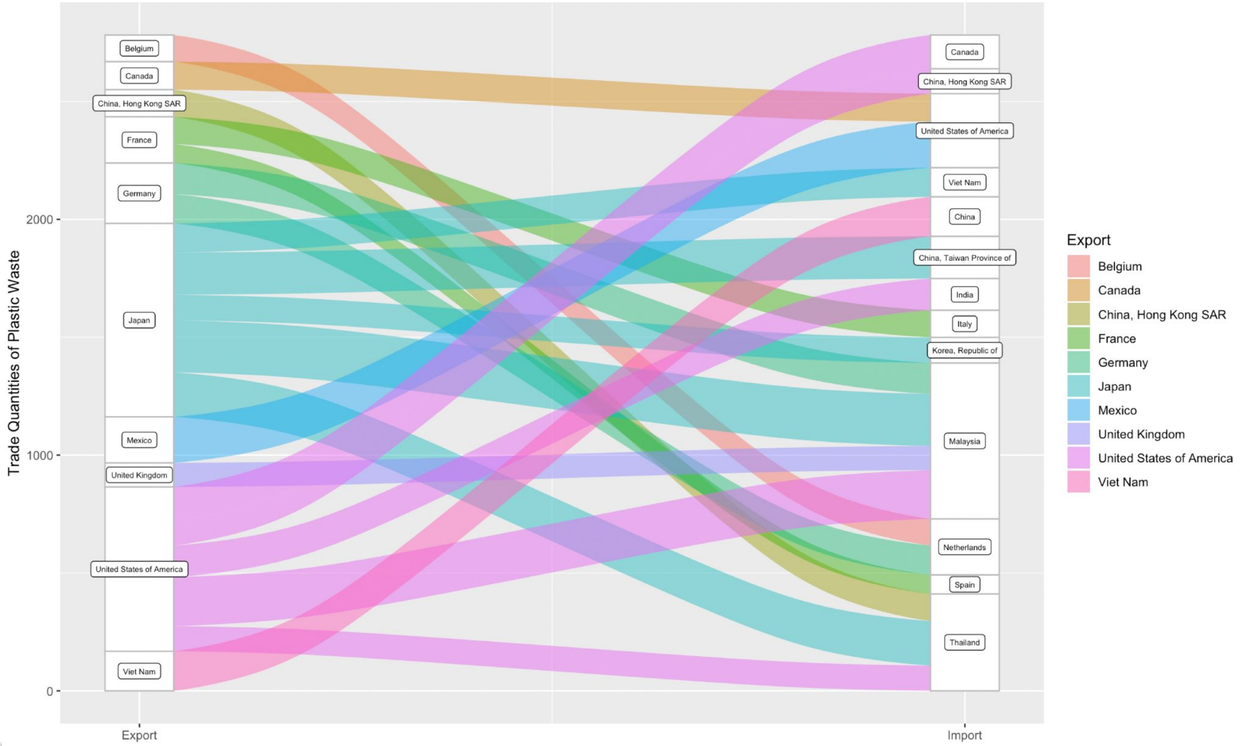


Figure 5: Flow of Global Plastic Waste Trade in 2018

decrease of plastic waste trade quantity from over 6000K metric tonnes in 2017 to nearly 3000K metric tonnes in 2018. **This decrease indicates that China's import ban may be a turning point at which exporting economies were forced to change their original way of managing plastic waste by trade.** We would like to elaborate on evaluating the quantitative impact of China's import ban on the global plastic waste trade flow in the modelling section.

Major Export Countries

Besides analyzing the top 20 exporters' trade flows, we want to scrutinize the impacts of China's import ban on their major trade partners. We select three representative countries (Japan, United States, Germany) of the top plastic waste exporters to China and plot their imports and exports by year. As displayed in figure 6&7&8, the blue shadow in the graph indicates the period of China starting to implement the import ban. After China implemented the ban, plastic waste exports of all three countries decreased drastically. However, the plastic waste imports of those countries appear inconsistent.

Japan's plastic waste imports increased during that period while Germany's decreased. **It urges us to assess both sides of the plastic waste trade to find the actual impacts of China's plastic import ban.**

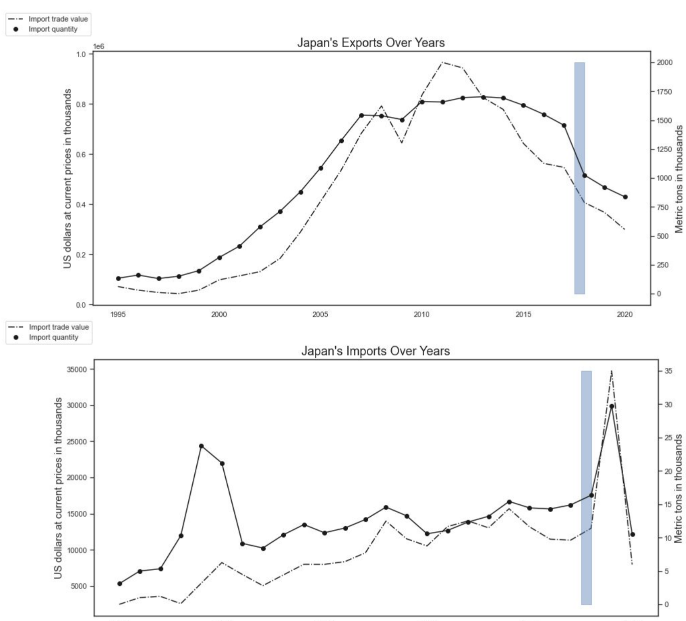


Figure 6: Year Trend of China's Imports vs. Exports of Plastic Wastes

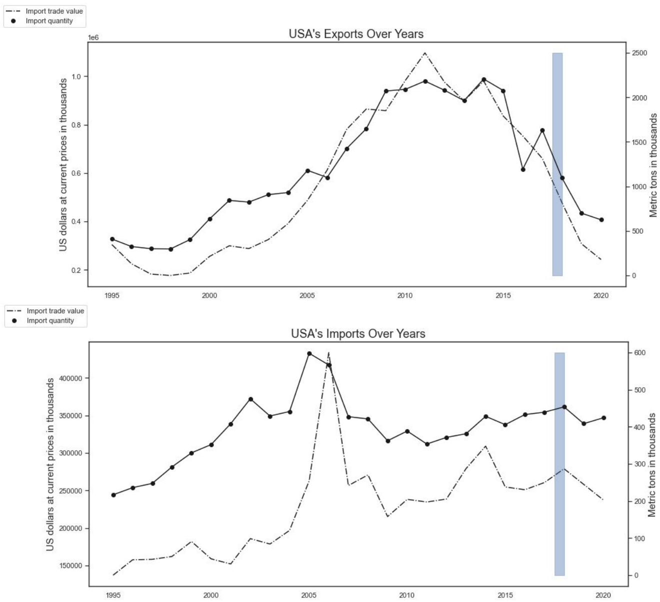


Figure 7: Year Trend of China's Imports vs. Exports of Plastic Wastes

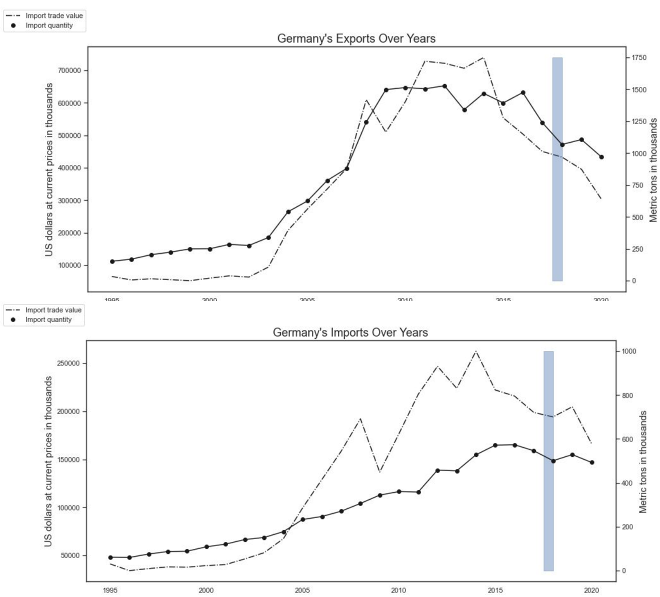


Figure 8: Year Trend of China's Imports vs. Exports of Plastic Wastes

Choice of Target Variables

We have shown with our EDA that there exists a large change of the trade flow of the plastic waste before and after China's import ban. From figure 5, we observe that the ban significantly decreased China's trade partners' plastic trade activities. To account for the possible variation in **both the plastic waste imports and exports of different countries**, we decide to mainly examine the **net export** which is the difference between export and import, measured in metric tons in thousands.

Modeling Approaches

Inspirations: PCA Synthetic Control

We need to conduct a powerful before-and-after analysis of the impacts of China's plastic waste import ban on its trade dynamics with top exporting countries. Traditional models trying to differentiate out global trends would neglect the systematic differences between growth paths of the countries. Thus, we choose to use the **synthetic control method** as it provides a data-driven algorithm to estimate the counterfactual treated unit. To effectively isolate the effect of China's import ban and establish causality, we need to construct a **donor group** of the countries that are mostly affected by the import ban before the policy comes into effect at the end of 2017.

This naturally leads us to select the ideal set of controls from the countries that China historically imported the least plastic wastes from. As a result, China's import ban should have rather minimal impact on their overall net exports of plastic wastes. However, the choice could still be arbitrary if we randomly pick countries from the bottom of the list. To better find the relationship between the treated group and the synthetic, we here introduce our customized **five-step robust PCA synthetic control algorithm**:

<u>Algorithm Outline</u>

- ➔ For the pool of controls, compute the functional principal component scores of selected feature matrix for the pre-intervention period
- ➔ Applies the K-means algorithm over these scores
- ➔ Identify the donor group as the untreated units that fall into the same or closest cluster as the treated ones
- ➔ Run a lasso-regression between the treated group and the donor group for the pre-intervention period; use cross-validation to select the best lambda hyperparameter
- ➔ Use the computed weights to calculate the synthetic control performance of treated units for the post-intervention period

We believe this setup can lead to proper causal inference for a few reasons:

1. Our method can automatically separate the donor pool from the non-relevant countries by using **supervised learning**.
2. The use of PCA can extract the low-rank structure of the control pool and is robust to any outliers and missing values.
3. LASSO regression allows us to reduce the chance of overfitting the donor group to the treated units. Additionally, the use of k-fold cross validation will **find the optimal weights** that minimize the MSE between the treated and the donor group.

K-Means: Control Group Construction

To identify countries in the donor pool similar to our treated units, we adopted the PCA for the pre-intervention period and executed the traditional K-means algorithm on the extracted 3D structure of country features. To cluster countries, we used the 2014 estimates of the waste generation data of countries as a measure of their demographics and environmental conditions. This dataset includes holistic measurements on dimensions such as the economic status, coastal population, waste generation conditions, and estimates of the proportion of plastic waste.

To choose the best K value, we implemented the elbow method, which tunes the number of clusters by plotting the inertia for each choice of K. From Figure 9, we can see that the "elbow" occurs when K=5, suggesting that we should split the treatment and control pool into five clusters.

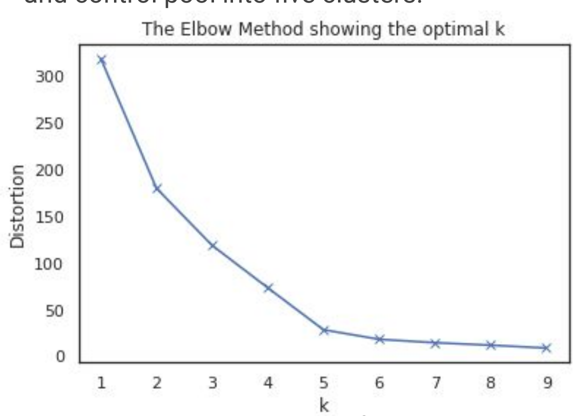


Figure 9: Elbow Method of Choosing K

Finally, after normalizing the feature values and imputing the missing values, our K-means model identified the donor group including **Bulgaria, Jamaica, Latvia, Norway, Sweden, and Turkey.** From the 3-D visualization of the clusters in Figure 10, we can observe that these are countries that are closest to the United States and Japan, which are the largest countries from which China historically imported plastic wastes from, and in the same cluster as some of the treatment units like Australia and Canada. Although this cluster also identifies countries including Panama, Cyrus, and Cuba, we decided to not include them in the donor group due to the lack of trade data on their plastic waste. One interesting observation is that China forms a single cluster with the greatest PC1 score, suggesting a distinctive pattern in its demographic composition and waste management structure.

Lasso Regression & Synthetic Control

After constructing the donor group, we can implement our synthetic control model to infer causality between the plastic waste net exports and China's 2017 import ban. Using the five-step algorithm we described in the previous section, we can run a linear regression between the donor group and the treated group before the import ban. Specifically, this means that we need to **regress the net export of each treatment unit on that of each identified control unit to reproduce the pre-intervention net export, and to project this estimated trend to the post-intervention era in order to compare with the actual trend**.

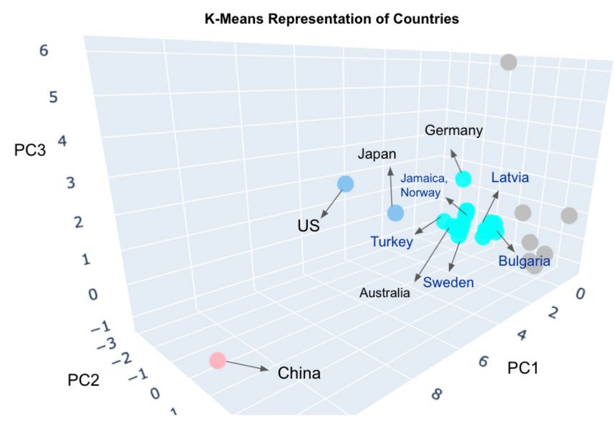


Figure 10: K-Means on PCA values

Before constructing the model, we plotted the average trend in plastic waste net export for each group, and observed that there seems to exist a distinctive effect of the 2017 import ban on the net export of the treated units. From Figure 11, it can be seen that **the average trade flow for the treatment group significantly decreased by 5000K metric tons**, while the trend in the donor group remains relatively consistent. However, this is just a simple observation from the graph, and more rigorous analysis is needed to isolate the causal relationship and to account for the potential confounding variables correlated with this observed trend.

To estimate the treatment effect with synthetic control, we need to construct a “fake unit” which closely resembles the pre-intervention performance of the treated unit on the net export of plastic wastes. In this way, the synthetic control method could help us reduce any arbitrary biases coming from the systematic differences between countries. We **used 5-fold cross validation** to choose the hyperparameter lambda and **ran a Lasso-regression** to fit the optimal weights for the synthetic control of our treatment group. The aggregated trend projected into the post-intervention period portrays a slightly increasing net export and contrasts sharply with the actual values (Figure 12 a). The difference between the actual and synthetic control values in Figure 12(b) further illustrates that China’s import ban in 2017 leads to **a sharp increase in the treatment unit’s net export margin of plastic wastes over the synthetic control**. Before the ban was in place, the difference between the actual and projected export flow remained at approximately zero level.

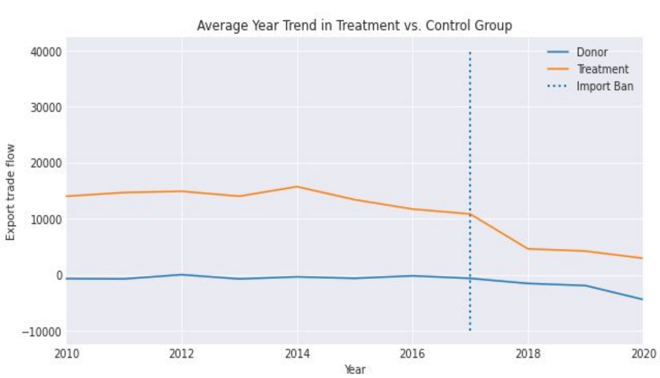


Figure 11: Year Trend in Treatment VS. Control

Placebo Test on Aggregated Margin

Before diving into the interpretation of SCM results, we need to conduct a placebo test in order to fully establish causality. To do this, we would re-run the synthetic control procedure on every unit in the donor group by regarding them as the treatment unit and other countries as controls. The figure 12(a) models the aggregated effect of the treatment group and the placebo effects by assuming the intervention actually happened to countries in the donor group. The figure 12(b) models the margin for each treatment unit and the placebo effects. Two observations can be derived from the graphs:

Observation 1: We noticed that the variance after the import ban is higher than the variance before the import ban. This is expected since synthetic control is created to minimize the difference in the pre-intervention period. Also, we can see that for the treatment group before the intervention, the fit between actual and synthetic control is not perfect for some years. This is also expected as the net exports for some countries cannot be well reproduced by a convex combination of other countries. Yet we still reason that the overall fit is

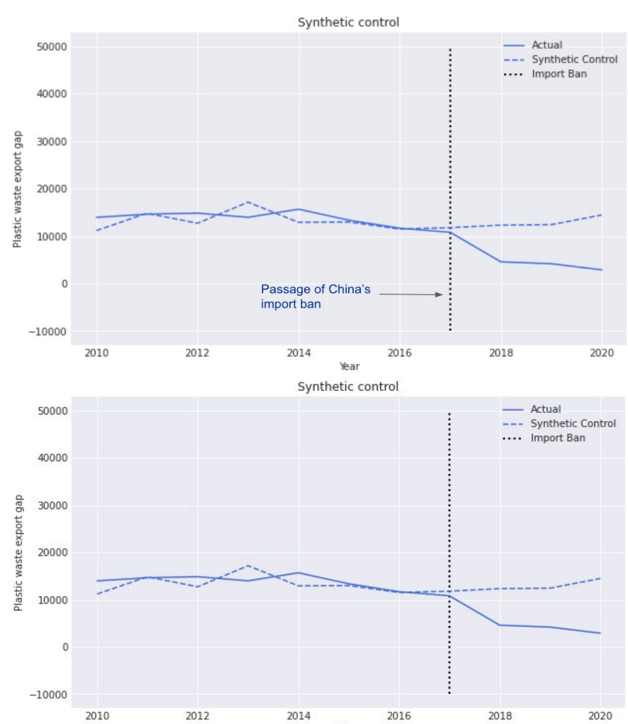


Figure 12: Synthetic Control Effect

the overall fit is excellent enough to validate the projected trend after the intervention.

Observation 2: We can see that the treatment group has a much more significant aggregate margin over the synthetic control compared to the placebo scenarios. This validates our hypothesis that China's import ban of 2017 does decrease the net export volume of plastic wastes for its top exporters. Moreover, a closer look at the individual countries reveals variances among the marginal effects for different countries. This suggests that among the top exporters, the impact of China's import ban on their export patterns is heterogeneous. While some countries experience a sharp decrease in their waste exports, a few countries exhibit a positive margin, probably due to the existence of new destinations for plastic wastes. However, the overall trend for the treatment countries experience much greater fluctuations than controls.

Estimation of Effect Margin

Finally, we are able to quantify the impact of China's import ban on the plastic waste net export. In table 1, we calculate the median margin over the synthetic control for both the treatment group and the donor group. The control margin comes from the results of the placebo procedure. Two conclusions can be drawn from the table:

Conclusion 1: We can see that after the passage of China's import ban, the net margin for the treatment group is consistently higher than that of the donor group. This confirms our claim that the import ban **produces a significant decreasing effect** on the net export of plastic wastes among the top exporters to China. On average, as a consequence of China's policy, the countries decrease their net exports of plastic wastes by 7141K metric tons.

Conclusion 2: Overall, the export margin of the treatment group is approximately 10 times greater than that of the donor group, which **peaks in 2018 with a ratio of 10.80**. This is consistent with our intuition that when China stops being the receiver of foreign plastic wastes, countries that used to depend on China as a destination will have few alternatives to turn to. Instead, they are **forced to decrease their plastic waste exports and manage the wastes domestically**. In the next section, we will investigate the effect of this decreasing margin on the plastic waste pollution with fixed effects regression.

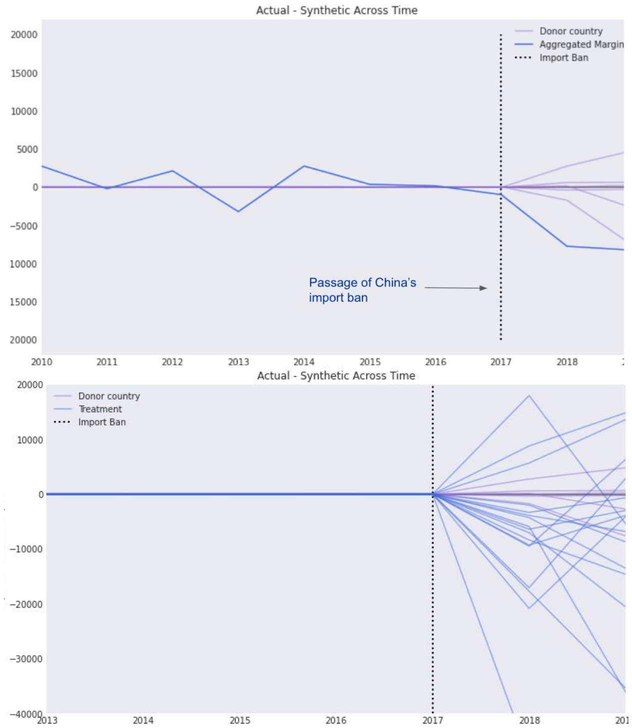


Figure 13: Placebo Effects of Control Group

Year	Median Effect (Treatment)	Median Effect (Control)	Treatment /Control
2018	-6814	-631	10.80
2019	-6878	-708	9.71
2020	-7730	-817	9.46
Average	-7141	-717	9.94

Table 1: Quantitative Measure of Median Effect Margin

Linking Pollution and Net Export Margin

We wish to further investigate the impact of China's import ban on pollution. We hypothesize that a decrease in the net export margin between actual and control level would lead to more domestic pollution due to the lack of waste management infrastructures. By running an OLS of pollution data on the net export margins with country and year dummy variables, we find that the net export margin is significant and displays a negative relationship with pollution. From Table 2, the result of running a fixed effect regression of the net export margins on the pollution statistics shows that a 1K metric tons decrease in net exports margin of plastic wastes will increase the plastic waste pollution by 0.49 tons. This result confirms our intuition that **a negative relationship exists between the amount of net export margin and the level of plastic waste pollution.**

Ordinary Least Squares Results

	Coefficients	Std.. error	t	P > |t|
Net export margin	-0.49**	0.221	-2.222	0.077
Country_Canada	24.35**	10.99	2.21	0.078
Country_France	22.58**	8.858	2.54	0.051
Country_Germany	44.97**	9.554	4.708	0.005
Country_Japan	42.36**	12.568	3.371	0.02
Country_Netherlands	33.51**	8.245	4.064	0.01
...	...	...	...	...
Year_2019	-25.37	6.414	-3.956	0.011
Observations		15		
R2		0.961		
F-statistic		12.17		

Table 2: OLS results of pollution on net export margin

Decision Tree on Aggregated Margin

As the net export margin is inversely correlated with pollution, we are motivated to understand the determinants of the different clusters of average net export margin based on country attributions using a decision tree. We observe that **countries with worse waste management capacity** (i.e. countries with lower rates of recycling and incineration of energy recovery) **appear to have a negative net export margin** (i.e. treatment net export lower than donor country net export), and this implies that these countries have their plastic waste net export decreased due to China's import ban. In other words, **countries with worse waste management capacity are more dependent on plastic waste trade as a way to cope with domestic plastic pollution** compared to those with better waste recycling infrastructure.

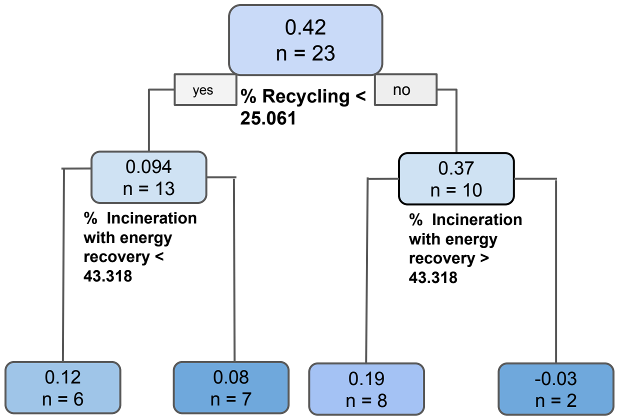


Figure 14: Back Attribution on Country Features

Caveats & Future Research

During the course of our analysis, we used data from a select group of developed countries **due to the limited data availability of pollution indicators at their developing counterparts**. By intuition, including the analysis on developing countries would be more ideal because the patterns of trade restriction effect on pollution can be very different across countries with varying traits. However, we believe our methodology is a principally grounded way to understand the impact of plastic importation restriction on pollution and we would recommend extending a similar methodology to other countries in the world and more plastic trade policies.

Appendix

For our submission, we included this report, and a zip containing code and a data folder for our external datasets. The files are aptly named towards their purpose in the analysis.

References

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2. Abadie, Alberto, et al. "Synthetic Control Methods for Comparative Case Studies: Estimating the Effect of California's Tobacco Control Program." 2007, doi:10.3386/w12831.
3. Brooks, Amy L., Shunli Wang, and Jenna R. Jambeck. "The Chinese import ban and its impact on global plastic waste trade." *Science advances* 4.6 (2018): eaat0131.
4. Wen, Zongguo, et al. "China's plastic import ban increases prospects of environmental impact mitigation of plastic waste trade flow worldwide." *Nature communications* 12.1 (2021): 1-9.
5. Wang, Chao, et al. "Structure of the global plastic waste trade network and the impact of China's import Ban." *Resources, Conservation and Recycling* 153 (2020): 104591.

Data Sources

Provided Data Sources:

1. Plastics trade by partner, annual: data from 1995 to 2020 for trade volumes (in current US dollars) of plastic products per stage of production (raw, intermediate, etc.) and country pair.
2. Merchandise trade matrix in thousands United States dollars, annual, 2016-2020: data from 2016 to 2020 for trade volumes (in current US dollars) of all kinds of products per country pair.
3. 1260352_supportingfile_suppl._excel_seq1_v1.xlsx: country-level statistics of waste generation and composition.

Additional Data Sources:

1. MUNW_19112021011414858.csv, MUNW_19112021011221217.csv: time series data of the volume of different categories of mismanaged wastes, by country (https://stats.oecd.org/index.aspx#)
2. MUNW_21112021064622284.csv: time series data of the waste management structure, by country (https://stats.oecd.org/index.aspx#)
3. population.csv: time series data of the population, by country (https://stats.oecd.org/index.aspx#)

Code

For our analysis, we used the following programming languages, tools, and packages:

- **Python** and **Jupyter Notebook** were primarily used for data wrangling, EDA, preliminary visualization, K-means, Lasso, and decision tree modelling. We used standard libraries such as **pandas, numpy, matplotlib, seaborn, statsmodels, sklearn,** etc.
- **R** and **RStudio** were used for EDA and preliminary visualization.