The Carbon Tax Effect: Lessons from Japan's Approach to CO_2 Emissions

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1 Introduction

In this paper, we have analyzed the impact of Japan's carbon tax policy on its CO_2 emissions from the transport sector. Japan became the first Asian country to implement a carbon tax in October 2012, with a rate of 2.89 Japanese yen (JPY) per ton of CO_2 emissions, equivalent to 2.65 USD per metric ton [8]. The tax aims to achieve an ambitious goal of reducing total greenhouse gas emissions by 80% by 2050. Despite this, few studies have employed empirical causal inference to evaluate the effectiveness of carbon taxes on CO_2 emissions. Existing studies have focused on cases like Sweden and the UK, where carbon taxes were introduced in the early 1990s and their effects on transport-sector emissions were analyzed. In our study, we found that Japan's carbon tax has not had a significant impact on CO_2 emissions. We also provide a detailed examination of the policy's shortcomings, potential areas for improvement, and the limitations of our analysis.

2 Assumptions

Our study assumes that Japan's transport sector relies majorly on gasoline consumption. This assumption helps us use only gasoline consumption as a covariate in our analysis (International Energy Agency, n.d. [5]) (Institute for Global Environmental Strategies, n.d. [6]). We also implicitly assume that the donor countries making up our synthetic Japan don't have any carbon tax in place for the duration of our study, 1990-2019.

3 Data

The dependent variable in our study is CO_2 emissions from transport (annual data) sourced from the World Bank. For the covariates, we considered GDP per capita, Human Capital Index, Urban Population, and Gasoline Consumption:

- **GDP per Capita** (constant 2015 USD, World Bank [1]): Controls for overall economic growth and the demand for transportation services.
- **Gasoline Consumption by Transport per Capita** (UN Data [2]): Reflects fuel usage patterns, capturing behavioral responses to price signals and policies.
- **Human Capital Index** (Penn World Table [3]): Measures workforce skills and productivity, potentially influencing technology adoption and transport efficiency.

- **Rate of Urbanization** (World Bank [4]): Accounts for urbanization's effects on transport patterns, modal choices, and emissions intensity.

The study period spans 1990 to 2019. The pre-treatment period (1990–2011) was used to construct a synthetic control for Japan by matching it to other countries. The post-treatment period (2012–2019) measures the impact of Japan's carbon tax on CO_2 emissions by analyzing deviations from the synthetic control during this time. The analysis ends in 2019, as the COVID-19 pandemic in 2020 significantly disrupted transport patterns and global CO_2 emissions.

While most countries in the study have GDP per capita and development levels comparable to Japan, Malaysia and Thailand were included to provide a broader perspective on countries with differing economic structures. Their inclusion helps test the robustness of the synthetic control method by introducing variability in key metrics, offering insights into how developmental differences influence the results.

Previous studies have noted that after determining the synthetic weights, the model adjusts for key features where significant differences exist, providing a balanced basis for comparison.

Table 1: Countries Considered in the Study

Country Code	Country Name
1	Australia
2	Belgium
3	Spain
4	Greece
5	Italy
6	Japan
7	New Zealand
8	Netherlands
9	South Korea
10	Malaysia
11	Thailand
12	Singapore

4 Methods

For our study, we used the synthetic control method [7], which is widely used in causal inference studies. This method has been chosen over other methods used for similar analyses like DiD (difference-in-difference) because of its assumption of parallel trends. Synthetic control method is also the appropriate approach since we have only one treated unit and multiple control units. We have the freedom the choose the control units according to our requirements. The covariates were selected to capture critical aspects of economic, social, and energy consumption characteristics that influence CO_2 emissions. GDP per capita reflects a country's economic output and wealth, while the Human Capital Index indicates societal development through education and health levels. The urban population highlights demographic trends and infrastructure, and gas consumption captures energy use patterns, particularly in transportation, a key contributor to CO_2 emissions. **Overall Setup:** The overall setup for our causal inference study involves 1) data cleaning 2) data analysis 3) defining features of interest 4) calculating optimal weights for synthetic control 5) assessing actual vs. synthetic outcomes.

5 Data cleaning

The data was cleaned and pre-processed using MS-Excel. Multiple datasets containing information for all countries were combined. We first isolated the countries of interest and transformed each dataset into a uniform format before compiling them into a single file. CO_2 emissions data, originally in metric tons (thousands), was converted to metric tons per capita for consistency. Similarly, gasoline consumption data was converted from metric tons (thousands) to kilograms of oil equivalent per capita.

6 Preliminary Data Analysis

We performed preliminary data analysis to compare various covariates for Japan against other countries over time. Figure 2 shows the trends of GDP (in constant USD (2015), Human Capital Index, Urban Population, and Gasoline Consumption for Japan versus other countries. This visualization helps identify differences and trends in these covariates, which are crucial for the synthetic control study.

In the figures, we can observe that Japan consistently shows higher mean values for GDP, Human Capital Index, and Gasoline Consumption compared to the mean of other countries. However, Japan's Urban Population is significantly lower than that of other countries, highlighting demographic and urbanization differences.

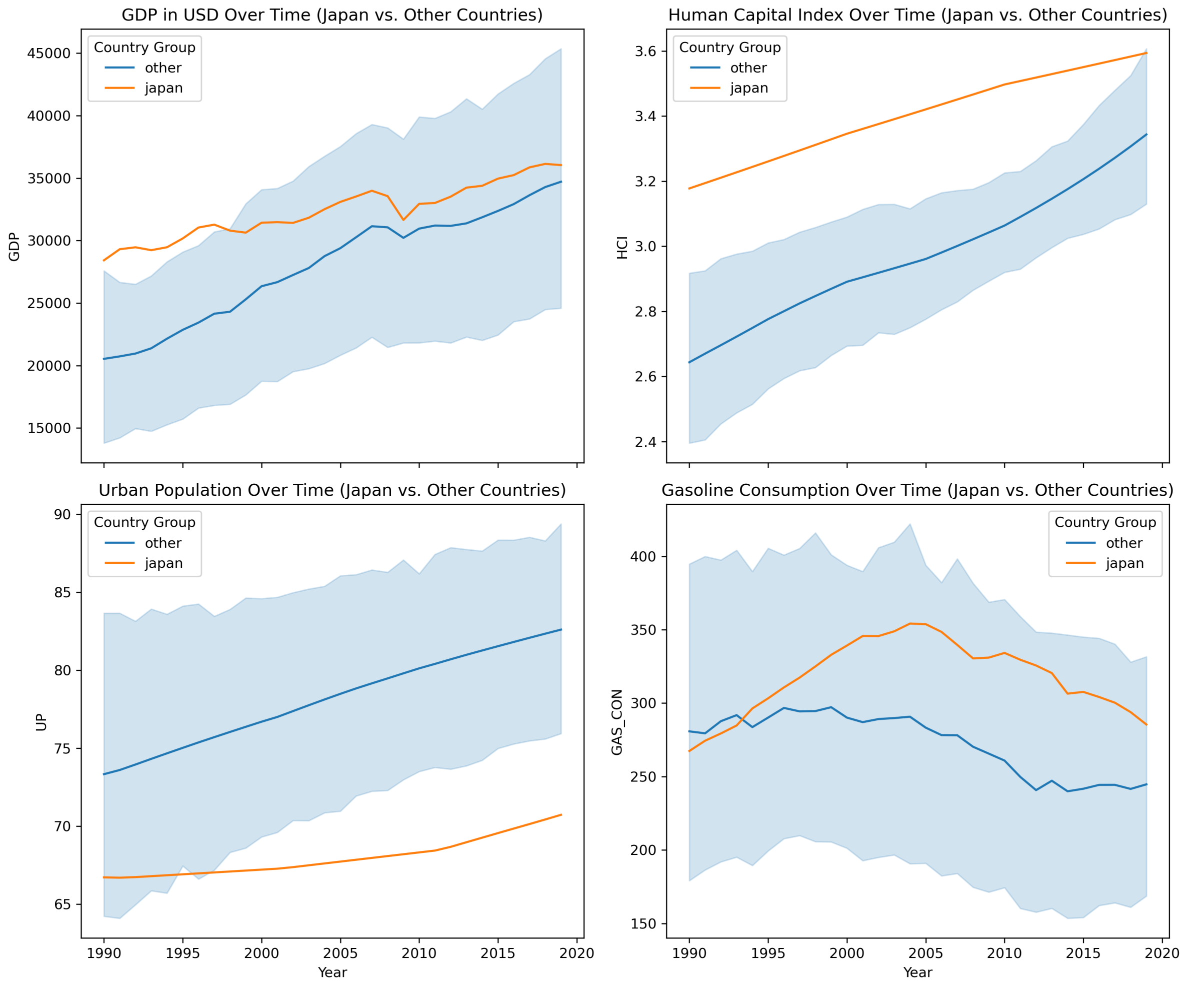


Figure 1: Trends in covariates (GDP, Human Capital Index, Urban Population, Gasoline Consumption) over time for Japan and other countries.

The summary statistics reveal insights beyond the covariate plots. Japan's CO_2 emissions are more stable (std: 0.16) compared to other countries (0.83), despite similar means. Gasoline consumption in other countries shows a wider range, peaking at 758.45, whereas Japan's maximum is 354.18. Urban population in Japan is stable, ranging from 66.71% to 70.74%, compared to the broader 49.79% to 100% in other countries. GDP for other countries varies significantly (2631.52 to 61333.66), indicating economic diversity, while Japan's range is narrower. Japan's lag variables ($CO2_{1995}$, $CO2_{2000}$, $CO2_{2008}$) show no variability, unlike the diverse trends in other countries.

The final dataset has been processed on Python, primarily using the reference slides from the class lecture. The results show that the carbon tax resulted in no significant reduction in CO_2 emissions.

Table 2: Summary Statistics: Japan

Statistic	co2_em	gdp	hci	up	gas_con	co2_1995	co2_2000	co2_2008
Count	30.0	30.0	30.0	30.0	30.0	24.0	19.0	11.0
Mean	1.86	32355.33	3.40	68.01	317.90	2.01	2.06	1.83
Std Dev	0.16	2187.42	0.13	1.20	25.02	0.00	0.00	0.00
Min	1.58	28422.21	3.18	66.71	267.44	2.01	2.06	1.83
Max	2.01	36138.53	3.59	70.74	354.18	2.01	2.06	1.83

Table 3: Summary Statistics: Other Countries

Statistic	co2_em	gdp	hci	up	gas_con	co2_1995	co2_2000	co2_2008
Count	330.0	330.0	330.0	330.0	330.0	264.0	209.0	121.0
Mean	2.01	27974.39	2.97	78.17	272.49	1.93	2.05	2.15
Std Dev	0.83	14663.30	0.39	13.36	173.27	0.79	0.85	0.87
Min	0.51	2631.52	2.05	49.79	48.13	0.80	0.72	0.77
Max	4.02	61333.66	4.35	100.0	758.45	3.75	3.94	4.01

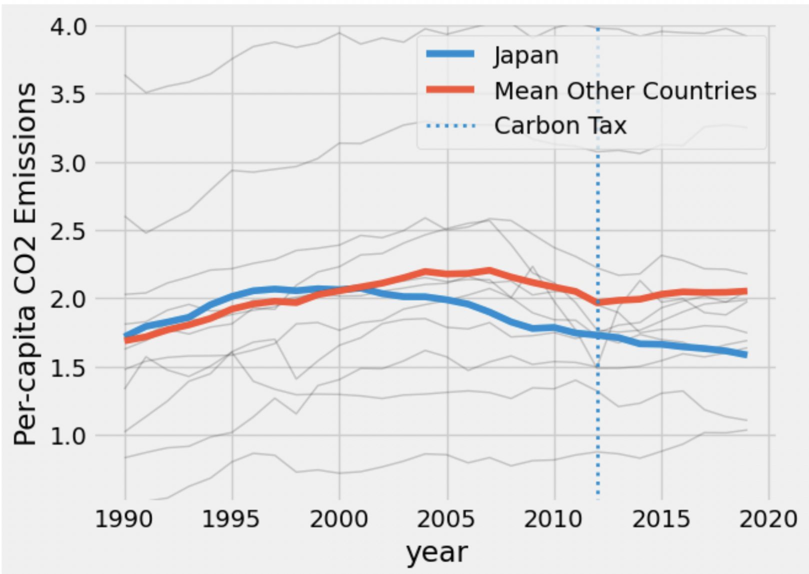
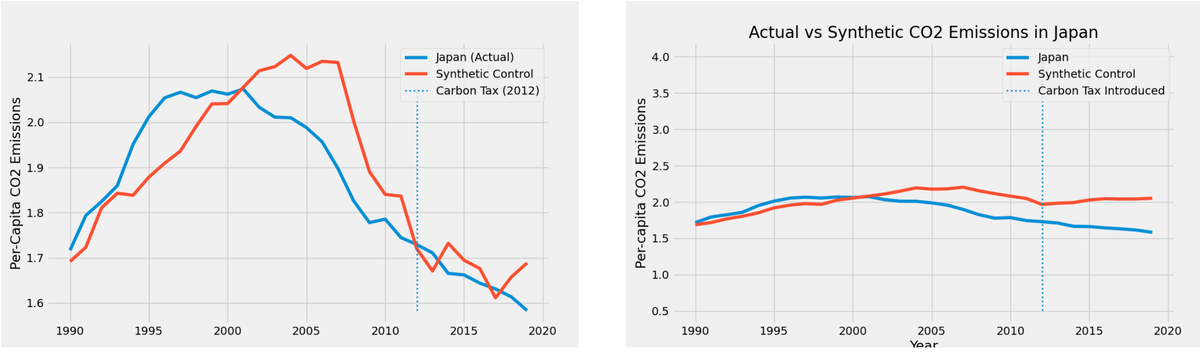


Figure 2: Trends in CO_2 emissions over time.



(a) Trends in CO_2 emissions for Japan and its synthetic control before and after 2012.

(b) Zoomed-out view of per-capita CO_2 emissions for Japan and its synthetic control.

Figure 3: Comparison of actual and synthetic CO_2 emissions for Japan.

7 Results

The results indicate that the carbon tax introduced in Japan in 2012 had no significant impact on CO_2 emissions compared to the synthetic control. As shown in Figure 3a, deviations between Japan and the synthetic control were evident before the treatment period (2012) and persisted afterward without any significant change (Gokhale, 2024 [8]). These findings align with existing literature, which highlights the limited scope and modest goals of Japan's carbon tax policy. Introduced at a relatively low rate compared to global standards, the tax aimed at a 26% reduction in emissions by 2030—a target considered modest by international benchmarks.

Figure 3b provides a broader view of the results, reaffirming the negligible impact of the carbon tax. The treatment effect, calculated as the difference between actual and synthetic emissions, was 0.009. Although this effect is positive, its magnitude suggests an insignificant reduction in emissions. Furthermore, a p-value of 0.5 indicates no statistical significance, supporting the conclusion that the carbon tax did not achieve meaningful emission reductions during the study period.

8 Limitations

CO_2 emissions from transport were available only from 1990, which limited our ability to select countries where carbon taxes were implemented around that time, as we lacked sufficient pre-treatment data. Additionally, the donor pool was smaller because many countries with economies similar to Japan had implemented carbon taxes either before or during the study's time frame. Since data was available only for gasoline consumption, we restricted the treatment country to one where gasoline, rather than diesel, was the primary transport fuel. Our study also does not account for ageing demographics, a significant factor in Japan. Furthermore, as the carbon tax was introduced in 2012 and our study period ended in 2019 due to the onset of COVID-19, the analysis captures only short-term impacts.

9 Conclusion

This study evaluated the impact of Japan's carbon tax policy on CO_2 emissions from the transport sector using the synthetic control method. The findings suggest that the tax, introduced in 2012, has not resulted in significant reductions in emissions during the study period.

The analysis highlights the need for more robust policy measures, including higher tax rates, broader sectoral applications, and complementary strategies such as investments in cleaner technologies and initiatives to drive behavioral change. Future research could address the limitations of this study, such as extending the analysis to longer time periods, accounting for demographic trends, and examining the role of multi-fuel consumption patterns.

While this is a class project with inherent constraints, it provides a valuable learning experience and a foundational understanding of causal inference techniques. The findings offer preliminary insights into the effectiveness of Japan's carbon tax policy and suggest directions for further investigation and policy refinement.

References

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