The Impact of Public Charging Piles on Purchase of Pure Electric Vehicles

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Abstract. The spread of charging infrastructure is an important factor in consumer acceptance of electric vehicles. This study analyses the data in China, and the econometric method is used to construct a fixed effect model to explore the impact of public charging piles on the purchase of pure electric vehicles. What's more, the impact of different public charging piles on the purchase of pure electric vehicles for different purposes is further explored. The conclusions are as follows: With the increase of public charging piles, consumers' willingness to buy pure electric vehicles has increased significantly. Specifically, rental and leasing pure electric vehicles are more dependent on public charging piles than non-business pure electric vehicles; Alternating current piles have a significant role in promoting the purchase of pure electric vehicles for rental and leasing. Direct current piles are more important to non-business pure electric vehicles; The popularity of ordinary public charging piles has a greater impact on rental and leasing pure electric vehicles than that of specialized public charging piles, while the impact of the two types of charging piles on non-business pure electric vehicles is not much different.

Keywords. Charging infrastructure; Electric vehicles; Public charging piles; Charging technology

1 Introduction

Sustainable utilization of energy is one of the great challenges for the entire world. According to EIA, the average annual energy consumption of the plant will increase by about 40% over the next twenty-three years [1]. If we continue to rely on fossil fuels as the primary source, carbon dioxide (CO2) concentrations could reach a threshold of 450 ppm equivalent [2]. The popularization of EV is considered indispensable for reducing carbon emissions and air pollution in the global transportation sector, which slows down global climate change [3-4].

There are various factors that affect consumers' decisions to purchase EV, such as a variety of demand-driven policies [5-6] and other social factors [7-9]. The short range of EV is also one of the most critical barriers to the adoption. According to a few studies using actual sales data, until further technological breakthroughs in energy storage and high-power charging are

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achieved. Limitations in technical and contextual factors such as charging infrastructure are a deterrent to consumers' willingness to purchase electric vehicles [10]. The availability of charging infrastructure is an important factor in consumer acceptance of EV, adequate charging infrastructure should not be overlooked when promoting EV, especially in urban areas, where the establishment of a tight public charging network can lower the acceptance threshold for EVs [11-12]. In our real life, charging infrastructure can be roughly divided into charging piles, charging stations and battery swap stations. Charging pile are the facilities with both parking and charging functions, and the arrangement of charging pile which occupies a small area is flexible, so the charging pile is still the currently the most focused charging infrastructure, and it is also the electric energy replenishment method chosen by most car users. Charging piles can be categorized into public charging piles that provide public charging services to social vehicles and private charging piles that provide charging services to private users. There has been a significant amount of research showing that one of the potential barriers preventing consumers from purchasing EV is the lack of public charging infrastructure [13-14].

In summary, many researches and practice demonstrated the role of government incentive policies, different types of consumer preferences and other influencing factors in the popularization of EV, but most of them ignore the impacts of private or public charging infrastructure development on consumer’s purchase behaviours of EV. In addition, although some scholars have noted that the construction of public charging piles is an important means of popularizing EV, little literature has focused on the specific question of how public charging plies affect pure electric vehicles purchase. In recent years, under China's " dual-carbon" strategy, the new energy vehicle market has shown explosive growth, and as of June 2023, the number of pure electric vehicles has exceeded 12 million, accounting for 77.8% of the total number of new energy vehicles. Meanwhile, in terms of charging piles construction, in 2022, the number of charging infrastructures reached 5.2 million units, an increase of nearly 100% year-on-year. Among them, the public charging piles grows about 650 thousand, and the total number reaches 1.8 million units. In addition, it is impractical to install private charging piles in China because EV owners in China are currently concentrated in populated urban areas with predominantly multi-unit dwellings, which is completely different from the single dwelling living structure in Europe and the US, and there are not enough private parking areas for each household to install private charging piles [15]. It can be seen from the above data that EV have become the main driving force for the growth of China's new energy vehicle ownership, and public charging piles have a broad development prospect, which plays an important role in the popularization of EV in China.

Therefore, based on econometric theory, this paper focuses on the effects of public charging piles on the purchase of EV by incorporating the number of pure electric vehicles purchased and public charging piles, per capita disposable income, and other data into the fixed effect model. On this basis, this paper also divides public charging piles into alternating current piles (ACP) and direct current piles (DCP) according to charging technology, and ordinary public charging piles (OPCP) and specialized public charging piles (SPCP) according to service object for heterogeneity analysis, and further studies the impacts of different types of public charging piles on PEV purchase for different purposes (leasing or non-business EV). The rest of the paper is organized as follows. Section 2 describes the econometric model and data used in this study. Section 3 constructs a benchmark model to examine the impacts of public charging piles on the purchase of EV and discusses the empirical results. The final section provides conclusions in this study and suggestions for future research.

2 Methodology and data

2.1. Panel fixed effect model

The panel fixed effect model assumes that the variable y_{it} consists of a mean value and a random error term u_{it} as well as λ_i and γ_t into which the mean value can be expressed as a linear function of the independent variables x_{1it} , x_{2it} , … , x_{kit} . The general form is:

$$y_{it} = \lambda_i + \gamma_t + \beta_0 + \beta_1 x_{1it} + \beta_2 x_{2it} + ... + \beta_k x_{kit} + u_{it} \tag{1}$$

where β_0 , β_1 , … , β_k are called regression coefficients, λ_i is an individual fixed effect, γ_t is a time fixed effect. In addition, $E(u_{it}) = 0$, $Cov(u_{it}) = \sigma^2$.

2.2. Data sources and descriptive statistics

In this paper, the data of the key independent variable, that is, public charging pile number (PCP) comes from China Charging Union. And the time of the total public charging pile data is from January 2017 to November 2020, with a total of 47 time points, including 31 provinces and cities. In addition, the data about DCP, ACP, public piles, and public piles are limited by availability, so we choose the time of selection is from January 2017 to December 2019, with a total of 36 time points, which includes 31 provinces and cities. The key dependent variable in this paper, that is, the electric vehicle purchases (EVP), is derived from the data of domestic passenger car purchases, which matches the public charging pile data. It is noted that several control variables are selected, including per capita disposable income (INC), population density (POP), educational level (EDU), air quality index (AQI), and average annual temperature (TEMP). INC is obtained from the quarterly disposable income per capita in the China Statistical Yearbook by exponential smoothing, and the unit is Yuan; POP is obtained by dividing the regional population and land area, where the population is also obtained from the quarterly data by exponential smoothing, and the land area is obtained from the China Statistical Yearbook by looking up the land area, and unit is people per square kilometre; EDU is the ratio obtained by dividing the number of undergraduates and above from the sample surveyed in the Statistical Yearbook with the total number of respondents; AQI is obtained from the online air quality monitoring and analysing platform; TEMP is obtained by querying the Weather Network, and the unit is Celsius degrees. The descriptive statistics of each variable are shown in Table 1.

Table 1. The descriptive statistics of variables

Variable	Mean value	Standard deviation	Minimum value	Maximum value
EV purchases (EVP)	1786.508	3072.961	0	25550
Number of public charging	11586.420	15223.390	9	76051

piles (PCP)				
Per capita disposable income (INC)	2423.290	1029.736	888.010	6603.740
Ppopulation density (POP)	465.247	708.832	2.775	3948.280
Education level (EDU)	7.799	5.735	2.391	35.305
Air quality index (AQI)	71.253	22.633	25	168
Average annual temperature (TEMP)	15.619	10.816	-19	31.5

3 Model and results

3.1. Benchmark model

In order to investigate the impacts of public charging piles on the pure electric vehicle purchases, this paper constructs the following panel fixed effect model:

$$EVP_{it} = \alpha_0 + \alpha_1 PCP_{it} + \sum_{j=1}^{n} \alpha_j X_{it} + u_{it} + \lambda_i + \gamma_t \tag{2}$$

In the formula, EVP_{it} is the number of the pure electric vehicle purchases, PCP_{it} is the number of public charging piles. And X_{it} is a control variable, including per capita disposable income (INC), population density (POP), education level (EDU), air quality index (AQI) and annual average temperature (TEMP), etc. n is the number of control variables. λ_i and γ_t control for individual fixed effects and time fixed effects respectively. u_{it} is the random error term. Using the panel fixed effect model, we can get the estimation results, as shown in Table 2.

Table 2. Benchmark model of the impacts of public charging posts on the EVP

	(1) EVP	**(2) EVP**	**(3)** $\ln EVP$	**(4)** $\ln EVP$
PCP	0.108*** (10.39)	0.111*** (8.29)		
$\ln PCP$			1.280*** (23.73)	0.851 (14.85)
Constant	540.123*** (4.50)	-1520.812*** (-2.97)	-5.065*** (-11.33)	-6.045*** (-2.71)
Sample size	1457	1457	1457	1457
R-squared	0.349	0.395	0.632	0.684
Control variable	No	Yes	No	Yes
Fixed effect	Yes	Yes	Yes	Yes

Note: the numbers in parentheses is the value of t, and *** indicates that the data are significant at 1% level of significance.

No control variables are included in regression (1) but control variables are included in regression (2), both of which are in the regression. The difference in these coefficients are small, indicating a robust relationship between the independent variables and the dependent variables.

The regression results show that the number of public charging piles has a significantly positive effect on the purchase of pure electric vehicles. Each additional public charging pile will increase the purchase of pure electric vehicles by 0.111, and for every 1% increase in public charging piles will increase the purchase of pure electric vehicles by 0.851%. These results indicate the fact that the willingness of residents to buy EV will be significantly strengthened with the universality of public charging piles. Subsequently, the robustness of the relationship between the independent variable and the dependent variable is verified by taking the logarithm of them in regression (3) and regression (4). The results show that the relationship between these variables is still significant, which proves that the regression results are relatively stable.

3.2. Heterogeneity analysis

In order to further explore whether there is heterogeneity in the relationship between different types of public charging piles and different types of pure electric vehicle purchases, a regression on the subsample is conducted in this section. The results are as follows:

This paper classifies pure electric vehicles into two categories: rental and leasing pure electric vehicles and non-business pure electric vehicles. The purpose of doing so is to examine the differences in the impact of the number of public charging piles on the purchase of pure electric vehicles for different purposes. Rental and leasing pure electric vehicles refer to taxis, online car-hailing and other pure electric vehicles for the purpose of earning profits. Non-business pure electric vehicles are used by individuals or enterprises. The regression results are shown in Table 3.

Table 3. Regression results for the impact of public charging piles on pure electric vehicle for different purchase purposes

	(1) Rental and lease $\ln EVP$	**(2) Non-business** $\ln EVP$
$\ln PCP$	1.574*** (12.64)	0.739*** (12.73)
Constant	-15.190*** (-4.25)	-6.095*** (-2.96)
Sample size	1457	1457
R-squared	0.396	0.688
Control variable	Yes	Yes
Fixed effect	Yes	Yes

Note: the numbers in parentheses is the value of t , and *** indicates that the data are significant at 1% level of significance.

The above results show that public charging piles have a significant impact on pure electric vehicles for both types of uses. The coefficient of influence of public charging pile on pure electric vehicles for rental and leasing is 1.574, while the coefficient of influence on pure electric vehicles for non-business is only 0.739, which suggests that compared to the purchase of pure electric vehicles for non-business, the purchase of pure electric vehicles for rental and leasing is more dependent on public charging piles. The conclusion is in line with our reality, the average daily mileage of pure electric vehicles for rental and leasing purposes is much higher than that of non-business pure electric vehicles, so in order to ensure the mileage, consumers need to charge at public charging piles in different areas from time to time. While most of the owners who own non-business EVs are more accustomed to charging at their home, they only use public charging piles when their daily driving range is exceeded.

Next, we divide the public charging piles into two categories, alternating current piles (ACP) and direct current piles (DCP). The impacts of public charging piles with different charging technologies on the pure electric vehicle purchases are discussed. The regression results are shown in Table 4.

Table 4. Regression results for the impact of public charging piles with different technologies on pure electric vehicle purchases

	(1) $\ln EVP$	**(2)** $\ln EVP$	**(3) Rental and leasing** $\ln EVP$	**(4) Rental and leasing** $\ln EVP$	**(5) Non-business** $\ln EVP$	**(6) Non-business** $\ln EVP$
$\ln ACP$	0.13*** (2.17)		0.682*** (6.86)		0.084 (1.52)	
$\ln DCP$		0.414*** (7.60)		0.367*** (3.78)		0.369*** (7.08)
Constant	-8.761*** (-2.53)	-8.071*** (-3.20)	-17.678*** (-3.70)	-25.410*** (-5.28)	9.341** (-2.66)	8.256*** (-3.61)
Sample size	1116	1116	1116	1116	1116	1116
R-squared	0.623	0.671	0.336	0.304	0.634	0.673
Control variable	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes

Note: the numbers in parentheses is the value of t , and **, *** indicates that the data are significant at 5%, 1% level of significance.

Firstly, by analysing the heterogeneity of impacts and the regression results, the influence coefficient of ACP on the pure electric vehicle purchases is 0.130, while the influence coefficient of DCP on the purchase of pure electric vehicles is 0.414, both of which are significant at 1% level of significance. Therefore, the impact of DCP on the purchase of pure electric vehicles is much greater than that of ACP. Secondly, the influence coefficient of ACP on the pure electric vehicle purchases for rental and leasing purposes is 0.682, while the influence coefficient of DCP on the purchase of pure electric vehicles for rental and leasing purposes is 0.367, both of which are significant at 1 per cent level of significance. Therefore, the impact of ACP is much greater than that of DCP on the rental and leasing pure electric vehicles. Thirdly, the effect of ACP on the purchase of pure electric vehicles for non-business is not significant, while the effect of DCP on the purchase of pure electric vehicles for non-business is significant with an impact coefficient of 0.369. This result shows that DCP are the most conductive for non-business pure electric vehicles, but ACP does not have a obvious effect. The reason for the above results may be that: On the one hand, most of consumers owing the non-business pure electric vehicles usually charge though their private charging piles at home to meet the next day's demand, and there may be less demand for long-distance travelling in the usage scenarios. On the other hand, long distance travelling requires high charging speed, however, public ACPs are difficult to meet the demand for fast charging while DCP can replenish electric energy for vehicles faster with the advantage of power and increase the mileage. Therefore, DCP are more important for non-business pure electric vehicles. In terms of rental and leasing pure electric vehicles, the usage scenarios are more complicated, and they generally do not have a fixed charging place. What's more, the leakage of fixed charging locations and the presence of a large amount of uncertainty lead to the importance of public charging piles. At the same time, the advantages of wide distribution, construction costs, and compatibility with various vehicle types make ACP even more important for rental and leasing pure electric vehicles. Long distance travelling requires high charging speed and charging time for EVs.

Next, this paper continues to explore the impact of public charging piles of different characteristics on the pure electric vehicle purchases by dividing public charging piles into two categories: ordinary public piles (OPCP) and specialized charging piles (SPCP). OPCP refers to charging piles that provide public charging services for social vehicles, and SPCP refers to the public charging piles built by enterprises for internal staff or for public utility vehicles. The regression results are shown in Table 5.

Table 5. Regression results of the impact of charging piles of different characteristics on pure electric vehicle purchases

	(1) $\ln EVP$	**(2)** $\ln EVP$	**(3) Rental and leasing** $\ln EVP$	**(4) Rental and leasing** $\ln EVP$	**(5) Non-business** $\ln EVP$	**(6) Non-business** $\ln EVP$
$\ln OPCP$	0.474** (7.15)		1.036*** (11.52)		0.388*** (5.80)	
$\ln SPCP$		0.388*** (6.63)		0.400*** (4.45)		0.361*** (6.34)
Constant	-7.120*** (-2.43)	-8.367*** (-3.17)	-19.955*** (-4.38)	-25.342*** (-5.45)	-7.664** (-2.52)	-8.430** (-3.10)
Sample size	1116	1116	1116	1116	1116	1116
R-squared	0.661	0.656	0.369	0.304	0.660	0.664
Control variable	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes

Note: the numbers in parentheses are the value of t, and **, *** indicates that the data are significant at 5%, 1% level of significance.

The regression results show that the difference between ordinary public charging piles and specialized charging piles in promoting the purchase of pure electric vehicles is not significant. The influence coefficient of ordinary public piles is 0.474, while the influence coefficient of specialized charging piles is 0.388, and ordinary public piles are slightly stronger than the other one in promoting the purchase of pure electric vehicles.

It is worth noting that for rental and leasing pure electric vehicles, ordinary public charging piles are more essential, which again proves that ordinary public charging piles are more important than specialized charging piles because pure electric vehicles for rental and leasing purposes have the problems of irregular charging location and time. For non-business pure electric vehicles, two types of charging piles are needed. For non-business use pure electric vehicles, there is no significant difference in the impacts of the two types of charging piles. This also suggests that consumers rely on both OPCP and SPCP.

4 Conclusions

In recent years we have witnessed the development of electric vehicles and charging infrastructure. The presence of charging infrastructure has a strong influence on vehicle purchases decisions and there is a large body of literature that supports this conclusion. However, most scholars do not refine this question to explore further how different charging infrastructures may affect the purchase of different types of electric vehicles.

After collecting data on the number of public charging piles, the number of pure electric vehicles purchased, per capita disposable income, and the education level of consumers in China, this paper explores the impact of public charging piles on pure electric vehicles by using econometrics to incorporate the data into a fixed effect model and conducting regression analyses. In addition, this paper classifies public charging piles into DC/AC charging piles, special charging piles and general public charging piles, and classifies pure electric vehicles into vehicles used for rental and leasing and non-business vehicles to analyse the heterogeneity of influencing factors. Finally, we explore how different public charging piles affect the purchasing of pure electric vehicles for different purposes. The conclusions are as follows: Firstly, the benchmark model confirms that as the number of public charging piles increases, so does the number of pure electric vehicles, which is consistent with previous studies. Secondly, public charging piles have a significant positive impact on both pure electric vehicles for rental and release purpose and non-business purpose, but public charging piles have a greater impact on rental and releasing pure electric vehicles. This may be due to the following factor. Unlike the owners of non-business pure electric vehicles, the owners of rental and releasing pure electric vehicles may be more range anxious and consider public charging availability seriously when making purchase decisions. Thirdly, the popularity of non-commercial pure electric vehicles depends to a large extent on the construction of DCPs, because these owners have higher charging speed requirements when driving long distances. On the contrary, due to the wide distribution and low charging cost of ACP, ACP can effectively reduce the charging and time costs of these owners, so ACP has a great impact on pure electric vehicles used for rental and leasing. Finally, ordinary public charging piles (OPCP) can overcome the problem of irregular charging locations, which has a great effect on the popularity of pure electric vehicles for rental and leasing. However, for the owners of non-business pure electric vehicles, ordinary public charging piles and specialized public charging piles (SPCP) have little impact on them. The questions examined in this paper also deserve further elaboration, for example, a great number of studies have found that the impact of charging infrastructure on consumers' willingness to purchase electric vehicles varies greatly in different regions, and it is worth exploring what factors contribute to this difference. In addition, the living conditions and available area of charging infrastructure vary from country to country, this article only analyses the existing data in China, so the conclusions may not be applicable in other countries. With the widespread introduction of EVs, the data is only getting more robust. This should allow future researchers to confirm and refine the relationships described in this article.

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