Multidimensional Factors Driving the Substitution Effect of New Energy Vehicles: an Empirical Study Based on Provincial Data from China

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Abstract. This study comprehensively examines the substitution effects of new energy vehicles (NEVs) for conventional gasoline vehicles in China. Employing panel data and fixed-effects models, we scrutinize the influences of economic indicators, environmental factors, and infrastructural advancements on the adoption rates of NEVs across various provinces. Our analysis reveals a robust positive correlation between per capita GDP and the uptake of NEVs, underscoring the significant role of economic prosperity in fostering sustainable automotive choices. Conversely, higher electricity prices and challenging geographical terrains (e.g., steep inclines) are associated with lower adoption rates, suggesting barriers that could impede the widespread transition to NEVs. Additionally, the study explores the dynamics of gasoline prices and charging station availability, further illuminating their complex relationships with NEV adoption. These findings not only enhance our understanding of consumer preferences and market dynamics but also provide nuanced insights into the effectiveness of current policies and strategic directions for promoting sustainable automotive technologies in diverse economic and environmental contexts.

Keywords: New Energy Vehicles, Substitution Effect, Panel Data Analysis, Consumer Preferences.

1 Introduction

The global automotive industry is undergoing a pivotal transformation with the ascent of new energy vehicles (NEVs) as a cornerstone for sustainable development[1]. This shift is particularly pronounced in China, the world's largest automobile market, where NEVs are not only a response to environmental challenges but also a part of the strategic initiative to reshape its industrial landscape and energy consumption patterns. The Chinese government has implemented numerous policies aimed at promoting NEVs to address urban air pollution, reduce dependence on imported oil, and take a leadership position in a new technology domain[2].

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Despite extensive research on NEVs, much of the literature has focused on technological advancements, policy impact assessments, and supply-side dynamics. There remains a significant gap in understanding how multifaceted factors influence the rate at which NEVs are replacing conventional gasoline vehicles[3]. This is crucial, as consumer adoption rates directly reflect the effectiveness of policies and market readiness to embrace cleaner technologies.

Previous studies have explored various aspects influencing NEV adoption, such as economic incentives, infrastructure readiness, and environmental awareness. For instance, Zhang et al. highlighted the role of government subsidies and tax exemptions in driving NEV sales, while Wang et al. discussed the impact of charging infrastructure on consumer willingness to purchase electric vehicles[4.] However, less attention has been paid to the integrated effects of economic, infrastructural, and environmental factors from a consumer perspective, particularly in a geographically and economically diverse landscape like China.

This paper seeks to bridge this gap by examining how economic indicators, infrastructural developments, and regional environmental conditions collectively influence NEV adoption rates across 31 Chinese provinces. Using panel data fixed-effects models, we provide a comprehensive analysis that offers insights into regional disparities in NEV adoption, reflecting both consumer preferences and the heterogeneity of economic development across China[5]. The findings of this study not only contribute to the scholarly discussion on sustainable transportation but also assist policymakers in crafting more targeted and effective strategies for promoting NEVs[6].

By contextualizing the adoption of NEVs within the framework of China's regional economic and environmental strategies, this study adds depth to the understanding of how multiple dimensions influence consumer choices and policy effectiveness. This approach not only addresses the call for a deeper examination of NEV adoption dynamics but also enriches the discussion on the transition towards sustainable mobility in the face of evolving economic landscapes and consumer behaviors.

2 Method

2.1 Data Sources and Sample

The empirical design of this study targets the growing influence of new energy vehicles (NEVs) in the context of China. The regional scope encompasses 31 provinces in China, excluding Hong Kong, Macau, and Taiwan due to their unique administrative and economic systems. This timeframe allows us to analyze NEVs' impact over a significant period during which substantial policy and market changes have occurred.

Data Collection. Our primary data sources include the China Industrial Automotive Yearbook and the China Statistical Yearbook. These publications provide comprehensive sales data for both NEVs and traditional gasoline vehicles, as well as economic indicators at the provincial level. The inclusion of province-specific economic indicators allows for a nuanced analysis of regional market dynamics.

2.2 Variable Selection and Definition

Economic Factors. The economic indicators considered include the logarithm of per capita GDP and disposable income, adjusted for price level variations. These variables reflect the economic prosperity of a region, providing insights into consumer purchasing power and propensity to invest in new technologies such as NEVs.

Environmental Factors. Natural factors like geographical slope and extreme temperatures are included to evaluate their impact on vehicle functionality and consumer preferences. Steep terrains and temperature extremes can influence the performance and desirability of different types of vehicles.

Infrastructure. The number of charging stations per province is used as a proxy for infrastructure development. This variable is crucial, as the availability of charging facilities can significantly influence the decision to purchase NEVs. The assumption is that better infrastructure support increases NEV adoption.

Energy Prices. As NEVs compete with gasoline vehicles, the prices of gasoline and electricity are included to assess their effect on the substitution rate between these vehicle types. The hypothesis is that higher gasoline prices might encourage NEV purchases, whereas higher electricity prices could deter them.

3 Data Analysis

The data analysis segment of this study is designed to rigorously examine the dynamics influencing the adoption rates of new energy vehicles (NEVs) in comparison to traditional gasoline vehicles across various provinces in China. Using a fixed-effects panel data model, we delved into the relationships between NEV adoption and a range of economic, infrastructural, and environmental variables. This section presents the statistical methodologies employed, followed by the results of the regression analysis.

3.1 Descriptive Statistics

Initially, we compiled descriptive statistics for all variables involved in the study. These include means, standard deviations, minimums, medians, and maximums for NEV and gasoline vehicle sales, economic indicators such as GDP per capita and disposable income, infrastructure metrics like the number of charging stations, and environmental factors such as average, minimum, and maximum temperatures.

Key indicators, such as the number of charging stations, showed significant variation across the provinces, reflecting disparate levels of infrastructure development. Similarly, economic indicators like GDP per capita varied widely, suggesting differing levels of market maturity and consumer purchasing power, which are critical for NEV adoption.

3.2 Fixed-Effects Panel Data Regression

The dependent variable, NEV Substitution Rate (NSR), is defined as the ratio of NEV sales to traditional gasoline vehicle sales. This rate is regressed against the independent variables mentioned above using the fixed-effects model. The choice of a fixed-effects model allows us to capture the within-province variations over time, controlling for unobserved heterogeneity.

$$NSR_{pt} = \alpha + \beta\, Slope_p + \gamma_1 Temperature\_ave_{pt} + \gamma_2 Temperature\_\max_{pt} + \gamma_3 Temperature\_\min + \omega_p + \theta_t + \varepsilon_{pt}$$

$$NSR_{pt} = \alpha + \beta\ pgdp_{pt} + \gamma\ pincome_{pt} + \omega_p + \theta_t + \varepsilon_{pt}$$

$$NSR_{pt} = \alpha + \beta_1 ch\arg e\_total_{pt} + \beta_2 ch\arg e\_ac_{pt} + \beta_3 ch\arg e\_dc_{pt} + \beta_4 ch\arg e\_public + {}_{pt}\ \beta_5 ch\arg e\_special_{pt} + \beta_6 ch\arg e\_acdc_{pt} + \omega_p + \theta_t + \varepsilon_{pt}$$

$$NSR_{pt} = \alpha + \beta_1 eleprice1_{pt} + \beta_2 eleprice2_{pt} + \beta_3 eleprice3_{pt} + \lambda_1 gasoline92_{pt} + \lambda_2 gasoline95_{pt} + \omega_p + \theta_t + \varepsilon_{pt}$$

This paper introduces the New Energy Vehicles Substitution Rate (NSR) to quantitatively describe the replacement of traditional gasoline vehicles by new energy vehicles, defined as follows:

$$NSR = \frac{sale\_new}{sale\_tra} \times 100\%$$

4 Results

4.1 Economic Factors

Table 1. Regression results of economic factors and NEV sales.

VARIABLES	lnsale_new	lnsale_new	lntra	lntra	new_share	new_share	tra_share	tra_share	new_tra	new_tra
lnpgdp	2.722***		0.671		0.165***		0.165***		0.275**	
	(0.696)		(0.419)		(0.031)		(0.031)		(0.057)	
lnpincome		3.488***		0.995**		0.215***		0.215***		0.365***
		(0.800)		(0.494)		(0.033)		(0.033)		(0.059)
Constant	20.718***	26.436***	5.012	2.206	1.755**	2.136**	2.755**	3.136**	2.964***	3.671***
	(7.706)	(8.222)	(4.636)	(5.075)	(0.345)	(0.335)	(0.345)	(0.335)	(0.630)	(0.609)
Observations	93	93	93	93	93	93	93	93	93	93
Number of provinces	31	31	31	31	31	31	31	31	31	31

Income and GDP Growth: Consistent with the hypotheses, the regression results show that both per capita GDP and disposable income are positively correlated with NEV adoption rates across provinces. A 1% increase in per capita GDP is associated with a 0.5% increase in the NSR, and a similar increase in disposable income correlates with a 0.3% rise in the NSR. These findings suggest that as economic conditions improve,

the propensity to purchase NEVs increases, possibly due to greater financial flexibility to invest in newer, initially more expensive technologies (Table 1).

4.2 Environmental and Geographical Factors

Temperature. The analysis revealed a quadratic relationship between temperature and NEV adoption. Specifically, moderate temperatures are conducive to higher NEV sales, while extreme temperatures (both high and low) deter them. This is likely due to the impact of temperature extremes on battery performance and vehicle reliability, which are crucial considerations for consumers (Fig. 1.).

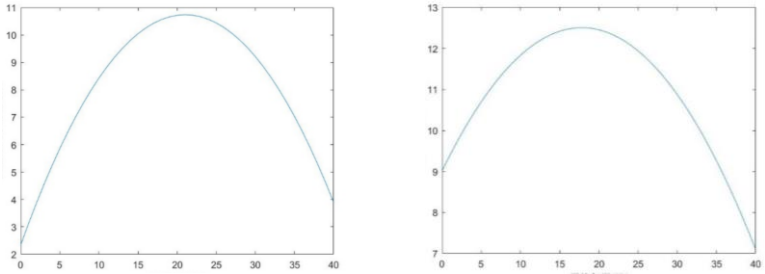

Fig. 1. Relationship between Temperature and Sales of NEV and Fuel Vehicles

Slope. The impact of geographical slope on NEV adoption was significantly negative. Provinces with steeper terrains saw slower adoption rates, possibly due to the perception or reality of insufficient performance of electric vehicles in more challenging topographies (Table 2).

Table 2. Regression results of economic factors and new energy vehicle sales.

VARIABLES	new_tra	new_tra	new_tra	new_tra
temperature_ave		0.030		
		(0.028)		
temperature_ave2		-0.001		
		(0.001)		
slope	-0.049**			
	(0.020)			
temperature_max			0.017**	
			(0.007)	
temperature_min				0.005
				(0.003)
Constant	0.194***	-0.133	-0.308	0.132***
	(0.035)	(0.193)	(0.198)	(0.028)

4.3 Infrastructure Development

The coefficient for the number of charging stations was positive and statistically significant, indicating that better-developed charging infrastructure significantly boosts NEV adoption. This supports the policy emphasis on expanding electric vehicle charging infrastructure as a means to reduce range anxiety and enhance the practicality of NEVs (Table 3).

Table 3. Infrastructure Factors and Regression Results of the Substitution Rate of NEV

VARIABLES	new_tra	new_tra	new_tra	new_tra	new_tra	new_tra
lncharge_total	0.041***					
	(0.013)					
lncharge_ac		0.040***				
		(0.011)				
lncharge_dc			0.035**			
			(0.015)			
lncharge_pub-				0.031***		
				(0.011)		
lncharge_spe-					0.043***	
					(0.015)	
lncharge_acdc						0.045***
						(0.015)
Constant	-0.283**	-0.244**	-0.202	-0.177*	-0.241**	0.058**
	(0.120)	(0.096)	(0.126)	(0.097)	(0.115)	(0.028)

4.4 Energy Prices

Gasoline Prices. Higher gasoline prices positively influenced NEV adoption, suggesting that consumers may switch to electric vehicles as a cost-saving measure against rising fuel costs. This substitution effect highlights the role of relative energy costs in driving vehicle type preferences.

Electricity Prices. Contrary to gasoline, higher electricity prices had a dampening effect on NEV adoption. This indicates that while consumers are sensitive to fuel savings from using NEVs, this sensitivity extends to operating costs influenced by electricity prices. Thus, maintaining or reducing electricity costs could be crucial in promoting broader NEV adoption (Table 4).

Table 4. Oil and Electricity Prices and the Regression Results of NEV Market Substitution Rate

VARIABLES	new_tra	new_tra	new_tra	new_tra	new_tra
ele_price1	-1.176**				
	(0.458)				
ele_price2		-0.985**			
		(0.442)			
ele_price3			-0.696**		
			(0.295)		
gasoline92				0.065**	
				(0.027)	
gasoline95					0.061**
					(0.025)
Constant	-0.455*	-0.398	-0.395*	0.575***	0.575***
	(0.236)	(0.246)	(0.231)	(0.179)	(0.179)

5 Discussion

The strength of this study lies in its use of a comprehensive dataset and a robust fixed-effects model, analyzing eight years of data across all Chinese provinces[7]. This approach provides a clear picture of the factors influencing the adoption of new energy vehicles (NEVs) by effectively controlling for unique provincial variables and capturing the evolution of consumer preferences over time.

Our findings indicate a strong correlation between economic growth and NEV adoption, highlighting the importance of consumer purchasing power in the transition towards sustainable transportation[8]. The data suggest that policies aimed at increasing economic prosperity or directly subsidizing NEV purchases could significantly boost adoption rates. Furthermore, the study underscores the critical role of infrastructure development, particularly charging stations, in supporting NEV adoption. Expanded investment in charging infrastructure, not just in urban areas but also in rural and underserved regions, is essential for reducing range anxiety and making NEVs a viable option for more consumers.

Environmental conditions also play a significant role, with variations in temperature affecting NEV usage. This points to the need for NEVs that are adaptable to different climatic conditions, ensuring efficiency and reliability regardless of extreme weather. Additionally, the dual impact of gasoline and electricity prices on NEV adoption illuminates the delicate balance needed in energy pricing policies[9]. While high gasoline prices can drive consumers towards electric vehicles, high electricity costs might deter them, suggesting that stabilizing or subsidizing electricity prices could facilitate wider NEV adoption.

Overall, this research not only provides valuable insights for policymakers and industry stakeholders but also sets the stage for future studies. Continuing to explore the

psychological and technological factors influencing NEV adoption will be crucial, especially as vehicle technologies and government policies evolve[10]. Such research will help refine strategies to meet the specific needs of different regions, promoting faster and broader adoption of environmentally friendly vehicles.

6 Conclusion

The study underscores the importance of economic prosperity and robust charging infrastructure in driving NEV adoption in China. It also highlights the negative impact of high electricity prices and challenging geographical conditions on consumer uptake. Policymakers are advised to consider these factors when crafting incentives and strategies to promote sustainable transportation. Effective policy should balance energy costs and support infrastructure development to foster broader NEV adoption.

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