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LEVERAGING PRIVATE PARKING SPACE CHARGING PILE POLICIES TO BOOST PRIVATE CAR ELECTRIFICATION: AN ANALYSIS BETWEEN HONG KONG AND MACAO

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Abstract

To investigate the impact of policy interventions on electric vehicle (EV) promotion in high-density cities, this study utilizes data on newly registered private cars in Hong Kong and Macao from 2020 to 2024. Employing the Difference-in-Differences (DID) method to construct a quasi-experimental framework, it empirically analyzes the policy-driven mechanisms behind the disparity in EV penetration rates between the two regions. The research reveals that the gap in EV penetration rates between Hong Kong and Macao widened from 3.84 percentage points in 2020 to 49.54 percentage points in 2024. Hong Kong's penetration rate surged from 12.41% to 71.09%, while Macao's increased only modestly from 8.57% to 21.55%. The DID model validation indicates that, despite Macao offering greater tax exemptions for EVs, Hong Kong's charging infrastructure support policy, centered on the "EV-charging at Home Subsidy Scheme," generated a significant net policy effect of 33.68 percentage points (adjusted R^2 =0.917, $p<0.01$), which was key to the rapid increase in penetration. The study confirms that systematic policy intervention can break the bottleneck of transport decarbonization through a virtuous cycle of "policy support → charging facility proliferation → consumer demand activation." The conclusions provide references for Macao to optimize its policy orientation, which currently emphasizes purchase over usage, and offer practical experience regarding policy synergy and infrastructure development for the transport decarbonization pathways of high-density cities globally.

Keywords: EVs Penetration Rate; Policy Effect; Differences-in-Differences (DID); Hong Kong and Macao Regions; Charging Infrastructure

1. INTRODUCTION

Due to multiple factors such as rapid urban expansion, accelerated industrialization, and upgrading resident consumption demands, the number of motor vehicles has also grown rapidly, leading to a sharp increase in carbon dioxide emissions and their proportion (H. Wang et al., 2025). According to International Energy Agency (IEA) 2022 statistics, carbon dioxide emissions from road transport (i.e., cars and vans) were approximately 5.78 Gt, accounting for about 80% of global transport sector CO_2 emissions (IEA, 2023). However, with the global push for energy conservation, emission reduction, and the goals of "carbon peak" and "carbon neutrality," electric vehicles have emerged as an effective means to structurally slow CO_2 emissions in the transport sector (IEA, 2025). Furthermore, large-scale adoption of EVs can amplify carbon reduction effects, potentially bringing forward the timeline for achieving "carbon peak" (Tong et al., 2023). Nonetheless, increasing the number and proportion of EVs and enhancing consumer purchase willingness can be addressed through measures such as charging service infrastructure construction (Le & He, 2019) and fiscal subsidy policies (Z. Wang et al., 2017). In other words, the increase in EV share is highly dependent on policy intervention (Rahman et al., 2025).

As Special Administrative Regions of China, Hong Kong and Macao are geographically proximate and have similar levels of economic development. However, from 2020 to 2024, the proportion of EVs among newly registered private cars showed a significant disparity: Hong Kong's share soared from 12.41% to 71.09% (The Government of Hong Kong SAR Transport Department, 2024a), while Macao's increased only slowly from 8.57% to 21.55% (The Government of Macao SAR Statistics and Census Service, 2024). The gap widened from 3.84 to 49.54 percentage points. This divergence provides a natural "quasi-experimental" setting for assessing policy effects. Theoretically, existing research often focuses on policy effects within single regions, lacking cross-regional comparative analysis. This study, by employing the DID method, can enrich the methodological system for regional policy evaluation. Practically, clarifying the policy-driven mechanisms behind the EV penetration rate difference between Hong Kong and Macao can provide references for Macao to optimize its EV promotion policies and offer insights for transport decarbonization pathways in other high-density cities. Additionally, Hong Kong's successful experience as an international financial center holds exemplary value for similar global cities, while Macao's developmental bottlenecks can serve as a warning for policymakers to avoid "policy inefficiency traps."

2. EV DATA AND KEY POLICY CONTENT IN HONG KONG AND MACAO

The policies examined in this study are the primary promotion policies related to the research theme implemented by Hong Kong and Macao to foster EV market development. To ensure authenticity and validity, the relevant content is sourced from the official government websites of the Hong Kong SAR Government, the Macao SAR Government, and their subordinate departments.

The core data for this study consists of the annual number of newly registered private cars by type (EV, internal combustion engine vehicle) in Hong Kong and Macao from 2020 to 2024. Data for Hong Kong primarily comes from the "Vehicle Registration and Licensing" annual statistics (2020-2024) published by the Hong Kong SAR Transport Department. It includes the annual counts of newly registered private EVs (pure electric, excluding hybrid cars) and fuel-powered vehicles (petrol), verified via the Transport Department's official website. Data for Macao primarily comes from the Macao SAR Statistics and Census Service (also called “DSEC”), containing classification statistics of newly registered private cars by power type, verifiable through the DSEC website. The update frequency of these data is annual, with no missing data or the need for outlier treatment.

TABLE 1 - DATA ON NEWLY REGISTERED PRIVATE CARS, ELECTRIC VEHICLE PENETRATION RATES, AND KEY POLICY CONTENTS IN HONG KONG AND MACAO, FROM 2020 TO 2024

Region	Year	Fuel Vehicles	EVs	EV Penetration Rate	Policy Announcements and Key Policy Changes
Hong Kong	2020	32441	4595	12.41%	Sale of only zero-emission new vehicles from 2035; Introduction of the "EV-charging at Home Subsidy Scheme" totaling HK$3.5 billion, to "subsidize the installation of EV charging infrastructure in car parks of existing private residential buildings, facilitating EV owners to easily install chargers suited to their needs in their residential car parks"; Government allocation of HK$120 million for a three-year plan to gradually increase the number of chargers in government car parks to 1,800 by 2022, aiming for no fewer than 5,000 public chargers by 2025, with plans to double thereafter.
	2021	29724	9583	24.38%	
	2022	17683	19795	52.82%	
	2023	15628	28541	64.62%	Phasing out of free charging at government car parks from end-2023, with fees levied by relevant operators to encourage market participation in charging services.
	2024	13503	33206	71.09%	
Macao	2020	5028	471	8.57%	Formulation of the *Application Guidelines for Installing EV Charging Facilities in Private Building Car Parks*, with ongoing coordination with relevant departments and the power company to optimize the application process and guidelines for installing private charging facilities.
	2021	5454	807	12.89%	
	2022	4044	1231	23.34%	Implementation of fees for public charging piles from July 28, 2022, as stipulated by Administrative Regulation No. 25/2022 *Electricity Supply Public Service Tariff System*, ceasing free charging services for residents.
	2023	5507	1343	19.61%	100% sale of zero-emission new vehicles by 2035; Newly built private and commercial building car parks must reserve charging power capacity and infrastructure for all parking spaces; all parking spaces in newly built public buildings must have such provisions; The government to add over 4,000 parking spaces capable of installing charging equipment in newly built public car parks before 2030.
	2024	7352	2020	21.55%	

Source: (Macao SAR DSPA, n.d.), (Macao SAR DSPA, 2020), (Macao SAR DSPA, 2023), (The Government of Macao SAR Statistics and Census Service, 2024), (The Government of Hong Kong SAR Environment Bureau, 2021), (The Government of Hong Kong SAR Transport Department, 2024a), (The Government of the Hong Kong SAR Environmental Protection Department, 2022), (The Government of the Hong Kong SAR Environmental Protection Department, n.d.)

To ensure comparability, the aforementioned data underwent preprocessing: 1) During data cleaning, statistical calibers were unified (including only private-use small passenger cars, excluding commercial vehicles, government vehicles, etc.) to ensure consistency between Hong Kong and Macao; 2) Data was checked for anomalies to prevent impact on analysis; 3) Core variables were constructed. The core variable in this study is the EV penetration rate (EV_{it}). This indicator describes the proportion of EVs in the newly registered private car market, reasonably reflecting the preference for EVs among residents in Hong Kong and Macao when purchasing new private cars under government policy influence, while avoiding distortion from differences in absolute private car registration numbers due to population disparities. The calculation is shown in Formula 1.

EV penetration rate: $EV_{it} = \frac{Number\ of\ newly\ registered\ EVs\ in\ the\ year}{Total\ number\ of\ newly\ registered\ private\ cars\ in\ the\ year} \times 100\%$ (Formula 1)

The collated core data is shown in Table 1, including annual counts of EVs, fuel vehicles, penetration rates, and key policy content for both regions.

Regarding policies, in addition to the content shown in the table above, both Hong Kong and Macao have implemented varying degrees of tax exemption policies during the EV purchase process. For instance, Macao has fully exempted EVs from the Motor Vehicle Tax since the enactment of Law No. 5/2002 *Motor Vehicle Tax Regulations* in 2002 (Macao SAR DSPA, 2023). In contrast, Hong Kong adopts a more conservative approach to the First Registration Tax (FRT) concession for EVs. The general concession cap for electric private cars is only HK$97,500, adjusted down to HK$58,500 effective April 1, 2024 (The Government of Hong Kong SAR Transport Department, 2024b). In additional, the Hong Kong Government launched the "One-for-One Replacement" Scheme in 2018, which falls outside the study period. Under this scheme, residents could trade in their old private cars that had been owned for more than 18 months and first registered for over 6 years, and deduct up to HK$287,500 from the First Registration Tax (FRT) of a new EV (Smart Hong Kong, n.d.).

The EV policies of the two regions exhibit characteristics of "respective strengths and weaknesses, differentiated focus." Macao's policies promoting EV consumption mainly focus on purchase tax exemption, addressing only the "difficulty of purchase" for consumers without providing efficient solutions for the "difficulty of charging" in daily use. Furthermore, as seen in Figure 2, under the dual impact of "public charging fees" and the "lack of private charging facilities" around mid-2022, Macao's EV penetration rate slightly declined in 2023, reflecting insufficient consumer confidence in EV purchases. Hong Kong, however, focuses its policy tools on resolving residents' charging difficulties, particularly highlighting support for private charging piles. The EV-charging at Home Subsidy Scheme lowers the threshold for installing private charging piles, effectively addressing the anxiety of "nowhere to charge." Even though Hong Kong also phased out free charging at government public charging piles by the end of 2023, the steady growth rate of EVs in Hong Kong, as shown in Figure 1, indicates that Hong Kong consumers remain willing to purchase EVs. Meanwhile, "One-for-One Replacement" Scheme serves as

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a supplement to the FRT exemption for EVs; however, Hong Kong’s overall tax incentives are still less comprehensive than Macao’s full tax exemption policy for EVs. Nevertheless, Hong Kong’s EV penetration rate is far higher than that of Macao. This phenomenon clearly indicates that the EV charging facilitation scheme is the "core driver" rather than an auxiliary measure, and the charging infrastructure policy is more effective.Thus, a preliminary conclusion can be drawn: Hong Kong's support for private charging piles has evolved from a supporting measure to a core lever for leveraging transport electrification.

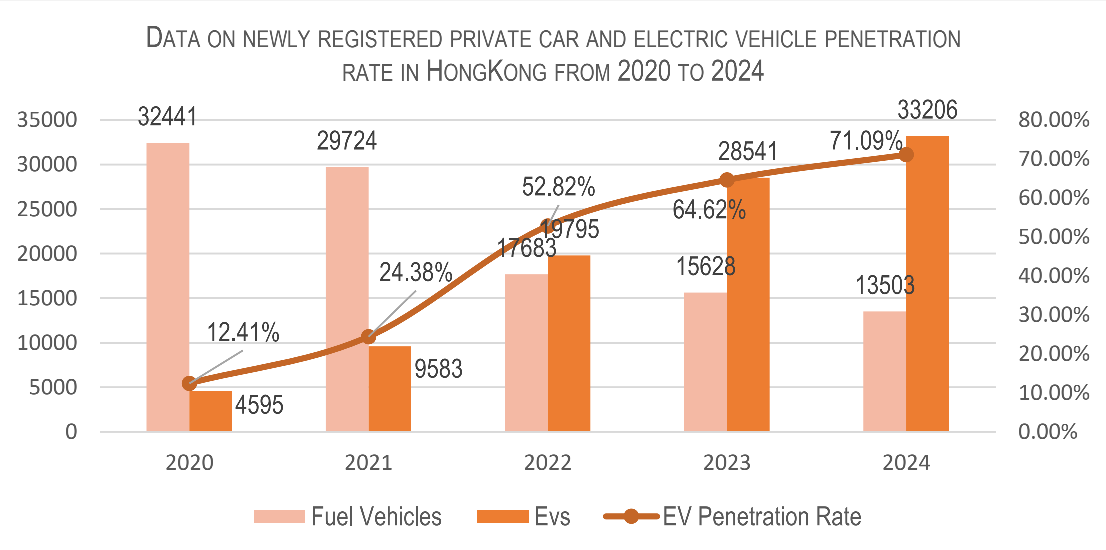

FIGURE 1 - DATA ON NEWLY REGISTERED PRIVATE CAR AND ELECTRIC VEHICLE PENETRATION RATE IN HONGKONG FROM 2020 TO 2024

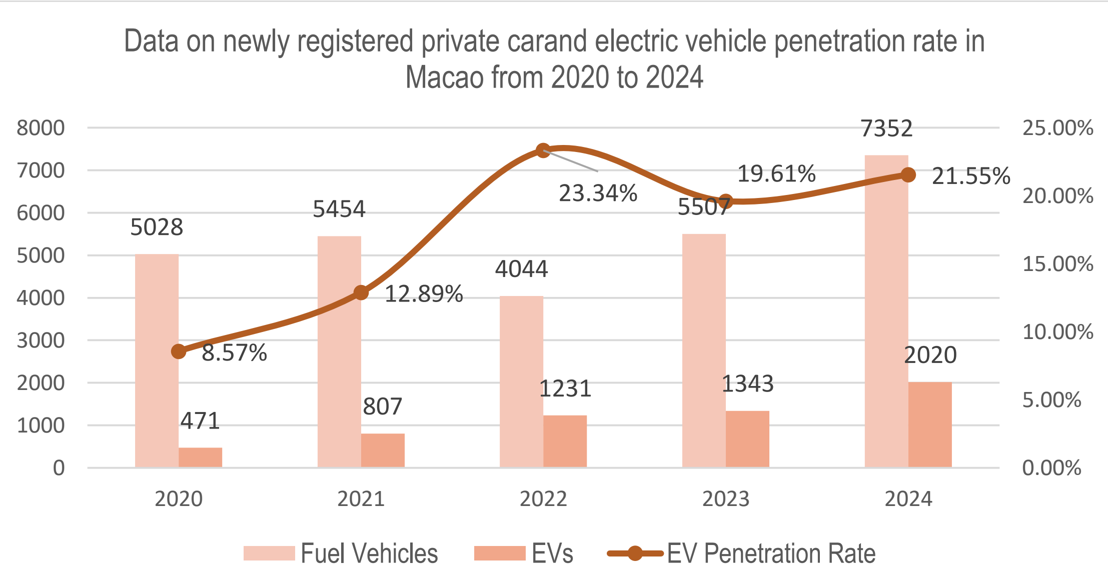

FIGURE 2 - DATA ON NEWLY REGISTERED PRIVATE CAR AND ELECTRIC VEHICLE PENETRATION RATE IN MACAO FROM 2020 TO 2024

3. DATA PROCESSING AND ANALYSIS METHODS

3.1. Data Processing

As shown by the data in Table 2, the panel data for this study comprises 10 observations (N=2 regions, T=5 years). The descriptive statistics of the core variables after collation are shown. The table indicates that the mean EV penetration rate in Hong Kong (45.06%) is significantly higher than in Macao (17.19%). Moreover, the standard deviation for Hong Kong (25.56) is much larger than for Macao (6.24), suggesting faster growth and greater fluctuation in Hong Kong's EV penetration rate. This preliminarily implies a potential impact from policy interventions by the Hong Kong SAR Government regarding EV tax incentives and charging infrastructure construction.

TABLE 2 - DESCRIPTIVE STATISTICS OF CORE VARIABLES

	Obs. Count	Mean	Std. Dev.	Min	Max
HK EV Penetration Rate	5	45.06%	25.56	12.41%	71.09%
Macao EV Penetration Rate	5	17.19%	6.24	8.57%	21.55%

Source: Own processing

3.2. Analysis Methods

The Difference-in-Differences (DID) method is an important quasi-experimental (also termed "natural experiment") research approach, whose development reflects significant progress in econometrics within the field of policy evaluation. The theoretical framework of DID was primarily established in the 1990s. A 1994 paper by Card and Krueger on the impact of minimum wage policy in New Jersey is regarded as a pioneering application of the DID method. By comparing employment changes in the fast-food industry in New Jersey and Pennsylvania before and after policy implementation, it effectively addressed selection bias in policy evaluation (Card & Krueger, 1994). With the widespread application of DID, scholars have continuously expanded its theoretical boundaries and application scope. For instance, in public health, DID has been used to evaluate the effects of new medical guidelines or vaccination campaigns (Wing et al., 2018); in environmental economics, DID helps policymakers assess the effects of pollution, energy consumption, and climate policies using observational data (Hornbeck, 2012); in social policy evaluation in China, scholars began using DID to study rural tax reform (Zhou & Chen, 2005) and later examined whether rural credit cooperatives increased support for farmers (Zhao & Sun, 2010).

The basic DID model for this study is specified as follows:

$$EV_{it} = \beta_0 + \beta_1 \times Treated + \beta_2 \times Time + \beta_3 \times (Treated \times Time) + \varepsilon$$

Where:

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- Treatment group dummy ($Treated$): Indicates whether an individual (region) is affected by the policy. In this study, 0 represents Macao SAR (the group not implementing strong EV promotion policies), and 1 represents Hong Kong SAR (the group implementing strong EV promotion policies).
- Time dummy ($Time$): Indicates before or after policy implementation. In this study, 0 represents the pre-policy period (2020-2021), and 1 represents the post-policy period (2022-2024).
- Interaction term ($Treated \times Time$): This variable measures the net policy effect. In this study, it equals 1 only when both conditions "Hong Kong region" AND "2022-2024" are satisfied, and 0 otherwise.

To ensure the validity of the DID model, three key assumptions must be identified and established:

1. Parallel Trends Assumption: Before policy implementation, the EV penetration rates of the treatment group (Hong Kong) and the control group (Macao) followed similar trends. That is, in the absence of policy intervention, the difference in penetration rates between the two regions would have remained stable.
2. No Spillover Effects: Limited by the requirements for new private car registration in both regions and the fact that Hong Kong's EV policies implemented from 2022 onwards are restricted to Hong Kong, these policies should not affect Macao's EV market (i.e., Macao residents would not purchase EVs across the border due to Hong Kong's policies).
3. No Other Confounding Policies: During the 2020-2024 period, aside from Hong Kong's "EV-charging at Home Subsidy Scheme," there were no other significant policies in either region (such as fuel vehicle purchase restrictions, carbon taxes) that would substantially affect EV penetration rates.

Among these assumptions, the parallel trends assumption is the core prerequisite for the DID model (Y. Yu & Zhang, 2017). In this study, limited by the small number of interaction terms for the treatment group dummy $Treated$ (only 5 observations), a "time trend graph" approach was adopted to test for parallel trends. This method, used in studies examining the impact of purchase restrictions on technological innovation and the impact of industrial policy on corporate technological innovation (M. Yu et al., 2016), involves plotting the mean of y over time for treatment and control groups. It is simple and intuitive, allowing judgment on whether significant differences exist between groups via visual inspection. For this study, the annual growth rates and differences in EV penetration rates for the two regions during the pre-policy years (2020-2021) were calculated, as shown in Table 3. In the two pre-policy years, Hong Kong's penetration rate increased from 12.41% to 18.63%, a growth of 6.22%; Macao's increased from 8.57% to 10.25%, a growth of 1.68%. The difference in growth rates was 4.54%, with no significant fluctuation (the difference in penetration rates was 3.84% in 2020 and 8.38% in 2021, primarily due to base effects, with the growth rate difference stable). Furthermore, in Figure 3, the vertical dashed line marks the 2022 policy node. While Hong Kong’s EV-charging at Home Subsidy Scheme was launched in 2020, it was not until 2021－2022 that it entered a period of large-scale implementation; meanwhile, data in Table 1 shows a significant jump in Hong Kong’s EV penetration rate in 2022 (from 24.38% to 52.82%), which serves as a key node of structural change. Furthermore, although Hong Kong had other relevant policies in place during the same period, the charging infrastructure support policy was the most prominent differentiated policy around 2022.

Before the policy (2020-2021), the slopes of the two trend lines were similar (Hong Kong slope: 5.99, Macao slope: 2.16), showing stable trends. After the policy (2022-2024), Hong Kong's trend line became significantly steeper (slope: 15.57), while Macao's remained gentle (slope: 2.89), providing visual verification that the parallel trends assumption holds.

TABLE 3 - COMPARISON OF EV PENETRATION RATE TRENDS IN THE TWO REGIONS PRE-POLICY (2020-2021)

Year	HK Penet (%)	Macao Penet. (%)	HK Growth (%)	Macao Growth (%)	Growth Diff. (%)	Penet. Diff. (%)
2020	12.41	8.57	-	-	-	3.84
2021	24.38	12.89	11.97	4.32	7.65	11.49

Source: Own processing

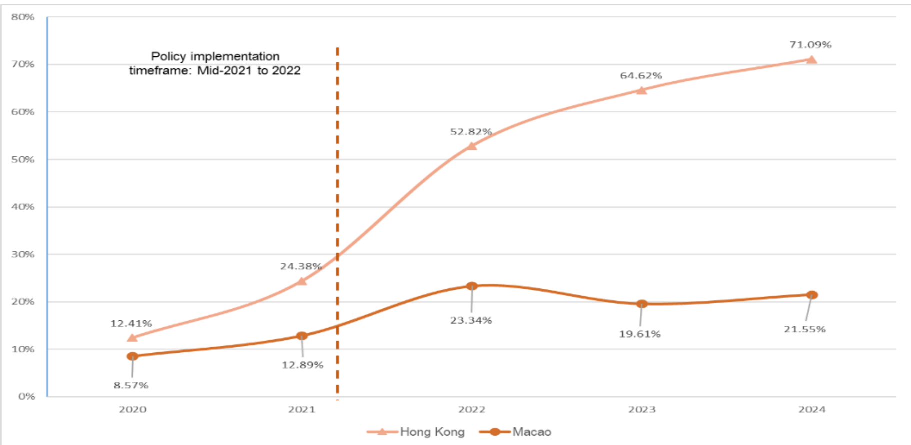

FIGURE 3 - PARALLEL TRENDS TEST OF NEWLY REGISTERED EV PENETRATION RATE IN HONG KONG AND MACAO FROM 2020 TO 2024

To ensure the robustness of the research findings, a benchmark regression analysis was conducted, employing the Ordinary Least Squares (OLS) method to estimate the core model. By isolating region fixed effects ($Treated$), time fixed effects ($Time$), and their interaction term ($Treated \times Time$), the net policy effect can be precisely identified. Concurrently, the benchmark regression helps disentangle common trend disturbances unrelated to the specific policy—such as technological advancement and shifts in market demand—thereby allowing the analysis to focus exclusively on the distinct impact of Hong Kong's private charging pile policy on vehicle structure transformation. The core coefficients derived from this regression provide a direct quantitative basis for assessing the policy effect. Furthermore, the goodness-of-fit and significance test results of the benchmark regression serve to validate the rationality of the model specification, thereby laying a solid foundation for the reliability of the study's conclusions.

TABLE 4 - BENCHMARK REGRESSION ESTIMATION RESULTS OF THE DID MODEL FOR EV SHARE IN HONG KONG AND MACAO

OLS Regression Results		
	Coefficient	**95% CI**
Constant	0.107 （-2.307）	-0.007 ~ 0.221
Treated	0.077 （-1.165）	-0.084 ~ 0.238
Time	0.108 （-1.794）	-0.039 ~ 0.255
Treated*Time	0.337** （-3.966）	0.129 ~ 0.545
Observations	10	
R2	0.945	
Adjusted R2	0.917	
F-statistic	F (3,6)=34.305,p=0.000	

Note: Dependent Variable = EV Penetration Rate
*p<0.05 **p<0.01

Source: Own processing

As shown in Table 4, the benchmark regression analysis yields an adjusted R^2 of 0.917, and the F-statistic is 34.305, significant at the 1% level, indicating strong overall explanatory power and statistical reliability of the model. The regression coefficient for the core explanatory variable, the interaction term (Treated*Time), is 0.337. This implies that after policy implementation in Hong Kong, its EV share increased significantly by 33.68 percentage points compared to the control group (Macao). The net policy effect is significant and economically meaningful. In summary, the benchmark regression results preliminarily verify the positive effect of Hong Kong's private charging pile subsidy policy on enhancing EV market penetration.

4. CONCLUSION AND IMPLICATIONS

4.1. Conclusion

Based on data of newly registered private cars in Hong Kong and Macao from 2020 to 2024, this study empirically examines the impact of policy intervention on EV penetration rates using the DID method. The results indicate that policy intervention is the core driving factor behind the observed disparity. Specifically, Hong Kong's subsidy policy for private charging piles (the "EV-charging at Home Subsidy Scheme"), compared to Macao's approach, was the key factor in Hong Kong's rapid increase in EV penetration. This policy fostered a virtuous cycle of "policy support → charging pile proliferation → alleviation of charging difficulties → growth in new energy vehicle consumption," systematically addressing charging convenience and directly promoting the rapid development of the EV market. Simultaneously, validated by the DID model, the net policy effect led to a significant increase of 33.68 percentage points in Hong Kong's EV penetration rate compared to Macao. The model's goodness-of-fit (adjusted R^2=0.917) and parallel trends test results indicate strong statistical reliability of the conclusions, confirming the crucial role of systematic policy intervention in transport decarbonization for high-density cities.

This study acknowledges the following limitations: (1) The limited sample size (with only data from 2 regions over 5 years) imposes certain constraints on statistical power; (2) The Difference-in-Differences (DID) method assumes the exogeneity of the policy shock, yet there may be other confounding factors in practice; (3) This research focuses on the correlational rather than strictly causal inferences regarding policy effects. Future studies could extend to more cities and longer time periods, and adopt more sophisticated causal identification methods to enhance the robustness of the conclusions.

4.2. Implications

Policy Optimization Direction for Macao: Macao must transcend the current policy limitation of “emphasizing purchase over usage” by addressing the gaps in charging infrastructure. Drawing on Hong Kong’s “EV-charging at Home Subsidy Scheme,” a dedicated subsidy program should be established for installing private charging piles in existing private residential parking spaces. This subsidy should cover core costs such as engineering design, equipment procurement, and construction installation, thereby lowering the barrier for residents. For newly constructed private and commercial buildings, alongside mandatory requirements for reserving charging power capacity and infrastructure, construction subsidies should be provided to developers to promote the synchronous planning, construction, and delivery of charging facilities along with the buildings. Meanwhile, approval procedures should be streamlined with clearly defined timelines, and application guidelines, fee standards, and progress inquiry channels should be made publicly accessible to address the pain points of “difficult application and cumbersome procedures.” Furthermore, a core indicator monitoring mechanism for EV promotion should be established to regularly track data on EV ownership and penetration rate changes, charging pile utilization rates, and resident charging satisfaction, with annual policy evaluation reports compiled. In response to the decline in the penetration rate in 2023, in-depth investigations into consumer pain points—such as charging wait

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times, equipment failure rates, and fee reasonableness—should be conducted to dynamically refine policy details, ensuring that policies remain aligned with actual needs.

General Lessons for Transport Decarbonization in High-Density Cities: As representative high-density cities characterized by scarce spatial resources and concentrated transport carbon emissions, Hong Kong and Macao's developmental differences offer important references for similar cities that must reconcile spatial constraints with emission reduction demands through policy synergy. On one hand, policy coordination is crucial, requiring cross-departmental collaboration among environmental, transport, fiscal, and energy authorities to form a systematic intervention within a statutory framework. On the other hand, both demand-side and supply-side measures must be balanced. Activating consumer demand through fiscal subsidies for infrastructure construction, expanding the coverage of public charging networks, and stimulating the private charging pile market can collectively foster a "high-density, wide-coverage" charging ecosystem, thereby avoiding the trap of policy inefficacy.

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