

The Role of Electric Vehicle Manufacturing Innovation in Reducing Smog in China

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Abstract: Serious smog has always been one of barriers in improvement of environment quality around the world. This study uses a panel fixed effect model and mediating effect techniques to verify the effects of China's innovative electric vehicular manufacturing on pollution. The conclusions derived from the study are: 1) Electric vehicle manufacturing innovation positively and statistically significantly impact smog; 2) The mediating role of electric vehicle production is validated within the relationship between the manufacturing innovation of electric vehicles and smog; 3) Environmental fees can reduce the effects of manufacturing innovations in electric vehicle technology on particulate matter. The conclusion indicate that for the first time, that electric vehicle manufacturing innovation can reduce the occurrence of smog with the mediating role of electric vehicles' production, and levying environmental tax significantly enhances the effect of electric vehicle manufacturing innovation on smog.

Keywords: electric vehicle, smog, environmental tax, manufacturing innovation

1. Introduction

In the current era of rapid economic growth, air pollution, especially smog, has become a critical global issue. Smog not only endangers public health but also obstructs ecological civilization construction [1,2]. Reducing emissions is crucial globally, and the use of clean energy is widely promoted.

China, as a major emitter, advocates for electric vehicles to cut down on emissions from traditional vehicles [3,4], which benefits both the environment and the economy.[5,6,7]

The previous literature shows that the emission of fine particles from vehicle gas is an important factor that aggravates smog [8,9], yet the impact of electric vehicle manufacturing innovation on smog in China is unclear. Although such innovation can boost production and potentially ease smog [10,11], the mediating role of production remains under - explored. Moreover, environmental tax policies can encourage manufacturing innovation [12,13]. In order to facilitate the advancement of a green economy, Chinese governments have imposed environmental taxes [14, 15]. In regions characterized by relatively high environmental - tax rates, enterprises are motivated to improve their innovation capacities. Consequently, a greater reduction in air pollution can be achieved, which contributes to alleviating the intensity of smog. [16]

On the basis of the Hausman test findings, we decide in favor of a fixed - effect model over a random - effect model to study the relationship between the factors mentioned above and smog. The fixed - effect model suits our study as variables like electric vehicle manufacturing innovation vary over time and it accounts for all time - invariant regional disparities. According to mediating effect models, electric vehicle manufacturing innovation can reduce smog levels via electric vehicle production. Furthermore, our observation reveals that the influence of this innovation on smog is more pronounced in regions with high environmental taxes compared to those with low environmental taxes. This suggests that increasing the environmental tax significantly enhances the impact of electric vehicle manufacturing innovation on smog.

To date, no empirical study has employed the production volume of electric vehicles and environmental tax as variables to investigate the correlation between innovation in electric vehicle manufacturing and smog. This research offers the subsequent contributions: 1) For the first time, it summarizes the direct impact path from electric vehicle manufacturing innovation to smog. 2) It delves deeper into the mechanisms between electric vehicle manufacturing innovation and smog, covering the intermediate effect of electric vehicle production and the modulating effect of environmental tax. 3) It suggests that governments ought to raise environmental taxes to achieve a harmonious equilibrium between industrial advancement and environmental conservation.

2. Review of Literature and Formulation of Hypotheses

2.1. Electric Vehicle Manufacturing Innovation and Smog

Gas emissions from traditional energy vehicles contribute to smog [9]. International organizations like the UN and W.H.O. advocate for developing cleaner energy vehicles, especially electric ones, and limiting emissions.

Previous literature indicates a link between electric vehicle manufacturing innovation and production [17]. For example, Sovacool's research shows innovation can boost production.

This study explores the correlation between electric vehicle manufacturing innovation and smog, with electric vehicle production as a mediator. We quantify regional smog by PM_{2.5} concentration and measure innovation by the number of electric vehicle - related invention patents in each provincial administrative region. Invention patents are a better proxy for innovation.

Accordingly, two hypotheses are proposed:

H1: *Electric Vehicle Manufacturing Innovation is statistically associated with smog.*

H2: *Electric Vehicle Manufacturing Innovation correlates with smog via the intermediary function of electric vehicles' production.*

2.2. The Nexus between Environmental Tax and Smog

Previous studies show that environmental tax can effectively accelerate manufacturing innovation and reduce air pollution [17,18,19]. Chinese governments in all provincial regions of China mainland have implemented different rates of environmental tax to strengthen the construction of ecology [20,21]. Such tax contributes to the development of environment and to reduce the occurrence of smog [22,23]. In China, environmental tax varies in different regions (**Appendix**). Therefore, the influence of electric vehicle manufacturing innovation in bringing about a decrease in smog within these regions could be more conspicuous. [24,25]

Based on the aforementioned analysis, we arrive at the conclusion that environmental tax acts as a moderating variable in the correlation between innovation in electric - vehicle manufacturing and smog. More specifically, a relatively elevated environmental tax reinforces the link between innovation in electric - vehicle manufacturing and smog. Thus, we posit the following hypothesis.

H3: *Enhancing the environmental tax regime may reinforce the association between innovation in electric - vehicle manufacturing and smog.*

3. Empirical Analysis

The purpose of this research paper is to quantify the influence of electric vehicle manufacturing innovation on smog in China, considering the intermediate function of electric vehicle production and the modulating function of environmental tax.

3.1. Summary Statistics

According to the IPAT - E theory [26], explanatory variables including population, environmental regulation, industrialization, and forest coverage rate may potentially affect smog. As a result, in this study, these variables are chosen as control variables.

We gather panel data from 31 mainland regions in China spanning from 2010 to 2019. This data encompasses all the control variables utilized in this research (*source: CSMAR database and Wanfang Database*).

Once we've gathered all the data, we aim to measure how electric vehicle manufacturing innovation affects smog. We'll use electric vehicle production as a mediator variable and environmental tax as a moderator variable. Then, we'll use STATA to do the regression in (A):

$$Smog_{i,t} = \alpha lnInnovation_{i,t} + \sum_{i,t} \beta_{i,t} Control_{i,t} + \varepsilon_{i,t} \quad (A)$$

In (1), the parameters α and β represent the regression coefficients, $Smog_{i,t}$ represents the smog level in region i during year t , $Innovation_{i,t}$ is the level of electric vehicle manufacturing innovation (quantified by the invention patent counts of electric vehicles) of i region in t year, $Control_{i,t}$ stands for all the control variables applicable to region i during year t , and $\varepsilon_{i,t}$ denotes the error term associated with region i in the regression analysis for year t .

Table 1 presents the metrics of the factors employed in this study. Nevertheless, a considerable amount of variability is detected in the majority of the variables. For example, variables like innovation and GDP display substantial fluctuations, as evidenced by their high standard deviation (SD) values.

Table 1: Description of Statistics

	Variable	Definition	Mean	SD	Min	Median	Max
Dependent Variable	Smog	Concentration of PM2.5 in the air (mg/m3)	142	97.649	3	153	597
Independent Variable	Innovation	The number of invention patents about electric vehicles (piece)	23.152	65.947	0	3	501
Control Variable	POP	Population (ten thousand)	4,954	7,540	317.600	3811.700	100,047
	Environmental Regulation	Environmental protection expenditures (trillion yuan)	12.369	23.783	4.394	10.482	31.762

Table 1: (continued).

	Industrialization	The proportion of the 2 nd industry in GDP (%)	50.336	55.707	16.200	43.520	54.140
	Forest	Forest coverage rate (%)	33	18.090	4.240	35.84	66.800
Mediator Variable	Production	Production of EV (ten thousand)	2.389	3.155	0	1.100	15.440
Moderator Variable	Environmental tax	Environmental tax charge rates for SO ₂ in air pollution (yuan)	5.928	10.562	1.2	1.8	12

The correlation analysis of various variables reveals that innovation (Innovation) is negatively correlated with smog (Smog) ($r = -0.207^{***}$, significant at the 1% level), indicating that innovation in electric vehicle manufacturing may, to some extent, inhibit smog. Additionally, industrialization (Industrialization) is positively correlated with smog ($r = 0.347^{**}$, statistically significant at the 5% significance level), suggesting that industrial development may exacerbate smog.

We conducted the Breitung panel unit root test to examine the stationarity of the panel data. Test findings show most variables, such as smog (Smog), innovation (Innovation), and urbanization (Urbanization), are highly statistically significant in the $I(0)$ context, with p - values much less than 0.01. This indicates the variables are stationary, so we reject the null hypothesis of a unit root (non - stationarity). Thus, the data meets the stationarity requirements for subsequent regression analysis.

Table 2 presents the findings of the Granger causality tests. From these findings, it becomes clear that innovation serves as the Granger cause of smog. However, when we specifically focus on the variable smog within the test, the collective importance of the parameter reveals a chi - square value of 0.103 along with a corresponding p - value of 0.892. This strongly implies that smog does not Granger - cause innovation. Consequently, the available evidence underscores that innovation in electric vehicle manufacturing leads to a Granger - induced decrease in smog, while there is no such causal relationship in the opposite direction.

Table 2: Granger Causality Tests

Equation	Excluded	Chi-Square	Prob > Chi-Square
Acid Rain	R&D	8.001	0.004
R&Dss	Acid Rain	0.103	0.892

3.2. Baseline Results

Due to the fact that the result of the Hausman test shows a p - value of 0.044, we decide to employ fixed - effects regression models for the purpose of data analysis. Table 3 presents the fundamental results of our study, including the definitions of the parameters and their Robust t - statistics. Smog, quantified by the PM2.5 concentration, is the dependent variable in this analysis. Innovation, on the other hand, acts as the independent variable. As stated previously, **Table 1** contains all the definitions of the variables used in this study.

In the first column, only the explanatory variable is included together with annual and regional fixed effects. The coefficient of “Innovation” is -2.077, highly significant at the 1% level, showing a high - degree correlation between electric vehicle manufacturing innovation and smog.

In the second column, upon the addition of control variables to the prior estimation, the coefficient of “Smog” attains a higher level of significance, specifically reaching the 0.1% significance level. This suggests the positive correlation holds with control variables. These results are consistent with H1, validating that electric vehicle manufacturing innovation can reduce smog levels in China.

Table 3: Baseline Analysis of Innovation and Smog

Dependent Variable	Smog	1	2
Independent Variable	Innovation	-2.077*** (3.131)	-1.900*** (2.635)
Control Variable	POP		0.233* (1.868)
	Environmental Regulation		-0.033* (1.901)
	Industrialization		1.239*** (4.051)
	Forest		-2.217*** (3.307)
	Constant	-51.679*** (-4.791)	-49.071** (-2.678)
Observations		310	310
Adj.R ²		0.401	0.463

Note: Year and Province: fixed effect; * p < 0.05; ** p < 0.01; *** p < 0.001.

3.3. Findings of the Mediating Effect in Electric Vehicle Production

Mediator analysis aims to identify, through statistical means, if a particular variable assumes a mediation role. In prior research, the causal step procedure has been utilized to examine mediation. Specifically, all relevant variables are subjected to analysis within the context of the regression equations described in Model (A), (B), and (C). From the results of these analyses, we deduce that the production of electric vehicles indeed plays a mediating function.

In this study's models, we test production's mediating role in how innovation affects smog. The direct impact of innovation on smog is statistically significant ($\alpha = -2.077$, $p < 0.001$, from baseline findings). In Model (B), a significant positive link ($\alpha' = 1.734$, $p < 0.001$) shows innovation boosts electric vehicle production. In Model (C), the relationship among smog, innovation, and production is significant ($\alpha'' = -0.924$, $p < 0.001$). Combining these with the previous two models, we find production has a statistically significant mediating effect. Panel fixed - effect regressions are in **Table 4**.

$$Production = \alpha' \ln Innovation_{i,t} + \sum_{i,t} \beta'_{i,t} Control_{i,t} + \varepsilon'_{i,t} \quad (B)$$

$$Smog_{i,t} = \alpha' \ln Innovation_{i,t} + \sum_{i,t} \gamma_{i,t} Production_{i,t} + \sum_{i,t} \beta''_{i,t} Control_{i,t} + \varepsilon''_{i,t} \quad (C)$$

Table 4: Regressions with Fixed Effects in the Analysis of Mediating Effects

Dependent Variable		Model (B)	Model (C)	
		Production	Smog	
Independent Variable	Innovation	1.734*** (3.429)	Innovation	-0.924*** (6.156)
			Production	-2.451*** (2.995)
Control Variable	GDP	1.535*** (3.975)	GDP	1.747*** (4.144)
	Trade Openness	1.892** (2.361)	Trade Openness	1.924*** (3.521)
	Information	1.246*** (3.135)	Information	1.626*** (4.145)
	Infrastructure	-2.274*** (2.551)	Infrastructure	-3.051*** (2.797)
	Environmental		Environmental	
	Regulation		Regulation	
Constant		23.157*** (3.901)	Constant	19.245*** (6.125)
Observations		310	Observations	310
Adj.R ²		0.301	Adj.R ²	0.299

Note: Year and Province: fixed effect; * p < 0.05; ** p < 0.01; *** p < 0.001.

3.4. A Comprehensive Analysis of the Moderator's Influence

The **Appendix** presents the rates of environmental tax on sulfur dioxide (SO₂) related to air pollution in various regions of mainland China. We use this metric as the moderating factor. Remarkably, its value fluctuates significantly from one province to another.

All data samples are divided into a lower - tax group (14 provinces with values below the median) and a higher - tax group (17 provinces with values above the median) based on environmental tax rates. In this research, Model (A) is employed to perform regressions on both groups. In the lower tax - paying category, only one controlled factor shows statistical significance. Conversely, among the high - tax cohort, all variables are statistically meaningful. The findings of the analysis are presented in the tabular presentation.

Table 5: Moderator Effect Test of Environmental Tax

Dependent Variable		Smog	
		Lower tax group	Higher tax group
Independent Variable	Innovation	-1.033 (1.025)	-4.632*** (3.167)
	GDP	2.981 (1.932)	3.782** (1.875)
Control Variable	Trade Openness	5.157*** (7.665)	10.892*** (6.368)
	Information	0.159 (0.913)	1.378*** (3.016)
	Infrastructure	-1.077 (0.691)	-2.084*** (3.332)
	Environmental		
	Regulation		

Table 5: (continued).

Constant	57.167 (0.234)	80.267*** (3.306)
Observations	140	170
Adj.R ²	0.501	0.569
Difference		0.933
Chi-square		4.63***

Note: Year and Province: fixed effect; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

In the lower - tax group, the variables exhibit a low degree of statistical significance. In contrast, within the higher - tax group, the variables are characterized by a high level of statistical significance. Following the regression analysis, a seemingly unrelated estimation is carried out. The results, with a difference of 0.933 and a chi - square value of 4.63, suggest a significant disparity between the two groups. As a result, it can be inferred that the environmental levy acts as a mediating factor within the correlation linking electric vehicle manufacturing innovation and smog in China.

4. Conclusion

In the past few years, the green economy has emerged as a worldwide concern. The extensive acceptance and use of alternative - fuel vehicles, notably EVs, are crucial for addressing the ecological contamination. In this research, we use panel fixed - effects regression models for the analysis of the Chinese dataset and verify hypotheses, reaching these conclusions: 1) Electric - vehicle manufacturing innovation significantly correlates with smog.2) This innovation relates to smog, with electric vehicle production as an impact pathway.3) Environmental tax reinforces the relationship between innovation in electric - vehicle manufacturing and smog.

This research bears substantial significance within the framework of ecological civilization construction in the context of the objective of achieving carbon emissions peak and carbon neutrality. Below exist several strategic suggestions derived from the outcomes of this investigation.

Firstly, automotive manufacturers ought to contemplate producing a greater number of electric vehicles to satisfy the requirements of the green economy. Secondly, this paper presents a substantial quantity of empirical proof. Based on this, the central government and local governments across China can formulate more incentives to stimulate innovation in electric vehicles, thereby promoting the production of cleaner - energy vehicles. Thirdly, for the relevant governmental departments in the People's Republic of China, appropriately raising the environmental tax rates is a viable option. This is because it can expedite the process of cleaner - energy application.

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Appendix

Environmental Tax Charging Criterion

Type	Province	Charging Criterion (yuan/equivalent)	Type	Province	Charging Criterion (yuan/equivalent)
Higher Tax Regions	Beijing	12	Lower Tax Regions	Ningxia	1.2
	Tianjin	10		Qinghai	1.2
	Jiangsu	8.4		Anhui	1.2
	Shanghai	6.65		Fujian	1.2
	Hebei	6		Tibet	1.2
	Shandong	6		Zhejiang	1.2
	Henan	4.8		Jiangxi	1.2
	Sichuan	3.9		Yunnan	1.2
	Chongqing	3.5		Inner Mongolia	1.2
	Hainan	2.4		Xinjiang	1.2
	Guizhou	2.4		Liaoning	1.2
	Hunan	2.4		Gansu	1.2
	Hubei	2.4		Shaanxi	1.2
	Shanxi	1.8		Jilin	1.2
	Guangdong	1.8			
	Guangxi	1.8			
	Heilongjiang	1.8			