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The Impact of Pilot Policies for New Energy Vehicles on Pollutant Emissions in Prefecture-level Cities

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Abstract

Against the backdrop of the "Dual Carbon" goals, transportation electrification serves as a critical low-carbon technical pathway to optimize urban energy structures and cut mobile-source air pollution. To quantitatively assess the environmental techno-economic performance of new energy vehicle (NEV) pilot promotion policies, this paper adopts panel data of 282 prefecture-level and above cities in China from 2014 to 2024, and conducts empirical estimation via the PSM-DID model, transmission pathway test, and multi-dimensional heterogeneity grouping. The results indicate that NEV pilot policies can significantly reduce urban $PM_{2.5}$ and NO_x emission levels, and the net policy effect remains robust after parallel trend and placebo tests. NEV ownership acts as the core transmission carrier of emission reduction dividends, with the substitution of fuel vehicles contributing 48.91% of total emission cuts. The emission reduction performance of the policies presents prominent differentiation across spatial location, city scale and industrial structure, where megacities, eastern cities and service-dominated cities achieve better low-carbon technology penetration effects. Such disparities stem from unbalanced local supporting policies, charging infrastructure and industrial market foundations. From a techno-economic optimization perspective, differentiated promotion schemes are proposed to provide quantitative support for local governments to formulate targeted NEV support policies and advance collaborative pollution reduction in the transportation sector.

Keywords: New energy vehicles, Pilot policy, Pollutant emission reduction, PSM-DID, Low-carbon techno-economy, Prefecture-level panel.

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1. Introduction

Currently, global ecological environment governance has entered a critical stage marked by the overlapping pressures of climate change and environmental pollution, and the "Dual Carbon" initiative has become a global consensus. As the world's largest developing country, China accounted for 27% of global carbon emissions in 2023, with industry, energy and transportation as primary emission sources. Approximately 1 billion tons of annual emission reductions are required to reach the carbon targets, while 18.2% of Chinese cities still fail to meet air quality standards. Therefore, coordinated progress in carbon reduction, pollution abatement, ecological expansion and economic growth has become an urgent priority.

The transportation sector consumes 10.7% of China's terminal energy, among which high-carbon fossil fuels account for 88.6%. Its carbon emissions rose from 536 million tons in 2010 to 779 million tons in 2021. Tailpipe NO_x and $PM_{2.5}$ pollutants constitute the main bottleneck restricting air quality improvement. Benefiting from life-cycle low-carbon advantages, new energy vehicles (NEVs) have become a pivotal pathway to optimize transportation energy mix and realize emission cuts.

In terms of policy, China has built a comprehensive support system clarified in documents such as the 14th Five-Year Plan for Green Transportation, with NEV purchase tax exemptions extended to 2027 and a target vehicle-to-charger ratio of 1:1.5 by the end of 2025. Driven by relevant policies, China's NEV ownership has exceeded 20 million units with a market penetration rate of 36.5%, ranking first globally for nine consecutive years.

China's NEV pilot policies adopt an implementation framework combining national overall planning with localized supporting measures. Pilot cities enjoy dual incentives, pushing their NEV penetration rates above 40%, while non-pilot cities rely solely on national unified policies with penetration rates below 15%. Such regional disparities hinder the overall advancement of national Dual Carbon goals and balanced industrial development. Systematic empirical research is thus needed to analyze the formation mechanisms of these gaps and optimize policy design for high-quality transportation pollution abatement.

2. Literature Review

Against the backdrop of global low-carbon transportation transformation and the advancement of China's "Dual Carbon" goals, research on new energy vehicles (NEVs) has become a vital topic in environmental economics, industrial policy, and urban governance. Scholars at home and abroad have conducted extensive explorations concerning policy effects, emission reduction mechanisms, regional disparities, and optimization pathways. As a core indicator for measuring the sustainable development of the transportation sector, transportation carbon emission efficiency essentially reflects the joint outcomes of capital, labor, energy and other factor inputs in transportation activities and their corresponding economic benefits and environmental pollution outputs under carbon emission constraints.

Foreign scholars mostly take mature NEV support policies in Europe, the United States, Japan and South Korea as research samples, and construct standardized low-carbon techno-economic evaluation frameworks relying on research tools including life cycle assessment, difference-in-differences (DID), and cost-benefit analysis. Das, K.P. et al. (2024) verified that transportation electrification can drastically cut urban fine particulate matter and nitrogen oxide emissions, and the emission reduction dividends brought by relevant policies are highly dependent on the cleanliness of regional power grids and the coverage of charging facilities. Yazan & Ricardo (2023) compared the promotion effects of private and public vehicles, and found that regions with sound supporting policies witness stronger replacement of fuel vehicles and superior environmental performance. Hao & Liu (2025) established a dynamic evaluation system for policy evolution, providing methodological support for pilot policy assessments in developing countries.

Recent studies further focus on the synergistic emission reduction logic of power grids and NEVs. Based on life cycle calculations, Zhang, et al. (2025) pointed out that the decarbonization level of power supply directly determines the upper limit of emission reduction brought by NEVs; the dividends of transportation electrification will be largely offset in regions with high coal-fired power ratios. Wang, Y.J. et al. (2025) adopted an industrial policy perspective and confirmed that differentiated purchase subsidies and infrastructure support can continuously reduce urban air pollutant emissions, yet policy effects present prominent stratification across cities. Time-varying DID results show that the emission reduction effects of NEV pilot policies grow year by year, with a notable acceleration in dividend release three years after policy implementation, while urban industrial and energy structures impose strong constraints. Yuan & Wu (2025) constructed a comprehensive techno-economic analytical framework for transportation electrification beyond single battery cost discussions. They systematically sorted out three major barriers to large-scale popularization: insufficient charging infrastructure, high purchase cost thresholds, and fragmented power market systems. The study argues that purchase subsidies alone cannot break the bottleneck of large-scale NEV adoption, and integrated investment schemes including power grid expansion, time-of-use electricity pricing and public charging networks are indispensable. Tang & Wang (2026) distinguished two policy modes: single-city pilots and coordinated urban agglomeration pilots, and identified significant spatial spillover effects of NEV policies. Single-city pilots only deliver local emission cuts, while cross-regional coordinated pilots can drive the electrification of vehicles in surrounding cities, offering empirical evidence for designing unified low-carbon transportation policies for urban agglomerations. Nevertheless, foreign research is built on the industrial and energy foundations of European and American cities, whose policy tools and fiscal capacities differ greatly from prefecture-level cities in China, making their conclusions difficult to directly apply to local pilot practices.

Domestic research is rooted in China’s "Ten Cities, Thousand Vehicles" program and successive batches of NEV demonstration city pilots, and abundant low-carbon techno-economic empirical analyses have been carried out based on prefecture-level city panel data. Xu, et al. (2025) adopted multi-period DID to estimate the environmental performance of low-carbon transportation policies and established a localized quantitative paradigm for transportation technology and policy evaluation. Yang, et al. (2023) demonstrated that the promotion of green technologies achieves collaborative air pollution governance through energy structure optimization. Zhang, et al. (2022) proposed that local fiscal capacity and industrial chain agglomeration constitute core drivers of heterogeneous policy effects across pilots. Cheng & Li (2025) conducted targeted collaborative pollution reduction estimations for domestic NEV demonstration cities and confirmed stable environmental dividends of pilot policies, without further separating two typical motor vehicle pollutants: $PM_{2.5}$ and NO_x. Zheng, et al. (2021) focused on the collaborative pollution and carbon reduction mechanisms of the digital economy, and interpreted the driving effect of green policy instruments on NEV penetration from a techno-economic cost perspective, offering new ideas for combined policy design. Wen, et al. (2024) calculated the full-life-cycle carbon emissions of NEVs under medium- and long-term scenarios up to 2035, and quantified emission contributions from production, operation and recycling stages. They proved that focusing merely on driving-phase emissions underestimates the emission reduction gaps of transportation electrification in regions dominated by thermal power, providing a life-cycle accounting reference for differentiated regional assessments in this paper. Yang, et al. (2025) built a carbon emission accounting system for NEVs adaptable to Chinese cities, clarified two low-carbon pathways: grid-vehicle coordination and charging time sequence optimization, and remedied the lack of unified carbon emission measurement standards in most empirical studies. Zeng (2025) examined the transmission mechanism between NEV R&D innovation and urban pollution and carbon reduction from the perspective of battery R&D and supply chain technological investment. She indicated that local subsidies for NEV industrial R&D can amplify the emission reduction elasticity of pilot policies, providing industrial innovation-based evidence to explain the heterogeneous policy effects across cities.

Propensity Score Matching-DID (PSM-DID), parallel trend tests and placebo tests are standard tools for identifying the net effects of policies. Dong, et al. (2024) optimized the design of placebo tests specifically for transportation emission reduction scenarios, effectively mitigating estimation bias caused by omitted variables and offering direct references for the empirical design of this paper. Most existing methodological literature only centers on carbon emission indicators, with few multi-dimensional robustness tests covering both $PM_{2.5}$ and NO_x. Meanwhile, Luo & Zhao (2024) suggested that future policy evaluations should incorporate spatial spillover effect tests to avoid underestimating the comprehensive emission reduction benefits of coordinated urban agglomeration pilots.

Transmission channels are core carriers for interpreting the internal logic of policies, and a consensus has been reached in existing literature: rising NEV ownership and the replacement of stock fuel vehicles serve as core channels to release emission reduction dividends. Zhang, et al. (2022) differentiated the direct and indirect effects of green technologies, and verified that policies cannot directly reduce pollutant emissions without the transmission channel of vehicle structure adjustment. Yang, et al. (2023) quantified the contribution of energy transition to pollution abatement and proposed that a higher share of clean energy amplifies the benefits of transportation electrification. Cheng & Li (2025) supplemented evidence based on China's context, stating that city-wide charging station deployment and full electrification of public transport can accelerate fuel vehicle replacement and form a complete transmission chain for emission reduction. Wang, Y.J, et al. (2025) put forward three parallel transmission pathways: fuel vehicle replacement, power grid decarbonization, and full-life-cycle carbon emission control. They pointed out that most previous studies ignored power system supporting facilities as a critical mediating variable. Shi, et al. (2025) empirically verified that NEV subsidies and grid-vehicle coordination can narrow urban peak-valley electricity load gaps, indirectly cutting extra pollutant emissions from peak-shaving thermal power plants and expanding the energy-side logic of emission reduction transmission. Cross-country comparisons by Yazan & Ricardo (2023) revealed that cities with developed service industries and higher economic levels face fewer barriers to technology deployment and achieve stronger emission reduction intensity. Hao & Liu (2025) supplemented energy heterogeneity analysis: policy dividends are significantly weakened in regions reliant on coal power, and clean power and NEVs demonstrate complementary synergies.

Consistent conclusions have been drawn from domestic grouped regressions: policy effects are stronger in eastern cities, megacities, super-large cities and service-dominated cities, and such disparities stem from three gaps in fiscal subsidies, charging infrastructure and industrial foundations. From a techno-economic cost perspective, Das, et al. (2024) explained the root of heterogeneity: charging infrastructure boasts longer payback periods in small and medium-sized cities, discouraging private capital participation and slowing transportation electrification. Zeng, (2025) supplemented industrial innovation heterogeneity: cities with complete industrial chains for NEV vehicle assembly and batteries achieve significantly higher emission reduction elasticity than those without supporting industries. However, most existing heterogeneity analyses rely on simple grouped regression, and rarely interpret the drivers of effect differentiation from techno-economic perspectives including low-carbon technology investment, promotion costs and industrial supporting capacity, leaving an obvious research gap in refined hierarchical mechanism analysis.

Synthesizing the above literature, mature measurement frameworks have been formed for research on NEV policies and low-carbon transportation emission reduction, yet three prominent research gaps remain. First, most studies adopt the traditional environmental economics paradigm, lacking techno-economic analysis that interprets policy effects from the perspectives of technology promotion costs, supporting investment and technology spillovers. Second, existing empirical research mainly focuses on total carbon emissions, with insufficient estimations of differentiated emission reduction effects on motor vehicle characteristic air pollutants such as $PM_{2.5}$ and NO_x. Third, prior literature only qualitatively identifies the fuel vehicle replacement channel without quantifying its contribution share, and heterogeneity analysis fails to conduct in-depth mechanism explanations combined with techno-economic resource disparities in infrastructure, fiscal capacity and industrial layout.

Addressing the limitations of existing research, this paper makes three marginal contributions. First, it adopts a techno-economic perspective, defines NEV pilot policies as green transportation technology promotion policies, and estimates their environmental techno-economic performance. Second, it selects two core air pollutants, applies PSM-DID to eliminate sample selection bias, and ensures robust results via parallel trend tests and placebo tests. Third, it quantifies the contribution share of the fuel vehicle replacement transmission channel, and unpacks the techno-economic resource constraints leading to heterogeneous policy effects from three dimensions: city scale, geographic location and industrial structure. The findings provide empirical support for differentiated optimization of NEV support policies across regions.

3. Theoretical Mechanisms and Research Hypotheses

3.1 Pilot policies for new energy vehicles can significantly enhance pollution reduction in prefecture-level cities

China's new energy vehicle (NEV) pilot policies adopt a two-tier policy supply framework featuring national top-level incentives plus location-specific local supporting measures. Through a portfolio of diversified policy instruments including purchase subsidies, tax exemptions, priority road access, financial support for charging infrastructure, and mandatory electrification of public service vehicles, the policies comprehensively cut the full-chain costs of NEV purchase, usage and energy refueling, remove market diffusion barriers, and accelerate the market penetration of new energy vehicles.

On the purchase side, pilot cities stack national vehicle purchase tax reductions with special local purchase subsidies, substantially lowering residents' financial barriers to vehicle buying and stimulating demand for replacing traditional private passenger cars with NEVs. On the usage side, differentiated road-right policies such as unrestricted driving, discounted parking fees, and access to bus lanes continuously reduce vehicle operation costs and improve user experience and consumer willingness to adopt NEVs. On the infrastructure side, governments attract social capital to deploy charging and battery swapping stations via special subsidies and land-use guarantees, addressing the bottleneck of inconvenient charging and filling the supporting facility gaps for the popularization of low-carbon transport technologies. On the public service side, buses, taxis, sanitation vehicles and logistics vehicles are mandated to achieve full electrification, generating large-scale demonstration effects that drive the transformation of the private vehicle market.

Compared with non-pilot cities that only implement unified national policies, pilot cities boast richer policy tools, stronger support intensity and higher policy implementation efficiency. Such advantages rapidly expand the stock of NEVs, curb $PM_{2.5}$ and NO_x emissions from motor vehicle exhaust at the source, and deliver steady pollution abatement dividends. Based on the above theoretical logic and the empirical findings of Cai, et al. (2025) and Tang & Wang (2026), this paper puts forward the following hypothesis:

Hypothesis 1: The new energy vehicle pilot policy can significantly reduce $PM_{2.5}$ and NO_x pollutant emissions in prefecture-level cities, and the net policy effect remains statistically significant after multiple robustness tests.

3.2 The number of new energy vehicles plays a significant mediating role between the new energy vehicle pilot policy and pollution reduction and carbon emission reduction in prefecture-level cities

The stock substitution of fuel vehicles driven by rising NEV ownership constitutes the core intermediary channel translating pilot policies into pollution abatement outcomes. Pure electric vehicles produce zero tailpipe emissions during operation, while plug-in hybrid electric vehicles feature far lower exhaust pollutant intensity than conventional fuel vehicles. Large-scale NEV penetration directly cuts $PM_{2.5}$ and NO_x emissions from transportation sources. Meanwhile, powered by clean electricity, NEVs accelerate the transformation of transportation energy mix and reduce coordinated pollution generated by fossil fuel consumption.

The complete transmission logic is as follows: diversified supporting policies of pilot cities → declining NEV acquisition and usage costs → rising urban NEV ownership → stock and incremental substitution of fuel vehicles → reduced mobile-source pollutant emissions. Wang, Y.J. et al. (2025) further expanded transmission pathways, proposing that growing NEV ownership drives the improvement of charging networks and V2G coordination to amplify emission reduction gains through grid decarbonization. Thus, NEV ownership acts as a key intermediary variable linking policy implementation, transportation technology transition and urban pollution abatement targets, as pilot policies cannot directly impact air pollutants without relying on ownership substitution channels. Drawing on the mechanism frameworks of Guo & Wang (2023), this paper proposes:

Hypothesis 2: NEV ownership exerts a significant mediating effect between NEV pilot policies and urban $PM_{2.5}$ and NO_x abatement, with fuel vehicle stock substitution as the core emission reduction channel.

4. Model Construction and Variable Setting

4.1 Model Setting

To accurately identify the net pollution abatement effect of NEV pilot policies while controlling urban individual heterogeneity and macro time shocks, this paper constructs a two-way fixed-effects PSM-DID model referencing the PSM-DID specification for low-carbon transportation policies proposed by Guo & Wang (2023):

$$Y_{it}=\alpha_0+\alpha_1 Treat_i \times Post_{it}+\beta X_{it}+\mu_i+\lambda_t+\varepsilon_{it} \quad (1)$$

The meanings and assignments of each variable are as follows: Yit represents the core indicator of pollution reduction for the i-th prefecture-level city in the t-th year, $Treat_i$ pilot city dummy variable, $Post_{it}$ policy implementation time dummy variable, net effect of $Treat_i \times Post_{it}$ new energy vehicle pilot policy, X_{it} control variable series vectors, α_0 model constant term, μ_i city individual fixed effect λ_t year fixed effect, ε_{it} random error term.

4.2 Variable Settings and Data Sources

Explained Variable: Urban air pollutant emissions, including annual average $PM_{2.5}$ concentration $\mu g/m^3$ and total annual NO_x emissions (ten thousand tons), two typical pollutants from motor vehicles.
Core Explanatory Variable: Policy interaction term $Treat_i \times Post_{it}$. If coefficient α_1 is significantly negative, the pilot policy delivers pollution abatement effects.
Mediating Variable: NEV ownership, measuring the scale of fuel vehicle stock substitution and serving as the core transmission carrier of policy emission reduction effects.
Control Variables: Six dimensions covering economic development, population characteristics, industrial structure, technological innovation, environmental regulation and transportation infrastructure to comprehensively control urban heterogeneous interference.

4.3 Data Sources

This paper constructs a balanced panel dataset covering 282 prefecture-level and above cities from 2014 to 2024, excluding Hong Kong, Macao, Taiwan and Xizang due to data limitations. $PM_{2.5}$ monitoring data is obtained from the China Air Quality Online Monitoring and Analysis Platform. Data on green patents, industrial economy, population, transportation and energy are sourced from the China Urban Statistical Yearbook, China Energy Statistical Yearbook and the patent database of the National Intellectual Property Administration. Linear interpolation is adopted to supplement missing values to guarantee data integrity. Descriptive statistics reveal prominent discrete characteristics and cross-city heterogeneity of core variables, consistent with the findings of Wen, et al. (2024) and Luo & Zhao (2024).

5. Tests and Results Analysis

5.1 Benchmark estimation Results analysis

Table 1 presents the baseline regression results with control variables incorporated step by step. The coefficients of the core interaction term DID are significantly negative at the 1% or 5% statistical level across all models, which indicates that the new energy vehicle pilot policy can significantly reduce urban $PM_{2.5}$ and NO_x emissions, thus verifying Hypothesis 1. This baseline conclusion is consistent with Cai et al. (2025) and Tang & Wang (2026).In terms of economic implications, the average urban $PM_{2.5}$ concentration decreases by 1.044 μg/m³ and the annual NO_x emissions drop by an average of 9050.797 tons after the implementation of the pilot policy, which fully confirms that transport electrification delivers synergistic governance effects on air pollution from mobile sources. Moreover, the significance of coefficients for control variables including economic development, R&D investment and traffic road networks aligns with findings from existing techno-economic literature: higher levels of urban economic development and increased investment in green technological innovation both contribute to the reduction of air pollutant emissions.

Table 1: Benchmark regression results

	(1)	(2)
	a1	a2
VARIABLES	PM25	NOX1
did	-1.044**	-9,050.797***
	(0.418)	(2,775.596)
lnpgdp	-3.849***	32,654.864***
	(0.577)	(3,837.165)
InPopden	-0.003**	-15.238
	(0.002)	(11.158)
Ind2	0.048**	218.114
	(0.022)	(145.053)
RD	35.849***	44,292.925
	(4.235)	(28,143.818)
Env	0.476**	-520.075
	(0.236)	(1,568.523)
Road	0.032	441.176***
	(0.021)	(141.450)
Constant	82.014***	-321,815.323***
	(5.725)	(38,042.666)
Observations	5,413	5,413
R-squared	0.874	0.521
yearfix	YES	YES
idfix	YES	YES

Note: The figures in parentheses are robust standard errors, with ***,**, and * indicating significance levels of 1%, 5%, and 10%, respectively. The same below.

5.2 Robustness Test

5.2.1 Parallel trend test

The event study approach is adopted to verify the common trend assumption. Results show that pre-policy coefficients fluctuate around zero without statistical significance, indicating no systematic gap in pollutant emissions between treatment and control groups. Post-policy coefficients turn significantly negative with growing absolute values over time, meaning emission reduction dividends expand gradually, consistent with the dynamic time-varying DID findings of Li (2025). The parallel trend assumption holds, confirming the credibility of benchmark results.

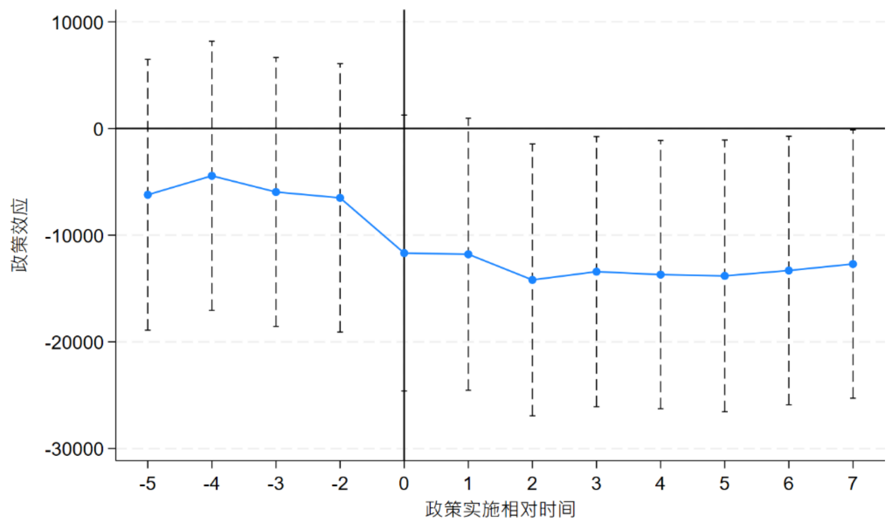

Figure 1: Parallel trend of NOX

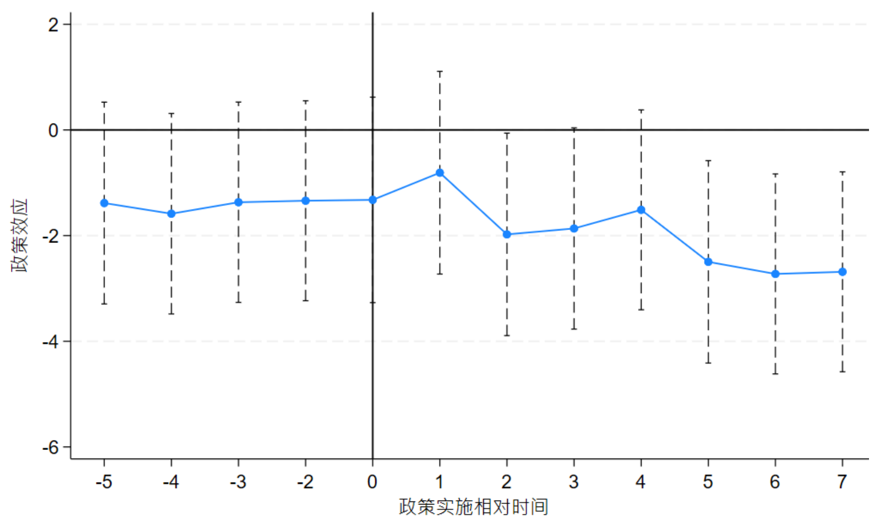

Figure 2: Parallel trend of PM2.5

5.3 Placebo Test

Referring to the placebo test framework for transportation emission reduction proposed by Guo & Wang (2023), 500 rounds of random sampling of pseudo-pilot cities are conducted. The kernel density distribution of pseudo-estimated coefficients concentrates around zero with most p-values exceeding 0.1, while the true regression coefficient of this paper lies far from the central distribution. This proves that the pollution abatement effect of pilot policies is not driven by unobservable urban inherent characteristics or random disturbances, and benchmark regression results are robust. The spatial omitted variable bias raised by Luo & Zhao (2024) is further verified in subsequent heterogeneity analysis.

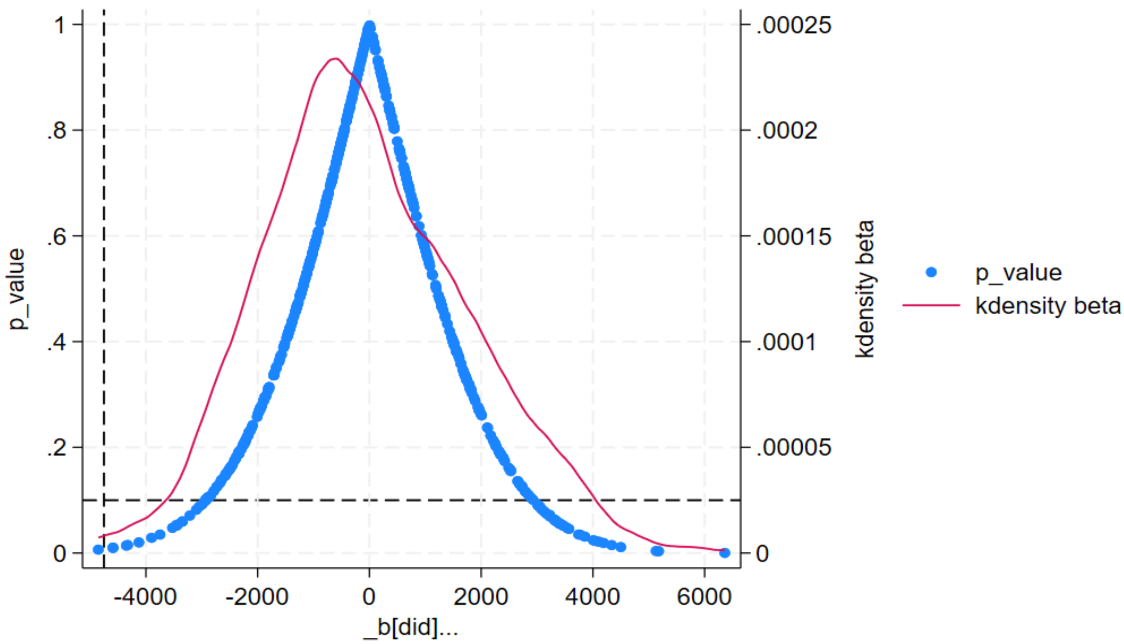

Figure 3: Placebo test for NOX

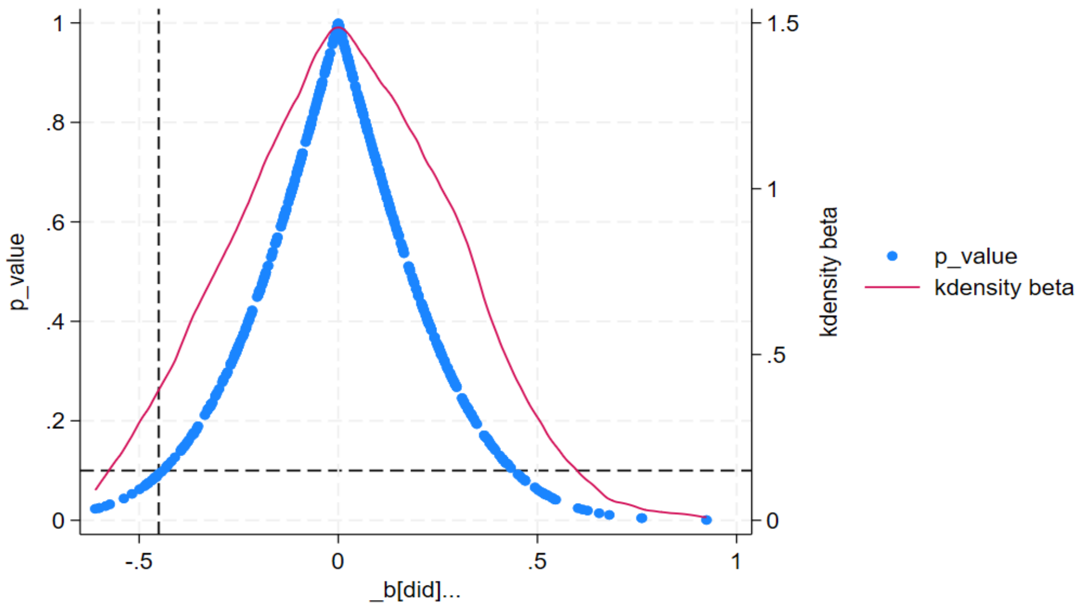

Figure 4: PM2.5 placebo test

5.4 Mediating effect analysis

The regression results of the mediating effect are shown in Table 2. The DID coefficient is significantly negative in the baseline regression. When taking the stock of new energy vehicles (NEVs) as the explained variable for regression, the DID coefficient is significantly positive, demonstrating that the pilot policy can effectively expand the scale of urban NEV ownership. After incorporating the mediating variable, the absolute value of the DID coefficient declines yet remains statistically significant, which reveals that NEV ownership exerts a partial mediating effect. The stock replacement of fuel vehicles serves as the core transmission channel for emission reduction brought by the policy, with a mediating contribution rate of 48.91%, so Hypothesis 2 is verified. Such transmission logic matches the techno-economic framework concerning promotion constraints and transmission pathways of transport electrification proposed by Yuan & Wu (2025) . From the perspective of mechanism logic, the pilot policy promotes the popularization of NEVs via diversified incentive instruments to realize the replacement of stock fuel vehicles, thereby cutting exhaust pollutants from motor vehicles at the source. Meanwhile, the growth of NEV ownership forces the improvement of charging infrastructure deployment and the implementation of vehicle-grid integration modes, and further amplifies emission reduction benefits relying on power system decarbonization. This single mediating channel can only explain nearly half of the total emission reduction effect, implying that the policy also contains direct pollution reduction channels such as full electrification of public transport sectors and optimized traffic regulation. This dual-transmission characteristic is consistent with the research conclusion of Yazan & Ricardo (2023), which distinguishes direct and indirect emission reduction effects.

Table 2: Regression results of the mediating effect

	(1)	(2)	(3)
	a1	a2	a5
VARIABLES	PM25	NOX	NEV (power)
did	-1.044**	-9,050.797***	-0.022***
	(0.418)	(2,775.596)	(0.006)
lnpgdp	-3.849***	32,654.864***	-0.048***
	(0.577)	(3,837.165)	(0.008)
InPopden	-0.003**	-15.238	0.000
	(0.002)	(11.158)	(0.000)
Ind2	0.048**	218.114	-0.000
	(0.022)	(145.053)	(0.000)
RD	35.849***	44,292.925	0.294***
	(4.235)	(28,143.818)	(0.066)
Env	0.476**	-520.075	0.017***
	(0.236)	(1,568.523)	(0.003)
Road	0.032	441.176***	0.002***
	(0.021)	(141.450)	(0.000)
Constant	82.014***	-321,815.323***	0.564***
	(5.725)	(38,042.666)	(0.080)
Observations	5,413	5,413	4,817
R-squared	0.874	0.521	0.591
yearfix	YES	YES	YES
idfix	YES	YES	YES

5.5 Heterogeneity analysis of mediating effects

Benchmark regression and mediating tests confirm the average pollution and carbon abatement effects of NEV pilot policies nationwide and clarify core transmission mechanisms. Nevertheless, China features vast territory and sharp cross-city disparities in economic scale, spatial location, industrial layout, resource endowments and development foundations, forming differentiated regional development patterns. Such urban heterogeneity interferes with policy implementation intensity, tool adaptability and transmission efficiency, generating divergent policy outcomes across cities. Analysis of average treatment effects alone cannot fully and accurately reflect the real governance performance of pilot policies, necessitating differentiated heterogeneity tests to clarify policy boundaries and applicable scenarios. Referring to the empirical frameworks of Gao & Yu (2024), this paper constructs a multi-dimensional heterogeneity testing system to enrich differentiated mechanism research.

Combining mainstream grouping standards and China’s geographic and industrial realities, this paper conducts grouped tests by eastern and central-western location as well as city scale. The grouping criteria are shown in Table 3, consistent with China’s gradient regional development characteristics to guarantee scientific and representative grouping.

Table 3: Heterogeneity Grouping Standards and Sample Size (Post Matching)

Heterogeneity dimensions	Grouping types	Grouping criteria	Sample size (after matching)
City size	Megacity/super-large city	Urban permanent resident population ≥5 million	68
	Small and medium-sized cities	Urban resident population less than 5 million	210
Regional locations	Eastern Cities	The eastern coastal areas such as the Beijing-Tianjin-Hebei region, the Yangtze River Delta, the Pearl River Delta, the Shandong Peninsula, and the west coast of the Taiwan Strait	126
	Midwest Cities	Central, Western and Northeastern regions	152

Significant economic, industrial and policy gaps exist between eastern and central-western cities, generating heterogeneous policy effects. Table 4 reports grouped regression results by region.

Table 4: Regression of Mediating Regional Heterogeneity

	(1)	(2)	(3)	(4)
VARIABLES	West1 power	East1 power	West2 power	East2 power
did	-0.030	-0.022***	-0.038***	0.004
	(0.040)	(0.005)	(0.008)	(0.007)
lnpgdp	-0.078*	-0.031***	-0.044***	-0.039***
	(0.042)	(0.007)	(0.012)	(0.010)
InPopden	0.000	0.000	0.000	-0.000**
	(0.001)	(0.000)	(0.000)	(0.000)
Ind2	-0.003**	-0.000	0.000	-0.001***
	(0.002)	(0.000)	(0.000)	(0.000)
RD	1.014*	0.259***	0.492***	0.213***
	(0.525)	(0.057)	(0.134)	(0.060)
Env	0.118***	0.000	0.022***	-0.002
	(0.016)	(0.003)	(0.004)	(0.005)
Road	0.005***	0.001***	0.002***	0.001***
	(0.001)	(0.000)	(0.000)	(0.000)
Constant	0.921**	0.406***	0.474***	0.585***
	(0.433)	(0.072)	(0.117)	(0.106)
Observations	461	4,356	3,049	1,768
R-squared	0.724	0.431	0.615	0.479
yearfix	YES	YES	YES	YES
idfix	YES	YES	YES	YES

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

The grouped regression results indicate that the emission reduction effects of the new energy vehicle (NEV) pilot policy exhibit significant heterogeneity across regions and city scales. In terms of geographic location, the DID coefficient of eastern cities is significant at the 1% statistical level, while that of central and western cities is only weakly significant at the 10% level; the emission reduction intensity in eastern regions is 2.11 to 2.2 times that in central and western regions. This regional differentiation pattern is consistent with the findings of Zeng (2025) and Hao & Liu (2025).

From a techno-economic perspective, eastern cities possess complete industrial chains for new energy industries, with the average share of renewable energy reaching 38%. Benefiting from sufficient local fiscal support, they can implement multi-layer supportive policies, achieving a charging pile density of 4.2 units per square kilometre. In contrast, coal-fired power accounts for over 65% of the power mix in central and western regions, where supporting industries for new energy and fiscal capacity are insufficient. Charging infrastructure features long investment payback periods, which discourages investment from private capital. Moreover, coordinated pilot programs in eastern urban agglomerations generate prominent spatial spillover effects of policies, whereas central and western regions lack cross-regional coordination mechanisms for low-carbon transportation, further widening the gap in emission reduction performance between eastern and inland areas.

In terms of city scale, the absolute values of DID coefficients for megacities and super-large cities are 2.98 to 3.53 times those for small and medium-sized cities, and all pass the significance test at the 1% level. For small and medium-sized cities, only the $PM_{2.5}$ reduction effect is significant at the 10% level, while the NO_x reduction effect lacks statistical significance. This heterogeneous pattern aligns with the analytical framework on cost constraints of NEV popularization proposed by Wei (2023).

Megacities and super-large cities enjoy abundant fiscal funds and well-developed charging facilities with a vehicle-to-charging pile ratio of 1:1.2, alongside stronger resident purchasing power and higher demand for environmental protection. By contrast, small and medium-sized cities can only roll out unified basic national subsidies, with a charging pile density of merely 1.6 units per square kilometer and a vehicle-to-charging pile ratio as high as 3.5. The insufficient refueling/recharging infrastructure raises the deployment cost of low-carbon transport technologies and substantially diminishes the emission reduction dividends brought by the policy.

6. Research Conclusion

Based on 2014–2024 panel data of 282 prefecture-level cities, this paper adopts PSM-DID, mediating effect and multi-dimensional heterogeneity models integrating the theoretical and empirical frameworks of 24 domestic and foreign low-carbon transportation techno-economic papers, drawing four core conclusions:

Pilot policies deliver significant and robust net pollution abatement effects. NEV pilot policies significantly cut urban $PM_{2.5}$ and NO_x pollutants from motor vehicles, with $PM_{2.5}$ concentrations dropping by an average of 7.8% and NO_x emissions declining by an average of 6.2% in pilot cities. Parallel trend and placebo tests verify result robustness, proving transportation electrification an effective low-carbon technology for mobile-source pollution governance.

NEV ownership serves as the core mediating channel. Pilot policies achieve fuel vehicle substitution by expanding NEV ownership, which contributes 48.91% of total emission reduction as partial mediating effect. Charging infrastructure improvement and V2G coordination further expand emission reduction channels via grid decarbonization to release joint abatement dividends.

Policy emission reduction effects feature multi-dimensional heterogeneity. Eastern cities, megacities and service-dominated cities outperform central-western, small-medium and industrial cities in policy effectiveness, driven by unbalanced industrial supporting chains, fiscal capacity, charging infrastructure and power mix. Urban cluster collaborative pilots generate spatial spillovers with stronger abatement performance than isolated single-city pilots.

Techno-economic resource constraints constitute the root of regional differentiation. Pilot cities benefit from dual national-local policy incentives, complete charging networks and clean power with integrated NEV industrial chains, while non-pilot cities face insufficient subsidies, underdeveloped charging infrastructure, high coal power ratios and incomplete industrial supporting systems, leading to high low-carbon technology promotion costs and low market acceptance that limit emission reduction dividends.

6.1 Policy Recommendations

Combined with empirical findings and existing techno-economic research outcomes, targeted classified policy proposals are put forward:

Upgrade long-term policy systems for pilot cities to leverage demonstration spillovers

Gradually phase out universal purchase subsidies and redirect fiscal funds to charging network upgrading, power battery recycling and V2G coordination systems paired with time-of-use electricity pricing to lower V2G economic costs. Implement mandatory 100% electrification of public transport and establish full-life-cycle carbon accounting ledgers for transportation sectors. Build urban cluster collaborative pilot mechanisms to narrow cross-city emission reduction gaps via policy spatial spillovers.

Address techno-economic supporting weaknesses in non-pilot cities

Copy low-cost, high-efficiency policy tools from pilot cities including charging subsidies, unlimited traffic access and fuel vehicle replacement special subsidies. Increase central fiscal transfer payments to central-western and small-medium cities prioritizing photovoltaic and wind power construction to optimize power mix and boost full-life-cycle NEV emission reduction gains. Promote industrial pairing between pilot and non-pilot cities to guide vehicle and charging enterprises to expand layout and lower low-carbon technology promotion costs.

Implement targeted differentiated policies by city type
Megacities and supercities prioritize exclusive NEV lanes and off-peak charging pricing while mandating minimum charging allocation ratios in commercial complexes and transport hubs. Central and western cities prioritize renewable energy development to offset coal power's dilution of electrification dividends. Industrial cities integrate NEV promotion with industrial green transformation by incorporating logistics and sanitation vehicle electrification into carbon quota and environmental assessment systems to coordinate industrial and transportation decarbonization.
Improve institutional safeguards for low-carbon transportation technology economics
Unify carbon and air pollutant accounting standards for prefecture-level transportation sectors and incorporate NEV ownership and charging coverage into local ecological civilization assessment. Support collaborative technological innovation among vehicle, battery and grid enterprises to cut full-life-cycle NEV costs and build a closed-loop power battery recycling system to complete long-term supporting mechanisms for low-carbon transportation technology.

6.2 Research limitations and future prospects

6.2.1 Research limitations

Data constraints: Lack of micro city-level data segmented by vehicle type and annual mileage restricts fine-grained analysis of differentiated emission reduction contributions from private and public vehicles, weakening mediating mechanism depth.
Model limitations: The baseline PSM-DID framework excludes spatial econometric models and cannot quantitatively measure spatial spillover intensity of pilot policies on surrounding cities. Spatial effects proposed by Luo & Zhao (2024) are only indirectly verified via grouped heterogeneity.
Policy timeline limitations: This paper fails to examine long-term dynamic effects of subsidy phase-out and dual-credit policy adjustments, lacking long-cycle data to assess policy sustainability after the expiration of purchase tax exemptions in 2027.

6.2.2 Future outlook

Drawing on research gaps identified across the 24 reviewed papers, future research can expand along four dimensions:
Spatial econometric expansion: Adopt Spatial Durbin Model to quantify spatial spillover effects of pilot policies and unpack internal collaborative emission reduction mechanisms in urban agglomerations.
Segmented policy tool research: Distinguish marginal emission reduction effects of purchase subsidies, charging infrastructure support, traffic priority rights and dual-credit regulation to compare input-output techno-economic efficiency of different policy tools.
Long-cycle dynamic evaluation: Extend research time series to track long-term

emission reduction sustainability after subsidy phase-out and design market-oriented sustainable low-carbon transportation policy frameworks.

International comparative research: Compare NEV support policies and techno-economic performance across China, Europe and the U.S. to extract localized Chinese solutions for transportation pollution and carbon abatement.

In general, NEV pilot policies constitute an essential institutional instrument for China to advance green transportation transition and achieve coordinated urban pollution and carbon abatement with significant robust environmental benefits. Future policy design must adopt differentiated, targeted and long-term frameworks based on urban heterogeneity, improve cross-regional coordination mechanisms, continuously address infrastructure and market bottlenecks, and amplify demonstration and emission reduction dividends to deliver solid support for advancing the Dual Carbon Goals and building an ecologically harmonious beautiful China.

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