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The Green Effects of Industrial Policy—Evidence from China's New Energy Vehicle Subsidies

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Abstract: The development of new energy vehicles has become a common choice for countries worldwide to reduce greenhouse gas emissions and improve the global ecological environment, with China being no exception. However, challenges, such as finding charging stations, accessing residential areas, and highway charging, have hindered the green and high-quality growth of the new energy vehicle industry. This study, set against the backdrop of China's 2018 policy to gradually redirect local purchase subsidy funds for new energy vehicles towards supporting the construction and operation of charging infrastructure, utilizes panel data from 282 prefecture-level cities from 2016 to 2021. A difference-in-differences model is constructed to compare the impact of infrastructure development on carbon emissions before and after the policy's implementation. The study finds that policy has a negative effect on carbon emissions, especially in the second and third year after the policy's implementation. Even after controlling for variables such as residents' wealth levels, population size, environmental pollution, energy consumption, and government support, the results remain significant. Heterogeneity analysis reveals that the effect of the promotion of charging infrastructure on carbon emissions is greater in southern and central parts of China.

Keywords: industrial policy; charging infrastructure; new energy vehicles; carbon emissions

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1. Introduction

The "Paris Agreement" reached at the Paris Climate Conference at the end of 2015 established long-term emission reduction goals for global temperature control, aiming to limit the temperature increase to no more than 2 degrees Celsius above pre-industrial levels, with an additional effort to keep it below 1.5 degrees Celsius. This agreement has facilitated a global shift towards a low-carbon trajectory. The European Union, United Kingdom, Japan, and South Korea have all proposed their own "net-zero emissions" targets for 2050 [1]. According to the search results, the UK has committed to achieving net-zero carbon emissions by 2050, and there are various strategies and technologies being explored to achieve this goal [2,3]. China has also set goals to strive for peaking carbon dioxide emissions before 2030 and achieving carbon neutrality by 2060 [4]. Developing new energy vehicles is a common choice for countries around the world to reduce greenhouse gas emissions and improve the global ecological environment. The use of modern vehicles, including electric and hybrid vehicles, can contribute to limiting the adverse impact of urban transport on the environment [5]. New energy vehicles are not only reliant on a greater proportion of green power, but they also serve a significant purpose in reducing carbon emissions as a result of improved aerodynamic resistance [6]. It is a primary direction for the global automotive industry's transformation and green development and is a strategic choice for the high-quality development of China's automotive industry. New energy vehicles have gained popularity due to environmental concerns and the depletion of fossil fuels.

However, there are some after-market concerns that need to be addressed. These include the difficulty and high cost for replacement of matched batteries and the safety of batteries. Battery technology used for electric vehicle (EV) applications is still developing, and the performance of batteries needs to be improved for the application of EVs [7]. The study also offers a guide for better battery selection based on exceptional performance proposed for traction applications (e.g., Battery Electric Vehicles (BEVs) and Hybrid Electric Vehicles (HEVs)), considering EV's advancement subjected to sustainability issues, such as resource depletion and the release in the environment of ozone and carbon-damaging substances [8]. Moreover, the cost of BEVs is still relatively high, with the battery system being the most expensive component [9]. However, there are studies that suggest that the cost of BEVs can be reduced by decreasing the environmental burdens of mobility, which are dominated by the operation phase [10]. Range anxiety, which refers to the fear of running out of power while driving, is another concern for BEV users. One study suggests that charging en route can address range anxiety and increase the uptake of BEVs [11]. Future electricity supply is also an important factor to consider, as BEVs can only reduce GHG emissions if they are operated with renewable electricity [12]. The decarbonization of the grid to meet targets, while building firm, dispatchable generation capacity to support the system, is resulting in previously acceptable cost [13].

To support and promote the development of China's new energy vehicle industry, China has introduced a series of industrial policies, which have achieved a historic leap from nonexistence to existence and from weakness to strength. In recent years, the academic community has engaged in heated discussions on the effectiveness of industrial policies. Some scholars believe that part of the miracle of China's economic growth can be attributed to China's successful industrial policy [14]. With the support of industrial policy, China has established a comprehensive and independently complete modern industrial system, with its industrial economy ranking first in the world in terms of scale. In 2019, the German government clearly stated in its "National Industrial Strategy 2030: Strategic Guidelines for a German and European Industrial Policy" that China's combination of market economy principles with proactive national policies has proven to be the most successful example of implementing industrial policy globally [15]. At the same time, other scholars believe that industrial policy is "planned economy in disguise" [16]. Subjected to the limited rationality of government officials and the distortion of incentive mechanisms, industrial policies cannot achieve their intended goals. Instead, they may foster corruption and result in high rent-seeking costs.

From the perspective of the effectiveness of industrial policy implementation, some literature mainly discusses the impact of various policy tools on enterprise output, profit levels, and R&D innovation. Government subsidies often lack efficiency and, in many cases, do not lead to an increase in enterprise output and competitiveness [17,18]. The specificity of policies, incentive mechanisms, and subsequent supervision will all have a significant impact on implementation outcomes [19,20]. Moreover, the stability of local government policies is an essential prerequisite for obtaining industrial investments [21–23]. The higher the stability and continuity of a policy, the better the enterprise's expectations for emerging industries. Therefore, policy incentives can often stimulate the rapid development of an industry [24–26]. As one of the strategic emerging industries, many countries around the world have implemented a large number of industrial policies for the new energy vehicle industry [27]. The question becomes, should the government implement policies for the new energy vehicle industry? Supporters have mainly conducted research from the perspectives of public goods, externalities [28], strategic industries [29], infant industry protection [30], and technological innovation [31] to provide a basis for the implementation of industrial policies. Opponents argue that industrial policies will lead to other dysfunctions and distortions in the new energy vehicle industry [32], namely, severe overcapacity [33], defrauded subsidies [20], and "subsidy dependence" [34].

Subsidies, as a monetary incentive policy, have played a significant role in promoting the use of new energy vehicles. Research in the U.S. [35], Japan [36], European countries [37], and France [38] all confirm this. Domestic scholars have also conducted in-depth studies on NEV subsidy policies. Cao and Yang [39] developed an evolutionary game model between consumers and the government to analyze the interactive mechanism between subsidy policies and NEV purchases. Xu and Xu [40] used principal component analysis to study factors influencing NEV purchases, identifying vehicle cost as a key factor. This study used game theory to analyze the game behavior between governments and car companies [41], suggesting that the government should dynamically adjust subsidy policies based on the development of car companies. Another study used signal game theory to analyze factors affecting energy conservation and emissions reduction during the subsidy application and distribution process [42]. However, inappropriate subsidies lead to frequent fraudulent claims and, once the industry expands, fail to effectively incentivize companies to invest in R&D, leading to homogenization and overcapacity [27].

From this, it is evident that academic debates on industrial policies focus mainly on their implementation effects and whether governments should implement them. Discussions on the green effects of these policies, especially NEV subsidies, are less frequent. As China enters a new era where industrial policies should fully embody concepts of innovation, coordination, green development, openness, and shared benefits, this article aims to study the green effects resulting from the shift in subsidy targets in the NEV industry.

2. Background and Theoretical Hypothesis

2.1. Background

China's new energy vehicle purchase subsidy policy began with the "Ten Cities, Thousand Vehicles" project in 2009 and was continuously supported until its official termination at the end of 2022. It was the most substantial fiscal incentive policy in terms of funding and had the strongest attraction for automotive companies. The policy played an indispensable role in the development of new energy vehicles. The purchase subsidy policy roughly underwent four policy phases: a small-scale pilot phase (2009–2012), a scaled promotion phase (2013–2015), a nationwide promotion phase (2016–2020), and a post-pandemic phase (2021–2022). These stages fully demonstrated the policy's approach of promoting the best, enhancing technical standards, and gradual phase-out.

Charging stations are essential infrastructure for new energy vehicles and belong to one of the seven major sectors of China's new infrastructure construction. They emerged as a burgeoning industry alongside the new energy vehicle sector and involve multiple stakeholders such as land, electricity, property management, fire safety, and charging infrastructure companies. Charging station manufacturing and operation companies connect to the power grid and serve new energy vehicle consumers. If their construction is inadequate or services are subpar, it will directly become a primary constraint in promoting new energy vehicles.

As of the end of 2021, China boasts the largest amount of charging infrastructure globally, with a cumulative total of 2.617 million charging stations and 1298 battery swap stations, forming the world's largest charging and swapping network. However, the industry is still in its nascent stages, and challenges such as "difficult charging" and "expensive charging" will persist in the short term. Currently, the charging infrastructure industry lacks a comprehensive policy system. There is complexity in administrative processes, and coordination between various stakeholders is challenging, resulting in a high car-to-charging-station ratio. Some new energy vehicle owners resort to makeshift wiring solutions for charging.

The challenge of charging can be summarized in several aspects:

1. In the early stages of industry development, major charging infrastructure companies aggressively staked their claims and operated independently, leading to an unreasonable layout of charging facilities. Issues like incompatible charging interfaces, communication protocols, and payment methods remain. Although the country has mandated standard interfaces and communication protocols, interoperability issues still exist between different charging stations and between charging stations and

vehicles. New energy vehicle owners have to download and use multiple apps from different operators for charging, which is cumbersome and time-consuming.
2. Installing charging stations in residential areas, especially in old communities within the older parts of cities, is a challenge. These areas often lack the necessary land and electrical capacity, leading some new energy vehicle owners to rely on makeshift wiring solutions, which are inefficient and pose significant safety risks.
3. Charging infrastructure companies face difficulties in achieving profitability and have yet to find a suitable business model. Initial investments for infrastructure development are high, and the benefits extend beyond the operators (positive externalities). Currently, the main revenue for operators comes from charging service fees, which often do not cover costs.
4. Building charging stations requires collaboration with various departments, such as land management, electricity providers, property management, and fire departments. Differing objectives and interests among these departments can slow down construction and require significant resources to navigate inter-departmental relations.

Recognizing these challenges, on 12 February 2018, the Ministry of Finance, the Ministry of Industry and Information Technology, the Ministry of Science and Technology, and the National Development and Reform Commission issued a "Notice on Adjusting and Improving the Financial Subsidy Policy for the Promotion and Application of New Energy Vehicles". The notice suggested that localities should gradually shift funds originally intended for new energy vehicle purchase subsidies to support the construction and operation of charging infrastructure. This shift aims to enhance the quality and efficiency of the new energy vehicle industry, bolster its core competitiveness, and achieve high-quality development. This policy shift offers a valuable quasi-natural experiment for studying the impact of charging infrastructure construction on carbon emission effects.

2.2. Theoretical Hypothesis

According to the "Regulations on the Administration of Admittance of New Energy Vehicle Manufacturers and Products" released by China's Ministry of Industry and Information Technology, new energy vehicles, in a broad sense, refer to cars that use unconventional fuels as their power source (or utilize conventional fuels with novel onboard power systems). They incorporate advanced power control and drive technologies, making them advanced in technical principles and incorporating new structures and technologies. Broadly defined, new energy vehicles include: hybrid electric vehicles (HEV), battery electric vehicles (BEV, including solar-powered cars), fuel cell electric vehicles (FCEV), hydrogen engine cars, and other new energy vehicles (such as those powered by supercapacitors, flywheels, and other efficient energy storage devices).

A hybrid electric vehicle (HEV) is equipped with two power sources: a thermal power source generated by conventional gasoline or diesel engines and an electric power source (battery and motor). Using an electric motor on an HEV allows the power system to be flexibly adjusted according to the vehicle's operational conditions. This ensures that the engine operates within its optimal performance range, resulting in reduced fuel consumption and emissions. Battery electric vehicles, on the other hand, derive their power solely from energy storage devices such as lead-acid batteries, nickel-cadmium batteries, nickel-metal hydride batteries, lithium-ion batteries, or supercapacitors. These vehicles rely on batteries and electric motors for propulsion, emitting no harmful gases into the atmosphere. Even when accounting for emissions from power plants generating the electricity, there is a significant reduction in pollutants and carbon dioxide. According to "Yearbook of Energy-saving and New Energy Vehicles of 2010", using crude oil for electricity generation in power plants, charging batteries, and then using these batteries to power vehicles is more energy-efficient than refining it into gasoline and then using a gasoline engine to power a car. This makes it more advantageous in terms of energy conservation and reducing CO_2 emissions.

Researchers have delved into the long-term environmental effects of new energy vehicles. Some scholars recognize their positive impact, believing that an increase in the use of new energy vehicles can realize transportation energy savings and reduce carbon emissions. Others argue that new energy vehicles might not effectively play a significant role in carbon reduction, asserting that their contributions are limited in this respect. Because power plants are mostly built in areas with lower population density, they allow for centralized pollution management, reducing harm to humans. Moreover, electricity can be sourced from various clean energy sources such as nuclear, hydro, wind, solar, and thermal. This reduces the dependency on oil characteristic of traditional vehicles, resulting in relatively lesser carbon emissions. In 2021, China's new energy vehicle ownership reached 7.84 million units, reducing carbon emissions by up to 15 million tons compared to traditional gasoline passenger vehicles in pure usage. Thus, in the long run, new energy vehicles will play a positive role in promoting carbon reduction.

However, the inadequacy of the charging infrastructure and other related supporting systems inadvertently affects people's preference for new energy vehicles. Issues such as "finding a charging station", "difficulty entering residential areas", and "difficulty charging on highways" significantly hinder the green and high-quality development of the new energy vehicle industry, constraining its vital contribution to carbon reduction in the transportation sector. Based on this, the paper hypothesizes the following: the perfection of charging infrastructure construction can effectively increase the usage of new energy vehicles, thereby promoting carbon reduction in the transportation industry.

3. Materials and Methods

3.1. Data

This paper utilizes the 2018 "Notice on Adjusting and Improving the Financial Subsidy Policy for the Promotion and Application of New Energy Vehicle" as a quasi-experiment. A difference-in-differences (DID) model is employed to examine the relationship between charging infrastructure construction and carbon emissions in various cities before and after the implementation of a policy that transitions local purchase subsidies for green vehicles to charging stations. The sample period spans from 2016 to 2021. After excluding cities with significant missing data, a panel with a total of 282 cities was obtained, resulting in 1410 sample observations.

The dependent variable is the carbon dioxide emissions (CE) of prefecture-level cities, sourced from another study [43], which calculated the carbon dioxide emissions of prefecture-level cities from 2011 to 2019 based on the approach used by another study [44]. For this study, data from the years 2016 to 2019 were selected, and linear interpolation was used to supplement the data for the years 2020 and 2021. This process yielded panel data covering the period from 2016 to 2021.

The per capita income and carbon dioxide emissions in urban areas are influenced by various factors. In order to eliminate the confounding of these factors on this study, the controlled variables include government support (gov), population size (popu), per capita income in urban areas (inco), degree of environmental pollution (poll), and energy consumption (pen). The implementation of policies is inseparable from government departments, and the degree of government support is represented by the proportion of general public budget expenditures to GDP. The population size measures the population scale of the region, reflecting the impact of the household sector on carbon emissions. Per capita income in urban areas measures the level of affluence and economic development in the region, which will have an impact on energy consumption and carbon emissions [28]. The degree of environmental pollution is derived from [43] and is calculated based on the industrial wastewater discharge, industrial sulfur dioxide emissions, and industrial smoke (dust) emissions in the region. Energy consumption refers to the per capita electricity consumption in the region. Coal is one of the main sources of carbon emissions, and thermal power generation requires large amounts of coal. According to the life cycle theory, energy consumption reflects the carbon emissions at the front end of the charging infrastructure industry chain. The remaining data are from the "China Urban Statistical Yearbook" and the statistical yearbooks of various prefecture-level cities.

The vehicle–station ratio (number of vehicles per charging station) measures the convenience of charging new energy vehicles. An excessive ratio is an important factor restricting the development of the new energy vehicle industry. Intuitively, according to the marginal diminishing effect, the policy of new energy vehicle subsidies to support charging infrastructure construction has a greater impact on cities with a high vehicle-to-pile ratio. In other words, local governments in cities with relatively less charging infrastructure have a greater response to the policy and will be more active. Cities with sufficient or even saturated charging infrastructure have a weaker response to the policy. Of course, the policy was also intended to stimulate areas with poor charging infrastructure. Based on this, this paper sets dummy variables (north and east) according to this study [34] to group the sample cities. In view of the fact that the policy of converting new energy vehicle subsidies to support charging infrastructure construction was issued in early 2018, the charging infrastructure vehicle-to-pile ratio (3.81) at the end of 2017 was used as the basis point. If the vehicle-to-pile ratio of the sample city is greater than or equal to 3.81, it is assigned as 1, which is the treatment group, otherwise assigned as 0, which is the control group. The data of new energy vehicle ownership in sample cities come from the national new energy vehicle monitoring and management platform.

3.2. Descriptive Statistics

Table 1 presents a downward trend in the vehicle-to-station ratio following the policy's implementation in 2018, as reflected by the rightward and downward shift in the density curves. Notably, the average vehicle-to-station ratio fell from 13.01 in 2018 to 7.54 in 2020, as displayed in Table 1. This drop signifies an enhanced utilization of charging stations in the aftermath of the policy. Figure 1 echoes this finding, with the density curves for the vehicle-to-station ratio showcasing a downward and rightward shift, indicating the vehicle-to-station ratio is no longer densely packed in the lower part of the sample. Interestingly, 2018 saw a sharp deviation in the pattern, characterized by an upward lift from the prior accelerated growth of new energy vehicles, followed by a decline instigated by charging stations' growth rate surpassing that of the new energy vehicles. These trends have been encapsulated in the data from Table 1. Notwithstanding these changes, there was a perpetual rise in carbon emissions throughout the sampled years. This continuous increase is attributed to a systematic upward trend in energy consumption evidently associated with developmental dynamics. It is crucial to note that the true treatment effect can only be ascertained by juxtaposing the actual outcomes and their counterfactuals. The counterfactual condition, in this instance, is an hypothetical scenario wherein the policy was not implemented. Reinforcing the accuracy of this comparison is the utilization of the difference-in-differences model in this research, which effectively captures the contrast between the observed trends and their potential alternatives in the absence of the policy.

The cities in the sample are nearly evenly geographically distributed all over the country, which provides us a representative sample and a good opportunity to study the heterogeneity of the policy effect in different regions. The composition of the treated group, which is approximately half the size of the control group, coincides with the assumption that cities with a higher vehicle-to-station ratio are more susceptible to the focal policy's repercussions. The grouping methodology used in this paper suggests that smaller, less developed cities are more likely to be included in the treated group due to their pre-existing higher vehicle-to-station ratio. This geographic and economic differences in city categorization can be discerned in Figures 2 and 3. The control group, consisting of more developed cities, exhibits wider dispersion in terms of per capita income and population size. Impressively, only cities from this category appear at the higher extremes of these distributions (no red line at the right tail), verifying the consistency of this grouping methodology. As a result of their advanced development, control cities have higher carbon emissions both pre- and post- policy implementation, as indicated by Figure 4.

The treatment effect this study seeks to identify in the subsequent analyses therefore lies in the differential distribution of carbon emissions between the treated and control groups during the pre- and post- treatment phases. This difference implies the potentially varied impacts of policy implementation across geographically and economically diverse urban settings.

Table 1. Descriptive statistics.

	2017	2018	2019	2020
Carbon	937.21 (448.08)	997.67 (462.28)	1117.06 (518.46)	1226.8 (551.15)
Car	728.07 (129.00)	5498.58 (905.50)	10,293.60 (1777.50)	13,737.55 (2695.50)
Station	616.15 (67)	930.38 (140.50)	1643.01 (296.50)	2405.07 (478.50)
Car/Station	9.67 (1.50)	13.01 (7.12)	9.34 (6.39)	7.54 (5.61)

The items take the form of mean (medium); the number outside of the parentheses is the mean, and the number inside the parentheses is the medium.

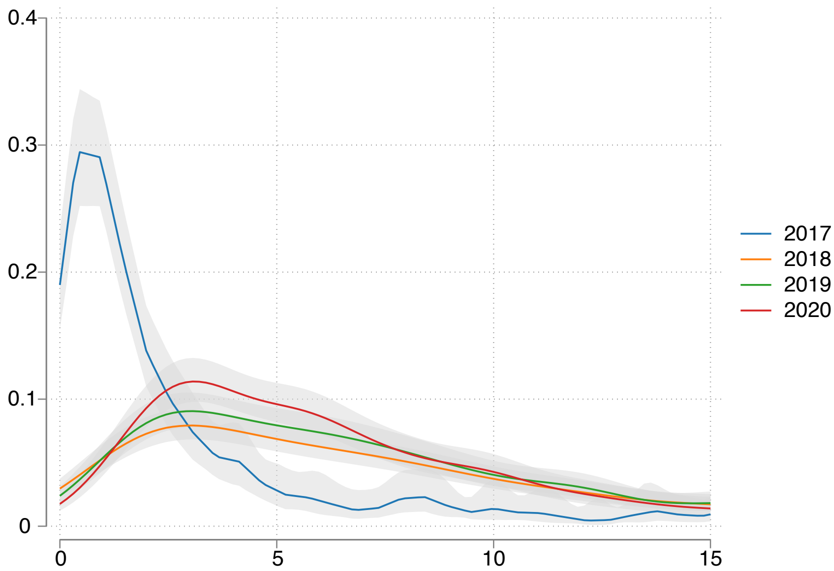

Figure 1. Density of vehicle to station ratio.

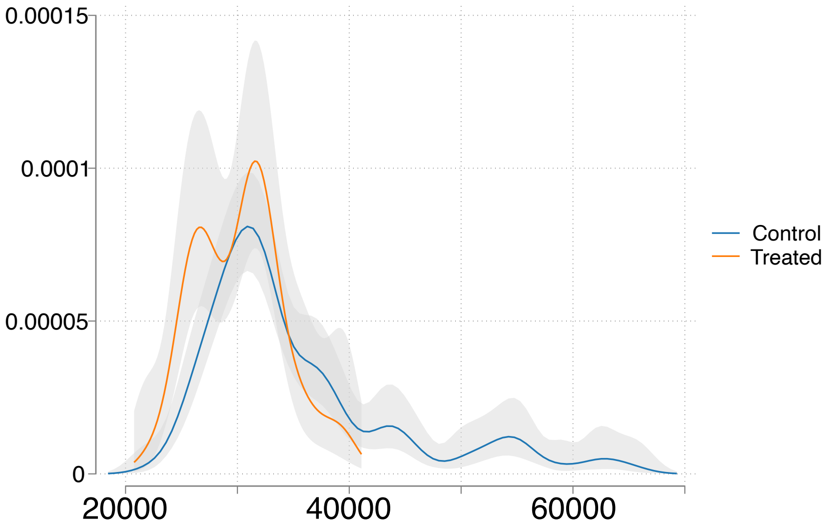

Figure 2. Density graph of income per capita in both groups.

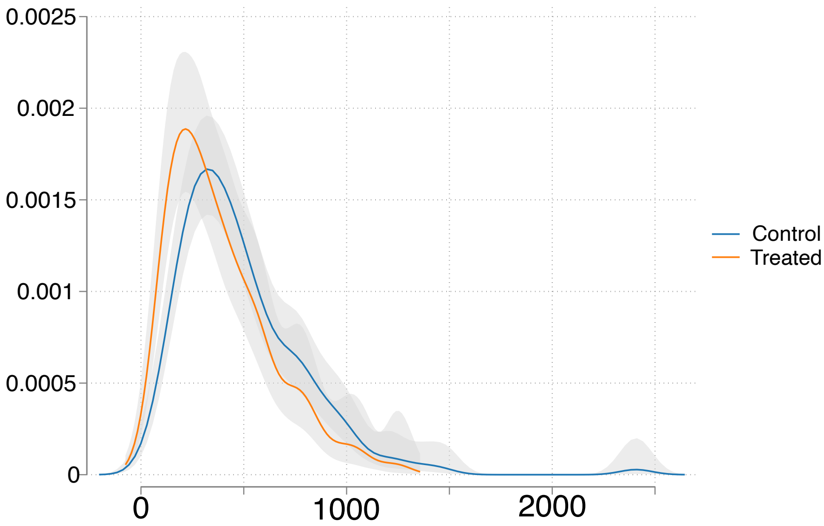

Figure 3. Density graph of population in both groups.

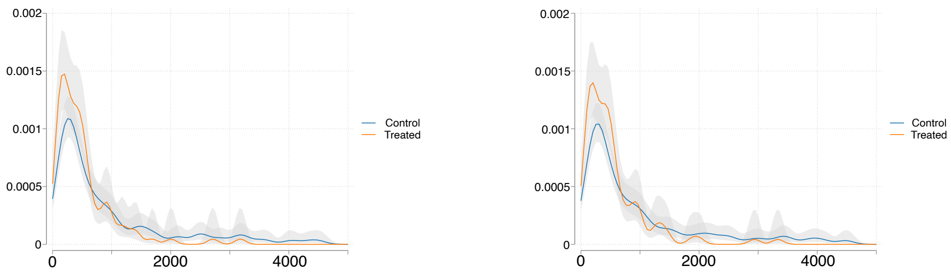

Figure 4. Density graphs of carbon emissions in 2017 (**left**) and 2018 (**right**).

3.3. Identification Strategies

This study uses a difference-in-differences (DID) framework based on the panel data of 282 cities in China from 2016 to 2021 to identify the effect of the policy implemented in 2018. A DID framework is a statistical technique that compares the outcomes of two groups before and after a policy change. Given the nationwide implementation of the policy in question, there is no natural control group. Therefore, the "dosage" effect is used to construct the treated and control groups [45]. Cities whose vehicle–station ratio is greater than the national average (3.81) in 2017 are assigned as the treated group and those whose is less than 3.87 in 2017 as the control group. The vehicle–station ratio is the number of vehicles per charging station, which measures the level of charging station utilization and serves as the "dosage" here. Another "dosage" is used to test the robustness of this paper in a subsequent section to show the results are robust to the choice of divider based on the implementation of the policy of gradually shifting local purchase subsidy funds for new energy vehicles to support the construction and operation of charging infrastructure in 2018. Figure 5 indicates a slighter rise of carbon emissions from the treated group after the policy, implying the effectiveness of the policy in reducing carbon emissions, which will be statistically tested in the regression.

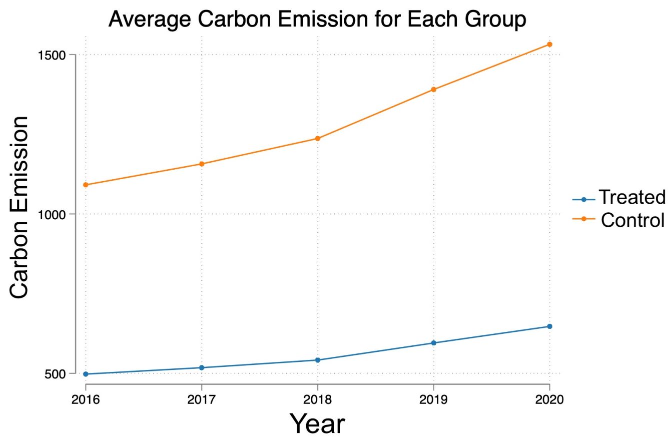

Figure 5. Trends of carbon emissions for both groups.

The baseline estimation is a two-way fixed effect (TWFE) DID equation for the whole sample:

$$carbon_{it} = \beta(treat_i \times post_t) + \mathbf{X}'\gamma + u_i + \lambda_t + \epsilon_{it} \tag{1}$$

where *treat* is a dummy variable indicating whether the city is in the treated group (equals 1 for treated group and 0 for control group); *post* is a dummy variable indicating whether the city is in the post-policy group (equals 1 for post-policy group and 0 for pre-policy group); **X** is a vector of control variables, including government expenditure, population, per capita income in urban areas, pollution, and energy consumption; u_i is the city fixed effect, which controls for time-invariant city-level characteristics; λ_t is the time fixed effect, which controls for time-specific shocks; and ϵ_{it} is the error term. The coefficient of interest is β, which measures the effect of the subsidy policy on carbon emissions. The standard errors are clustered at city level.

To enhance the flexibility of the model and to allow for examination of pre-trends, the DID analytic setup is adapted to a more efficient parametric regression:

$$carbon_{it} = \sum_{l \geq 2018} \beta_l(treat_i \times \delta_t^l) + \mathbf{X}'\gamma + u_i + \lambda_t + \epsilon_{it} \tag{2}$$

where δ_t^l is the Kronecker delta, which equals 1 if $t = l$ and 0 otherwise. The coefficient of interest is β_l, which measures the effect of the subsidy policy on carbon emissions in each year.

After using the "dosage" effect to construct treated and control groups, the existence of the parallel trend assumption—a potentially complicating factor—does not have a profound impact on this study, because the treated and control groups demonstrate comparability during the phase preceding the treatment period. The pre-treated years (2016 and 2017) are used as the baseline and compare the treatment effect in each year and mainly focus on the flexible estimation of treatment effects in each year after the policy. This analysis designates the pre-treatment years of 2016 and 2017 as the foundation for subsequent comparison of the treatment effects in each year. One of the key components of this study is the comprehensive analysis of the treatment effects. In fact, this research heavily focuses on the flexible estimation of treatment effects in the years following the policy's implementation. This estimation will enable a more nuanced understanding of the policy's impact over time, providing insights that could be useful for researchers and policymakers alike.

3.4. Robustness

3.4.1. Alternative Treated and Control Groups

The sample is divided into two groups based on the vehicle–station ratio in 2017, with a cut-off of 3.87. The threshold is not arbitrarily chosen but still raises robustness concerns that the results may be sensitive to the choice of divider. To address these concerns, an alternative divider is used to test the robustness of the results. Specifically, cities with a vehicle-to-station ratio ranking in the top third for the year 2017 are assigned as the treated group, and cities in the bottom third are the control group, mirroring this methodology [45]. This strategy allows us to avoid the arbitrary selection of a threshold while yielding two comparably sized groups, thereby enhancing the analytical rigor of this comparison.

3.4.2. Placebo Test

A concern in this DID framework is that the results may be influenced by omitted variables. To address this concern, a placebo test is conducted to test the validity of the results by randomly assigning the treated and control groups and re-running the DID regression 100 times to check whether the kernel density of the estimated coefficients stays around zero as it should; otherwise, it would indicate a misspecification of this treatment effect estimation, and the policy may just a placebo to the carbon reduction.

3.5. Heterogeneity Analysis

There exists a profound disparity in economic development across various regions in China, which may cause heterogeneous treatment effects of the subsidy policy at different regions. The academic discourse surrounding this matter encompasses a range of theories and perspectives aimed at comprehending the root causes and potential remedies for this persistent imbalance. More developed regions, like the southern and eastern parts of China, tend to have better infrastructure, including charging stations and supporting facilities, which can facilitate the adoption and use of NEVs. Additionally, regional differences in the availability of renewable energy resources and the presence of supportive industries can also influence the carbon emissions in a particular area. The western area is known for its abundant natural resources that contribute to the geographical features and ecological diversity. Therefore, this issue demands further analysis in light of its significant implications for the country's overall effect of the policy. A heterogeneity analysis is conducted to test whether the effect of the policy varies across different regions by adding interactions between the treatment effect and each region dummies. This triple difference (DDD) framework is conducted as below:

$$carbon_{it} = \beta_1(treat_i \times post_t) + \beta_2(treat_i \times post_t \times region_i) + \mathbf{X}'\gamma + u_i + \lambda_t + \epsilon_{it} \quad (3)$$

where $region_i$ is the region dummy. For this study, three different criteria are used to segment the regions: first, by dividing it into the Eastern, Central, and Western parts; second, by separating it into Northern and Southern sectors; and third, via a combined approach of the first two. The coefficient of interest is β_2, which quantifies the heterogeneous effect of the subsidy policy on carbon emissions across various regions.

4. Results

4.1. Baseline Results

The product of the baseline regression analysis, denoted as Equation (1), is presented in Table 2. This key coefficient β provides a measure of the impact of the implementation of the subsidy policy on carbon emissions. In this analytical model, city-level characteristics act as controlled variables. Post-control, a significant treatment effect has been observed, thus implying a successful route of action. This proves that providing subsidies for charging stations can work effectively in promoting the adoption and utilization of new energy vehicles (NEVs). Consequently, these actions pave the way towards a decrease in carbon emissions.

The usage of parametric estimation methods in this study reveals additional insight into the effect of the treatment on a yearly basis. For an exhaustive understanding of these results, one can refer to Table 2 and derive clear perceptions visually through Figure 6. The significance of the treatment effect has been shown to increase throughout the years 2018, 2019, and 2020, suggesting a progressive and more evident impact on carbon reduction.

The treatment effect for the year 2018 is great but noisy, possibly suggesting that the policy's impact requires a certain span of time before it can notably come into effect. Progressing to the coefficients of the following years, 2019 and 2020, it is seen that there are significant increases. This trend in data underlines that the subsidy policy begins to display its effectiveness in these years, further consolidating the results of this baseline regression analysis. In summary, this intensive analysis of the coefficient values across the years reinforces the hypothesis that a subsidy-oriented policy creates a positive environment for NEV adoption, thus playing a pivotal role in achieving sustainable carbon reductions.

Table 2. Results of baseline and parametric regression.

	Baseline	**Parametric**	**Alternative**
$treat \times post$	−30.541 *		−42.20 ***
	(9.967)		(7.618)
$1(2018) \times treat \times post$		−10.15	
		(4.998)	
$1(2019) \times treat \times post$		−18.97 **	
		(5.438)	
$1(2020) \times treat \times post$		−30.56 ***	
		(6.264)	

Significance levels are indicated by *, **, and *** for 10%, 5%, and 1%, respectively.

4.2. Robustness

To test the robustness of this paper, a stratified method is employed to categorize the top one-third and bottom one-third of the vehicle–station ratio in 2017 into treated and control groups, respectively. The findings, presented in the third column of Table 2, signify that the implemented policy has a more pronounced negative effect on carbon emissions within these defined groups. The robustness of this outcome is irrespective of the choice of divider employed, and the amplified effect is in line with the wider divergence—or "dosage"—observed between the treated and control groups. Despite these results, it is crucial to note that, as with any study, potential concerns regarding the validity of the findings may be present.

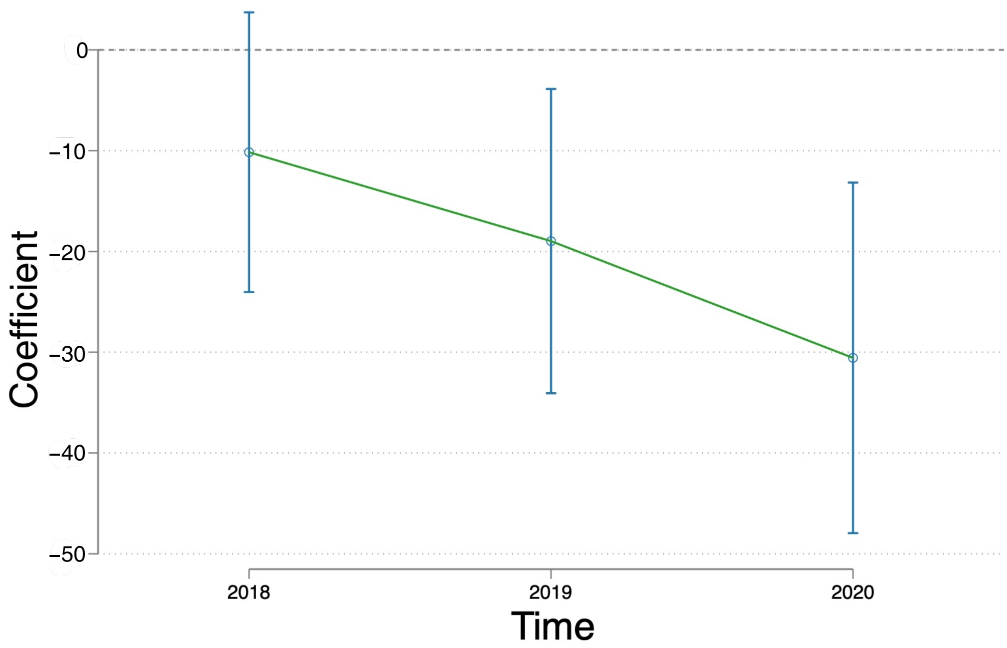

Figure 6. Graph for parametric estimation.

In steps to mitigate such concerns and to substantiate the credibility of this findings, a placebo test is conducted. The results demonstrated that the estimated placebo coefficients distribution is centered around zero, as depicted in Figure 7. This observation suggests that any treatment effect derived from randomly constructed treatment methods was negligible to none. Further, the baseline estimate is positioned at the left tail of the placebo distribution, with its corresponding cumulative probability being less than 0.1. This evidence aligns with this earlier finding that the baseline estimate holds significant value at the 10% level. The placebo test presents forceful evidence to support the validity of this baseline estimate, providing assurance that no misspecification blights this estimation of the treatment effect. Therefore, this bolsters confidence in this finding that the policy under investigation has a substantial negative effect on carbon emission, particularly within the stratified groups analysed. Ultimately, this lends credence to this core argument that targeted actions can indeed deliver robust impacts in reducing carbon emissions.

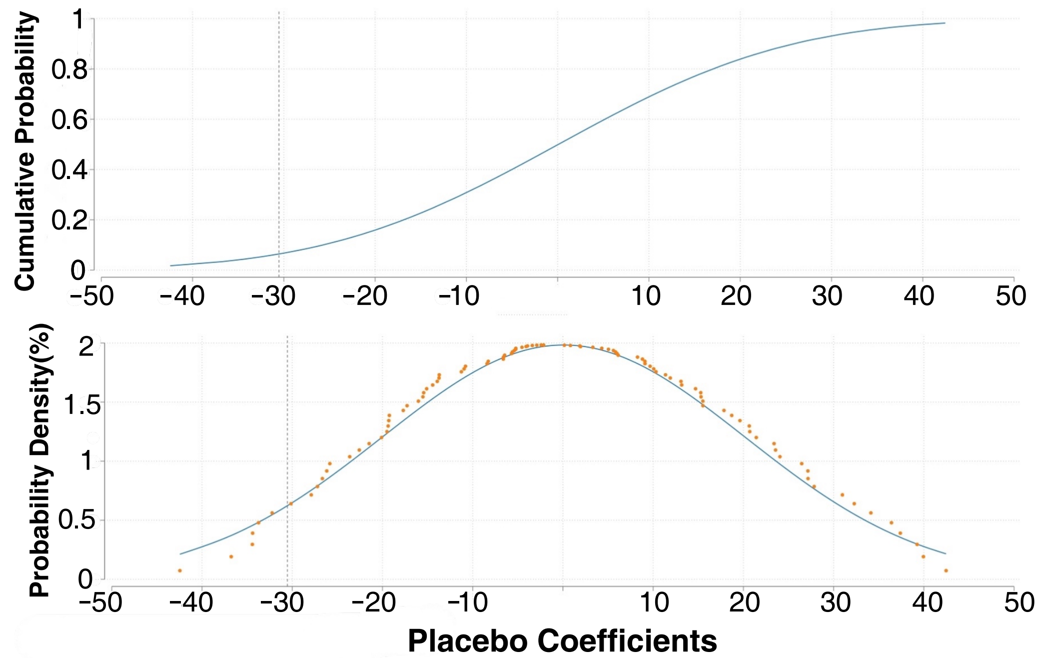

Figure 7. Graph for placebo test.

4.3. Heterogeneity Analysis

As discussed above, the disparity in economic development across various regions in China may cause heterogeneous treatment effects of the subsidy policy at different regions. Regressing Equation (3) provides a heterogeneity analysis. The results are shown in Table 3. The policy is more effective in the central area of China.

The estimated variance in the effectiveness of implementing charging station subsidies and the corresponding reduction in carbon emissions between different regions may be attributed to several mechanisms and reasons. To begin with, a plausible mechanism is the interplay of economic, geographical, and socio-political factors. Central regions, often characterized by less developed economies compared to eastern regions, tend to have less-established public charging stations. Thus, the introduction of electric vehicle charging station subsidies can trigger a more pronounced shift from conventional to electric vehicles, thereby leading to a decline in carbon emissions. In the cold western regions, limited battery life restricts the policy's effectiveness.

Moreover, in a broader view, the policy is also more effective in the southern area of China. A critical player in this variation could be the geographical aspect. Cultural preferences shaped by geographical location can significantly influence transportation choices, subsequently impacting the efficacy of charging station subsidies in curbing carbon emissions. Furthermore, the societal acceptance and adoption rate of EVs in southern and northern regions can also play a significant role. This may be because people in the southern part of China are more sensitive to subsidy.

The DID model captures the causal impact of the subsidies, although the heterogeneity analysis underscores the differential effects across different regions. From this, it is inferred that subsidies should be allocated in a geographically nuanced manner to achieve maximum carbon reductions.

Table 3. Results of baseline and heterogeneity analysis.

	Baseline		**By Region**	
treat × *post*	−30.541 * (9.967)			
Northeast		−18.173 (26.310)		
Northwest		151.855 (84.447)		
Northcentral		−31.410 *** (6.377)		
Southeast		0.000 (.)		
Southwest		−68.599 (25.964)		
Southcentral		−32.305 ** (6.304)		
Central			−29.021 * (7.279)	
West			−35.969 (25.957)	
East			−16.944 (25.837)	
South				−48.722 * (14.525)
North				−7.866 (13.119)

Significance levels are indicated by *, **, and *** for 10%, 5%, and 1%, respectively.

5. Conclusions and Discussion

The main direction for the transformation and upgrade of the global automobile industry is towards new energy vehicles. However, governing bodies are facing challenges with the incomplete construction of charging infrastructure. In order to address this issue, the Chinese government has implemented industrial policies to subsidize the construction of charging infrastructure, aiming to promote the green development of this industry. What is the green effect of this industrial policy? Can it effectively reduce carbon emissions? This paper is based on panel data from 282 prefecture-level cities in China from 2016 to 2021. It constructs a difference-in-differences model to compare the impact of charging infrastructure construction on carbon emissions in different prefecture-level cities before and after the implementation of the industrial policy. There is a treatment effect of charging station subsidy policy on reducing carbon emissions, especially from the second year after the policy and going forward. The results are robust to the choice of divider and the placebo test. The policy is more effective in the central area of China and the south area of China. This observed regional difference in how charging station subsidies impact carbon emissions can be attributed to geographical factors, economic disparities, existing EV penetration, and policy enforcement. These results show the importance of tailored regional policies and strategies for boosting EV adoption. Additionally, these insights provide valuable guidance towards targeting and refining the charging station subsidy policies for more effective climate action. This multifaceted analysis accentuates the need for a holistic and contextual understanding when designing and implementing such green policies.

The study results presented in this article suggest that the progressive growth in sales and use of new energy cars may be anticipated as a result of improvements in charging infrastructure. Simultaneously, as the nation implements pertinent industrial policies aimed at fostering the advancement of novel battery materials and enhancing the energy density ratio and power battery range, it will effectively facilitate the mitigation of carbon emissions within the transportation domain. This study also puts forward the following policy recommendations. The government should facilitate the continued expansion of electrification within the domains of public transit, logistics, and rental services. It is advisable to urge cities with significant adoption rates of pure electric vehicles and regions experiencing severe air pollution to progressively initiate experimental initiatives that prohibit the sale of fuel-powered vehicles. Additionally, it is recommended to foster collaboration among governmental bodies, enterprises, universities, and other relevant stakeholders to address pivotal shared technologies, including power battery materials, vehicle-grade chips, and chassis electronic systems. It is recommended to provide tax incentives or exemptions for corporations that demonstrate substantial investment in research and development activities. To enhance the industrial chain's weaker components, it is advisable to depend on government assistance. Additionally, there is a need to enhance the building of charging infrastructure. This proposal advocates for the widespread adoption of intelligent charging practices within communities as well as the exploration and implementation of novel battery swapping models. These measures aim to efficiently accomplish peak shaving and load reduction on the power grid.

The scientific justification of this study is that well-designed charging infrastructure can facilitate grid integration and support emissions mitigation strategies. By leveraging smart charging technologies, charging stations can optimize charging times to align with periods of low electricity demand and high renewable energy generation. The social justification of subsidies for charging stations also lies in their potential to align with broader environmental justice objectives. By promoting the adoption of EVs and establishing charging infrastructure in marginalized communities, subsidies can contribute to reducing the disproportionate burden of air pollution and environmental degradation faced by these communities. Additionally, the transition to a low-carbon transportation system can create opportunities for job creation and economic development, particularly in areas that have been historically disadvantaged. As policymakers strive to transition towards sustainable transportation systems, understanding and addressing the social dimensions of subsidy policies are essential for achieving a just and sustainable future.

This study still has certain limitations, and future improvements can be attempted considering the following aspects. First, industrial policies are national policies, which leads to the absence of obvious control and treatment groups in the samples. This study divided the sample cities based on the ratio of charging piles to vehicles. However, other criteria for division may lead to more accurate conclusions. Second, limited by data availability, this study conducted research based on annual data. If monthly data on public charging piles could be obtained, on one hand, it can more accurately determine the implementation nodes of the policies, and on the other hand, it can discuss the lag effect of the policies, studying the long-term green effects of this industrial policy, thereby further enhancing the credibility of this study. Furthermore, this study takes the construction of public charging piles as the explanatory variable to study its impact on carbon emissions. In reality, private charging piles also account for a large share in China's charging infrastructure, and their number even exceeds that of public charging piles. Therefore, replacing the explanatory variable with private charging piles or total charging piles may yield more comprehensive conclusions. These points can all be directions for future research.

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