Evaluation of the Influence of 2008 Scoping Plan to Carbon Emissions in California by DID

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Abstract. Global warming has been a crucial issue these years as the development of human society and technologies. The main factor is the greenhouse gas emissions, including water vapor, methane, carbon dioxide and nitrous oxide in the earth atmosphere. There are many countries with different kinds of policies to reduce greenhouse gas emissions to slow down the speed of global warming and protect the world environment, such as the California 2008 Scoping Plan. Difference-in-Difference is an estimation method to evaluate the effectiveness of a policy change on a group of individuals. This study selects the transportation sector as the indicator of carbon emissions in California and uses the data from 2004 to 2014 in all 51 states in the U.S. to estimate the influence of 2008 Scoping Plan on carbon emissions in California. The result shows the policy had a positive effect on reducing the carbon emissions in the transportation sector in California, which means that the Scoping Plan is worth continuing to implement and improve to achieve the goal of decreasing greenhouse gas emissions to protect the global environment.

Keywords: Carbon emissions; California; Scoping Plan; Difference-in-Difference; R.

1. Introduction

Greenhouse gases trap heat and make the planet warmer, and humans are responsible for the increase of greenhouse gas emissions in the atmosphere throughout human development history. If the world keeps getting warmer and warmer, the problems like the ablation of glaciers, desertification, the decline of the diversity of species and even the destruction on ecosystem, will deteriorate. Thus, retarding global warming has been a crucial issue in the contemporary world. To slow down the speed of global warming and protect the living environment for both the human and animals, the policies aimed at reducing greenhouse gas emissions are in need.

In recent years, there have been various policies released to solve the issue of global warming in different countries around the world. One of the main aspects is to reduce carbon emissions, including the sectors of transportation, electric power, industrial, commercial and residential, and so on.

In 2006, the California Legislature approved the Assembly Bill No. 32, which is the California Global Warming Solutions Act of 2006, proposing to create a multiyear project to alleviate the increment of greenhouse gas emissions in state. The act requested the California Air Resources Board to generate a Scoping Plan, which should depict the approaches to reduce greenhouse gases in California and achieve the purpose of decreasing the emission level to 1990 standards by 2020 [1]. As a result, California passed the first Scoping Plan in 2008, which included the policies regarding reducing air pollution, and kept amending it through the years [2].

When a policy change or a treatment occurs in an area, it is significant to evaluate how the area has been impacted, so that the government are able to make further decision on whether the policy should be kept and amended or abandoned. In this case, Difference-in-Difference (DID) estimation method is suitable for measuring the effects of a sudden policy change, or treatment, on a group of individuals [3].

This study bases on the DID estimation to evaluate the effectiveness of California 2008 Scoping Plan, aiming to figure out whether the Scoping Plan is an efficient policy to reduce the carbon emissions and worths to be sustainably improved to alleviate global warming phenomenon in California.

2. Data and Variables

2.1. Data Description

The dataset is collected from the U.S. Energy Information Administration website, which includes the transportation energy-related carbon dioxide emissions for each state in the U.S. from 1970 to 2021, in the unit of the million metric tons of carbon dioxide [4]. Transportation sector usually has the biggest percentage among the greenhouse gas emission categories. As figure 1 shows, transportation always accounted for the largest portion of greenhouse gas emissions in California from 2000 to 2020. Therefore, this analysis chooses transportation sector as the indicator of carbon emissions in the U.S.

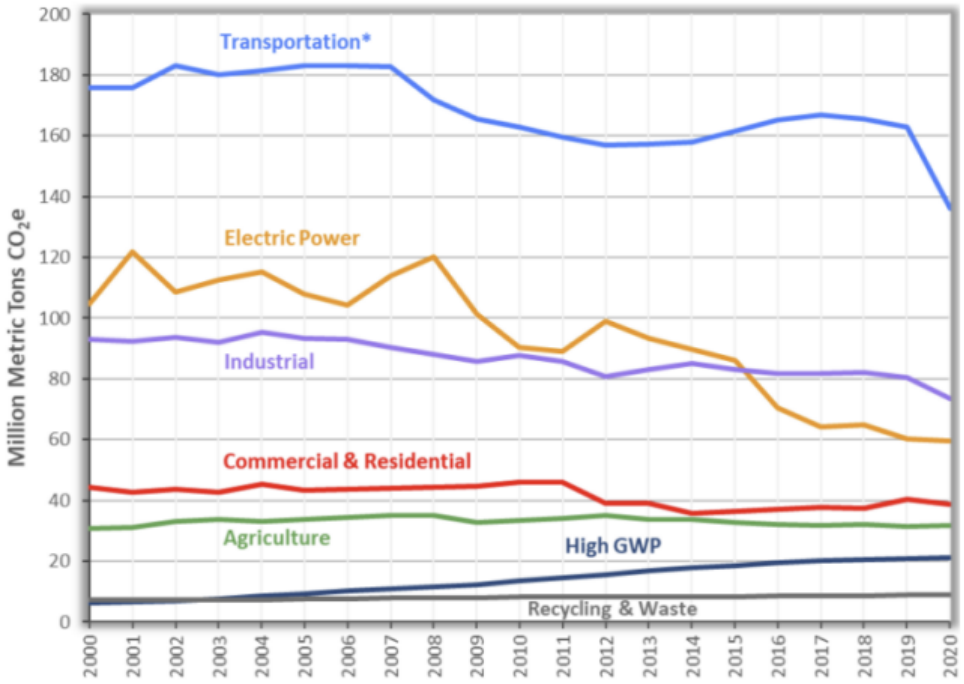

Fig. 1 Trends of California Greenhouse Gas Emissions

Data from California Greenhouse Gas Emissions for 2000 to 2020 [5].

2.2. Data Preprocessing

This study chooses the data from 2004 to 2014 to analyze whether the California Scoping Plan in 2008 had an effect on California carbon emissions. To convert the raw data into the format that are able to utilize for DID analysis, it's necessary to sort each year's emission data by state. First, the author lists each state with the eleven years in two columns, beside are the corresponding emission amount values. Then, the author creates a variable called "treatment", which is a dummy variable indicating whether the state was in a region that was under the 2008 Scoping Plan through the period. In this analysis, only California received the treatment, so the treatment value for California is 1, and is 0 for any other states. Totally, this study has four variables. As shown in table 1:

Table 1. Key variables.

Name	Description
state	State's name in the U.S.
year	Ranged from 2004 to 2014 for each state.
emission	Amount of carbon emissions, in the unit of the million metric tons of carbon dioxide.
treatment	Value indicating whether the state implemented the 2008 Scoping Plan or not.

3. Method Introduction

3.1. Basic Ideas

DID is an estimate method to evaluate a policy change by observing the before-after differences for treatment and control groups. It has the pre-intervention period, which is the period before the policy launched, and the post-intervention period, which is the period after the policy change. In DID, the treatment group refers to the ones that are affected by the policy change. The control group refers to the ones that are not affected by the policy change.

There are three key assumptions for DID method. First, the introduction of treatment doesn't affect control group's outcomes. Second, there should be no anticipation. The third one, which is also the most significant one, is that the time trend for control observations is what the time trend for treated observations would have been without the policy change. In other words, the treatment and control groups should have parallel trends in outcome. These three assumptions are significant for the prerequisite for the DID analysis. The study can only utilize DID when all these three assumptions are met.

3.2. DID Calculation

There are two different ways to calculate the DID estimate. One is cross-section estimate, the other is before-after estimate.

Table 2. DID Setup

	Pre	**Post**	**Difference**
Control (C)	$\overline{Y}_{C,Pre}$	$\overline{Y}_{C,Post}$	$\Delta\overline{Y}_{C,\cdot}$
Treatment (T)	$\overline{Y}_{T,Pre}$	$\overline{Y}_{T,Post}$	$\Delta\overline{Y}_{T,\cdot}$
Difference	$\Delta\overline{Y}_{\cdot,Pre}$	$\Delta\overline{Y}_{\cdot,Post}$	DiD

As for cross-section estimate, the relevant calculation method is as follows:

$\Delta\overline{Y}_{\cdot,Pre} = \overline{Y}_{T,Pre} - \overline{Y}_{C,Pre}$ is cross-section estimate from pre-period.

$\Delta\overline{Y}_{\cdot,Post} = \overline{Y}_{T,Post} - \overline{Y}_{C,Post}$ is cross-section estimate from post-period.

$DiD = \Delta\overline{Y}_{\cdot,Post} - \Delta\overline{Y}_{\cdot,Pre}$ is Difference-in-Difference estimate, which is the difference between the treated and controlled differences in the post-period versus pre-period.

As for before-after estimate, the relevant calculation method is as follows:

$\Delta\overline{Y}_{T,\cdot} = \overline{Y}_{T,Post} - \overline{Y}_{T,Pre}$ is before-after estimate for treated.

$\Delta\overline{Y}_{C,\cdot} = \overline{Y}_{C,Post} - \overline{Y}_{C,Pre}$ is before-after estimate for controlled.

$DiD = \Delta\overline{Y}_{T,\cdot} - \Delta\overline{Y}_{C,\cdot}$ is Difference-in-Difference estimate, which is the difference between the before-after estimate for treated and the before-after estimate for controlled.

3.3. DID Regression

The regression of DID can be explained by equation (1),

$$Y = \beta_0 + \beta_1 D_{post} + \beta_2 D_{treat} + \beta_3 D_{post} D_{treat} + e \quad (1)$$

Where Y is the outcome of interest. D_{post} is a time dummy (1 = post-intervention). β_1 is the time trend for controlled. D_{treat} is a treatment group dummy (1 = treatment). β_2 is cross-section difference between treated and controlled in pre-period. $D_{post}D_{treat}$ is a time times treatment interaction. e is the error term [6]. Besides, the OLS estimate of β_3 is numerically equivalent to Difference-in-Difference.

3.4. Advantage of DID

Compared to the two basic estimators, DID avoids some problems that may cause by them. If the research only uses the cross-section estimator, even including additional covariates, it may still have omitted variable bias, which will influence the accuracy of the estimation; if the research only uses the before-after estimator, perhaps the before-estimator is estimating a time-trend that would have happened even without the policy change, and then it will face the problem of time trend.

Additionally, compared with simple linear regression analysis, which only uses the difference between controlled and treated group in post-period, DID compares both the data from "pre" and "post" periods, which avoids the problems of using only cross-section or before-after estimator and in the meanwhile makes the estimation more accurate.

4. Theoretical Analysis

4.1. Evaluation of the Three Key Assumptions of DID

First, it is easily to identify that the California's Scoping Plan is state-specific, which would not influence other states in the U.S., which indicates that the objects meet the first assumption. Then, the data also accords with the assumption that there is no anticipation in it. Finally, in this analysis, the parallel trend assumption means that before the treatment, the development trend of carbon emissions in California and all other states should be parallel. This study creates the figure that involves the data of California carbon emissions and the average of the other 50 states from 2004 to 2007, and then scales down California's observations ten times to make the comparison easier, which does not change the trend [7]. The trend of California and other 50 states from 2004 to 2007 are almost identical, which satisfies the parallel trend assumption as shown in figure 2. Thus, this study accords with the three assumptions to use DID to do the analysis of the effect of 2008 Scoping Plan in California.

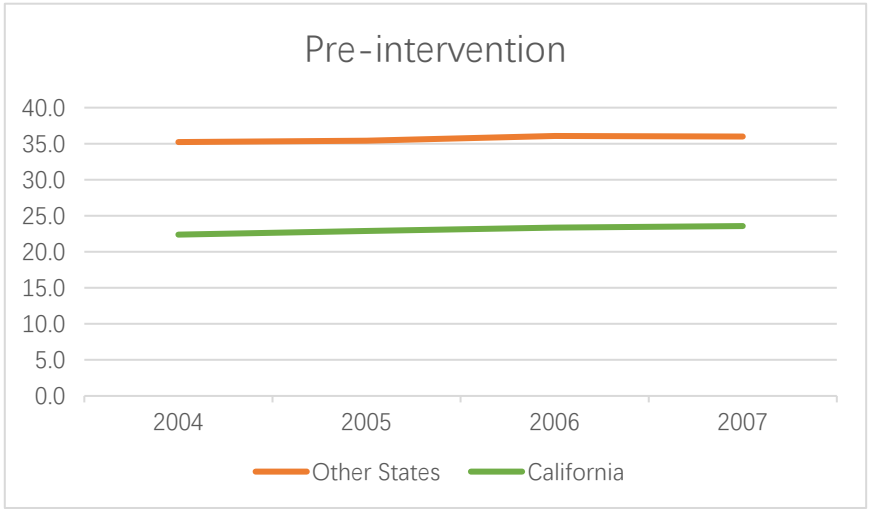

Fig. 2 Parallel Trend of California with Other States

4.2. DID Setup in R Studio

This study utilizes R Studio to help analyze the estimation. California is the treatment group and all the other states are the control group. This analysis uses the data on each state for both before (2004-2007), the pre-period ones, and after (2008-2014), the post-period ones, the policy was implemented. Then the author utilizes the Difference-in-Difference approach to estimate the effect of California 2008 Scoping Plan and sets 2008 as the policy implemented year. Hence, this research constructs a new dummy variable called "post", which is equals to 1 if year is larger or equal to 2008, and is otherwise zero.

Then the author creates a means table that includes the four necessary conditional expectations needed for the DID estimation (the mean of pre-period controlled, the mean of post-period controlled, the mean of pre-period treated, and the mean of post-period treated) and round to make presentation easier.

Table 3. The Result of the Means Table

	Pre	Post
Controlled	35.378	32.584
Treated	230.466	199.373

5. Results and Discussion

5.1. Results Display

This study utilizes the before-after estimate of DID to calculate the DID estimator, as shown in equation (2),

$$\begin{aligned} DiD &= \Delta\overline{Y}_{T,\cdot} - \Delta\overline{Y}_{C,\cdot} \\ &= (\overline{Y}_{T,\text{Post}} - \overline{Y}_{T,\text{Pre}}) - (\overline{Y}_{C,\text{Post}} - \overline{Y}_{C,\text{Pre}}) \\ &= (199.373 - 230.466) - (32.584 - 35.378) \\ &= -28.299 \end{aligned} \tag{2}$$

By calculating the difference between the before-after estimate for treated (California) and the before-after estimate for controlled (other states), the research gets the result of DID, which is -28.299. This estimation means that the 2008 Scoping Plan had a negative effect on the carbon emissions in California. In other words, it relatively reduced the carbon emissions largely in California under the situation that California held the largest transportation carbon emissions before 2008 [8]. Therefore, 2008 Scoping Plan is an effective policy to reduce carbon dioxide emissions.

5.2. Limitations Analysis

However, there are some limitations of this analysis. First, there may exist other kinds of emission reduction plan in other states that this study doesn't include in consideration. That is to say, some states in the control group may actually had similar changing trend with California due to their state-specific policies in 2008. Second, there are several different kinds of policies released around 2008 in California, trying to reduce carbon emissions, such as the Global Warming Solutions Act of 2006, which is the AB 32 Climate Change Scoping Plan that is introduced in the introduction, the 2013 Scoping Plan [9], and the California Cap-and-Trade project that implemented in 2013 as a multi-sectoral emissions trading system to lower the GHG emissions [10]. Hence, this analysis cannot be sure whether the Scoping Plan is the only factor caused the emissions to reduce. There is a possibility that the main factor of the declined trend of carbon emissions was led by another policy.

6. Conclusion

By using the DID model, this research considers the California 2008 Scoping Plan had a positive effect on reducing carbon emissions in transportation sector from 2008 to 2014 in California. However, the government can continue to improve and implement the Scoping Plan to reach the goal of emission reduction more efficiently. In future research, it's better to minimize the influence caused by other states' policies and the similar policies in state to give a more accurate estimation, for example, eliminating the data from the states that were under similar carbon emission reduction policy through the research period. Additionally, it's more comprehensive to include the analysis on other sectors, like electric power and industrial, which are also a big portion of the U.S. carbon emissions.

In fact, continued in 2022, California government had the new amended Scoping Plan to adjust the yearly changing situation of carbon emissions in California. Although the carbon emission amount has some fluctuation these years, it positively approaches the goal of California government mentioned in Assembly Bill 1279 that reduce the greenhouse gas emissions caused by human by 85% less than 1990 levels no later than 2045. Therefore, it's beneficial for the government to utilize DID estimation to measure the effectiveness of the Scoping Plan and make adjustment to decrease the carbon emissions as efficiently as possible, and make contribution to the protection of global environment.

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