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Alternative Incentive Policies against Purchase Subsidy Decrease for Battery Electric Vehicle (BEV) Adoption

Tianwei Lu, Enjian Yao *, Fanglei Jin and Long Pan

Key Laboratory of Transport Industry of Big Data Application Technologies for Comprehensive Transport, Beijing Jiaotong University, Beijing 100044, China; twlu@bjtu.edu.cn (T.L.); 14120837@bjtu.edu.cn (F.J.); longpan@bjtu.edu.cn (L.P.)

* Correspondence: enjyao@bjtu.edu.cn; Tel.: +86-010-5168-8344

Received: 6 March 2020; Accepted: 24 March 2020; Published: 2 April 2020

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Abstract: The purchase subsidy policy gives powerful support in battery electric vehicles' (BEVs) market penetration. However, the purchase subsidy is also a huge financial burden for the government, so it can only be considered as a transitional measure and will be canceled gradually. This paper aims to investigate the impact of purchase subsidy phase-out on BEV adoptions and explore alternative incentive policies to continue stimulating BEV adoptions. A stated preference (SP) survey is conducted in Beijing, and a binary logit (BL) model is established to describe how various factors affect BEV adoption preferences. In addition to the factors related to vehicle techniques, the policies of license plate restrictions and driving restrictions are focused due to Beijing's unique external policy environment. The vehicle use subsidy and bus line driving permit are tested as alternative incentive policies against the purchase subsidy decrease. The results show that incentive policies can significantly influence BEV adoption intentions. If the purchase subsidy policy is canceled in Beijing, the BEV choice probability will be reduced from 45.94% to 16.62%. In this case, the vehicle use subsidy needs to be set at the level of 4966 CNY/year (714.3 USD/year) to maintain the original BEV choice probability.

Keywords: electric vehicle adoption; purchase intention; subsidy policy; alternative incentive policy; binary logit model

1. Introduction

1.1. Backgrounds

In order to deal with the severe situation of global climate change, energy crisis, and air pollution in the transportation sector, battery electric vehicles (BEVs) are regarded as an effective way worldwide [1,2]. According to Global EV Outlook 2018 [3], the global stock of electric passenger cars reached 3.1 million in 2017, 40% of which were in China. The promotion and application of BEVs have become a primary goal of the Chinese government. According to the statistics from the Ministry of Industry and Information Technology (MIIT) of China, the number of BEVs has reached 1.7 million until the end of 2017, and it is expected to reach 5 million by the end of the "13th Five-Year Plan" in 2020, which makes China become one of the enormous markets in the world.

BEVs are widely produced and used due to their advantages of environmental protection, low energy consumption, and low operating cost [4]. So many countries are vigorously developing BEVs. However, BEVs have some technical defects, such as short cruising range, long charging time, few charging stations, etc., so the promotion of BEVs is difficult in many countries [5,6]. To a large extent, the current worldwide development of BEVs is attributed to incentive policy supports like subsidies [7].

During the initial launch of BEVs, many countries, including China, implemented respective subsidy policies to improve market penetration [8]. For example, China primarily launched the purchase subsidy in January 2009, which was only available to the public transport sector [9], and followed by an update in September 2013; the purchase subsidy covered both public and private purchases. The amount of purchase subsidy 15,000–50,000 CNY (2159.5–7197.4 USD) and the specific amount is determined by BEVs' cruising ranges. Besides, the purchase of conventional vehicles (CVs) has a 10% purchase tax, which BEVs are exempt from [10].

1.2. Motivations

Although purchase subsidy policies increase BEV adoption rates, they are still a huge financial burden for the government, so they can only be used as a transitional measure. With the increase in the implementation time of the purchase subsidy policy, the popularity of BEVs has increased, and the incentive effect of purchase subsidies on BEV adoption intentions is gradually weakened. Not surprisingly, China has begun to reduce the amount of purchase subsidies since the beginning of 2018 and plans to completely cancel it in 2020, which will bring an intuitive decrease for BEV adoption rates [9]. However, it is unclear how changes in purchase subsidy policies will quantitatively affect the consumers' BEV adoption intentions and to what degree the BEV adoption probability will be affected. Besides, the market cultivating for BEVs is a long-term mission. In order to maintain or even improve BEV market penetration without the purchase subsidy policy, steadily reaching the development goal of 5 million after 2020, the government needs to find other ways. However, what the feasible countermeasures will be and how they will perform are also worth studying.

Besides, to study BEV adoption intentions, Beijing's BEV market is an interesting case due to its unique policy environment. Briefly, Beijing has applied a vehicle license plate restriction policy via a publicly held lottery system for conventional vehicles (CVs). People can only use CVs after obtaining a license plate through lottery activities, which is held by this system six times a year. As a purchase incentive, there is no such rule for BEVs in Beijing. Very likely, this vehicle license plate restriction policy will affect consumers' adoption intentions when choosing their vehicle type. Especially from 2018, the license plate quota for CVs shrank from 90000 to 40000; the initial probability of obtaining a CV license plate is less than 0.05%. The vehicle purchase intention in this policy environment is probably no longer a simple vehicle technology preference but has to consider the opportunity to obtain a license plate. This raises another problem with the purchase subsidy policy. Due to CV license plate restrictions and the BEV purchase subsidies, some people who do not have a vehicle use demand also choose to purchase BEVs in order to get a license plate quota at a low price. That makes the BEV incentive policy counterproductive. For such reasons, other forms of alternative incentive policies are urgently needed to be proposed.

In addition to license plate restrictions, Beijing has also implemented the driving restriction policy. This policy restricts the driving of CVs in the central area of Beijing during the working day. The CVs in Beijing are prohibited from driving on the road one day a week, the prohibition day is determined by the license plate number, and there is no such driving restrictions for BEVs. Such restriction policies will probably have a positive effect on BEV adoption intentions. Thus, another important aim is to investigate the impact of restriction policies on BEV adoption intentions.

1.3. Research Objectives and Contributions

Given the above situation, the following problems in the development of BEVs in various countries need to be resolved:

- How does the abolishment of the BEV subsidy policy affect the BEV purchase probability?
- In addition to the subsidy policy, how do other incentive policies (e.g., driving restrictions and license plate restrictions) affect BEV adoption intentions?

- How to formulate specific alternative incentive policies to maintain or improve the original BEV adoption probability when subsidy policies phase out.

Thus, this paper analyzed BEV adoption intentions and choice probability under the situation of the purchase subsidy decreases or the purchase tax increases and how to make the alternative incentive policies against the purchase subsidy phase out. Considering the unique policy environment, Beijing is chosen where the survey is conducted. Besides, we proposed policies of vehicle use subsidies (e.g., parking fee discount and charging fee discount) and bus line driving permits as the alternatives for purchase subsidies. These two alternative incentive policies can either continuously stimulate BEV adoption or the use of BEV after purchase, which could avoid the problem of purchasing only for getting a license plate quota at a low price, ensuring the maximum utility of incentive policies. Figure 1 shows the specific relationship between purchase subsidy policies and alternative incentive policies.

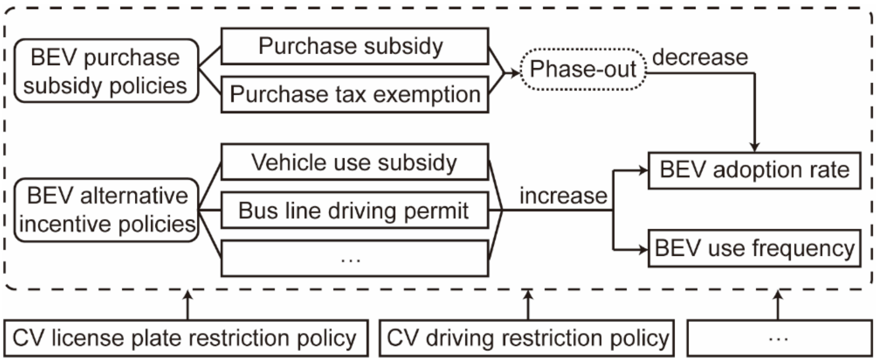


Figure 1. The relationship between purchase subsidy policies and alternative incentive policies. BEV = battery electric vehicle and CV = conventional vehicle.

Regarding the main contributions of this study, the following aspects are mainly included: (1) In terms of BEV subsidy policies, this paper quantifies the effects of purchase subsidy abolition on BEV adoption. Two alternative incentive policies against purchase subsidy decreases are proposed to provide references for future policy developments. (2) Regarding BEV nonsubsidized incentive policies, this paper studies the impact of Beijing's unique restriction policies on BEV purchases, including license plate restrictions and driving restrictions, to provide a basis for the formulation of restriction policies in China and other countries in the future. (3) For personal attributes, we analyze the impact of various personal attributes on BEV adoption (including age, education, income, daily travel distance, vehicle ownership, etc.). The categories of people who are likely to choose BEVs are further explored to provide a basis for the future development of the BEV market.

The rest of this paper is organized into four sections. Section 2, "Literature review", gives a literature review and background about BEV adoption preferences. Section 3, "Methodology", introduces modeling methods and the survey specifications and provides some statistical results of the collected data. Section 4, "Results and analysis", gives analysis results about what the impact of involved factors is, especially various policies, on BEV adoption intentions. Based on the model results, the impact of alternative incentive policies against the purchase subsidy decreases on BEV adoption intentions is analyzed. Section 5, "Conclusions and discussion", gives the concluding comments on the research points and provides plans for future research.

2. Literature Review

2.1. Personal Attributes/Vehicle Technical Features

Many early studies related to BEV adoption intentions discussed the impact of personal attributes and vehicle technical features [11]. In this field, Plötz et al. considered the impact of gender, age, place of residence, profession, and other personal attributes on BEV adoption preferences [12].

Moons et al. and Lieven et al. studied the effects of cruising range and vehicle performance on BEV adoption intentions [13,14]. Carley et al. considered the role of charging times and charging opportunities in BEV purchase decisions [15]. Egbue et al. analyzed factors of personal attributes on electric vehicle adoptions, especially for people with engineering or technical backgrounds [16]. Jensen et al. examined the differences in BEV adoption preferences between experienced and unexperienced BEV users [17]. Johan et al. investigated the influence of a set of attitudinal constructs on BEV adoption, including personal norms, social norms, ecological attitudes, opinion leading, and opinion seeking [18]. Dumortier et al. deeply studied the impact of BEV ownership costs on adoption intentions [19]. Javid and Nejat explored the factors that are deemed to be associated with BEV adoption and estimated the level of BEV penetration in 58 California counties [20]. Jakobsson et al. and Karlsson studied the impact of household travel patterns such as daily driving distances derived from GPS-logged movements to model the feasibility of BEV substitution [21,22].

The above studies explored the impact of personal attributes or vehicle technical features on BEV adoption intentions and quantified the relationship between these factors and the BEV choice probability. However, they did not consider policy factors and could not provide a direct reference for policy development.

2.2. Subsidy Policies

Under the strong support of countries for the development of BEVs, many related measures have been proposed to support the BEV market penetration. Since technological innovations need a long time, worldwide governments usually implement incentive policies to stimulate BEV adoption intentions, especially the subsidy policy [23]. This has led to extensive studies on the relationship between subsidies and the market.

Wang et al. explored the relationship between subsidy policies and 30 national electric vehicle market shares for the year 2015, utilizing the multiple linear regression method [24]. Morton et al. accessed whether the exemption of hybrid electric vehicles (HEVs) from the congestion charge affected the rate vehicle registrations were accessed in Greater London and the surrounding areas [25]. Glerum et al. designed a fractional factorial survey considering the impacts of incentive, price, fuel cost, and battery lease on BEV purchase demand and simulated the adoption probability when the purchase price of BEVs increased or decreased [26]. Zhang et al. pointed out that the sustainability of subsidy adoption depends to a large extent on consumers' perceptions and motivations for BEV adoptions [27]. Helveston et al. measured consumer preferences in both the U.S. and China and simulated the adoption probability of respondent choices for plug-in vehicles and their gasoline counterparts in the case of subsidy changes [28]. Zheng et al. pointed out that there would be a fall in sales responding to subsidies decreasing and deeply investigated the impact of government subsidies on the sensitivities of consumer acceptance, sales quantity, and total social welfare [29].

The above studies analyzed the impact of subsidy policies on BEV adoption intentions and market shares from different perspectives. However, these studies did not investigate the performance of alternative incentive policies against the subsidies phased out. Jenn et al. proposed a countermeasure which charges user fees on BEVs to overcome the decrease in revenue, including a flat annual registration fee in the U.S. [30]. This study considered the financial burden of BEV development and proved the applicability of countermeasures, but it did not explore how to maintain the original BEV adoption probability when the subsidy decreased. Wang et al. proposed countermeasures after the abolition of BEV subsidy policies, and the results provided references for the formulation of future policies [9], but they did not offer specific quantitative methods for alternative incentive policies against subsidy phase-out, so they could not directly provide a reference for future policymaking.

2.3. Other Incentive Policies

Since BEV subsidy policies are the most widely used in many countries, such as America, Europe, China, Japan, etc., most of the current research about incentive policies focus on subsidy policies.

However, in addition to subsidy policies, there are many other forms of nonfinancial incentive policies, such as special lanes (e.g., HOV/carpool lanes and bus lanes) driving permits, restriction exemptions, parking incentives, etc. Hardman studied the impact of nonfinancial incentives on consumers' adoption preferences, including special lane permission, parking incentives, charging infrastructure development, road toll fee waivers, and licensing incentives [31]. This study explored different stimulating effects on consumers between nonfinancial incentives and subsidies, but it did not study the impact of restriction policies (i.e., license plate restrictions and driving restrictions) and the alternative relationship between nonfinancial incentives and subsidy incentives. Zhao et al. estimated the impact of credit regulatory policies on BEV technology trends for the Chinese market [32]. However, the credit regulatory policy is only relevant to BEV manufacturers, so there is no direct analysis of the impact of consumers' BEV adoption preferences.

As a unique nonfinancial incentive policy, there are few studies on Beijing's restriction policies. Research of Zhang et al. and Wang et al. involved the impact of license plate restriction policies on BEV adoption [33,34] but did not consider the specific utility alternative relationship of other policies.

In summary, there are lots of relevant studies on BEV adoption intentions in various aspects, but the following deficiencies still exist:

(1) Existing studies lack research on the impact of purchase subsidy phase-outs on BEV adoption, and there is no research on alternative incentive policies against purchase subsidy phase-outs.
(2) Quantitative research on the effects of other incentive policies on BEV adoption is lacking, such as China's restrictive policy.

Regarding the deficiencies above, we focused on the Beijing's complex BEV policy environment, analyzed the impact of various policies on market share in the context of driving restrictions, license plate restrictions, purchase subsidy policies, etc., and then explored the formulation of alternative incentive policies against purchase subsidy policy phase-outs, filling in the gaps in the current BEV adoption research field.

3. Methodology

Given the data limitation of BEV adoption intentions, particularly under some hypothetical scenarios, a stated preference (SP) survey is designed to investigate BEV adoption intentions. The choices of vehicle adoption preferences in this paper are CV and BEV, which is a binary choice problem. However, the logit model can quantify the relative importance of each attribute and estimate the choice probability. Based on our previous related research [35], we use the binary logit (BL) model to analyze BEV adoption intentions, especially the impact of policy factors.

3.1. Model

The BL model was initially proposed by Luce [36], and McFadden later studied the model from the perspective of econometrics [37]. At present, the model has been widely used in the study of choice preferences. According to the theory of random utility, the utility, U_{in}, that a traveler, n, chooses a particular alternative, i, is given by

$$U_{in} = V_{in} + \varepsilon_{in} \tag{1}$$

where V_{in} is the deterministic part of the utility function of alternative i for traveler n, and ε_{in} represents the stochastic term. Typically, the deterministic part takes a linear form:

$$V_{in} = \sum_{l=1}^{L} \theta_l X_{inl} \tag{2}$$

where X_{inl} stands for the lth explanatory variable of alternative i for traveler n, and θ_l is the coefficient to be estimated associated with the corresponding variable. The specific form of X_{inl} will be described in detail in Section 3.2 "3.2 Model specification" below.

The probability that traveler n chooses mode 1 p_{1n} can be expressed as

$$p_{1n} = \frac{\exp(V_{1n})}{\exp(V_{1n}) + \exp(V_{2n})} \quad (3)$$

3.2. Model Specification

According to Beijing's real BEV market situation and policy environment, some factors affecting BEV adoption intentions are selected as the explanatory variables in the model, which are divided into scenario variables and basic variables. Figure 2 shows the specific contents.

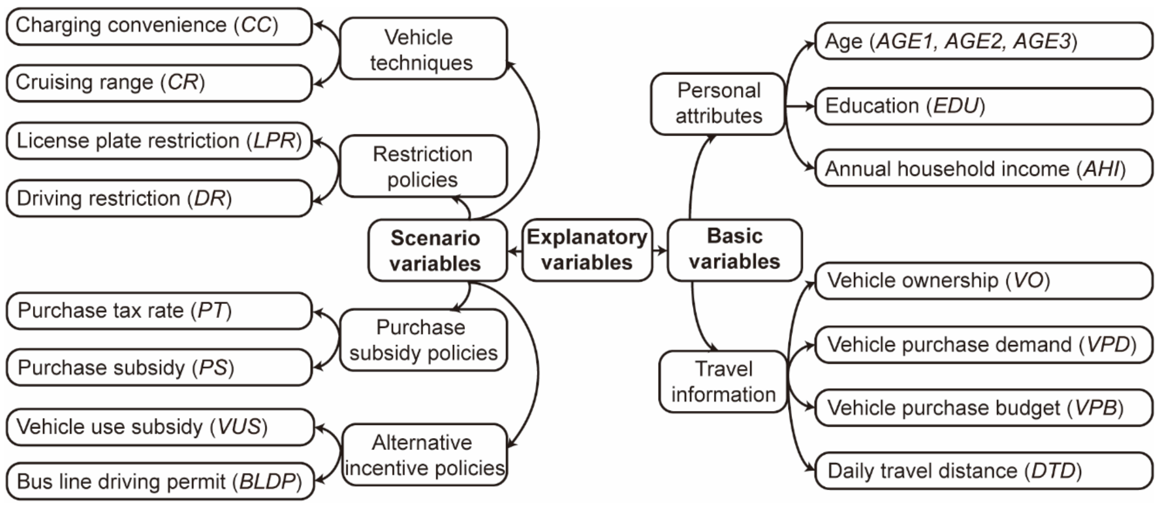


Figure 2. Explanatory variables classification.

Scenario variables are used to describe hypothetical vehicle techniques and policies of BEVs and CVs to explore the impact of different scenario factors on potential consumers' adoption intentions. They are divided into vehicle technique variables, restriction policy variables, purchase subsidy policy variables, and alternative incentive policy variables. Table 1 shows the specific descriptions and the values of these variables in Beijing's real situation. Vehicle technique variables are used to describe the respective vehicle techniques of BEVs or CVs, including charging convenience (*CC*) and cruising range (*CR*). Due to the technical defects of BEVs at the current stage, compared with CVs, BEVs are relatively inconvenient to charge (CC_{BEV} = 0, CC_{CV} = 1) and have a lower cruising range (CR_{BEV} = 0, CR_{CV} = 1). Restriction policy variables are applied to describe the restrictive policies adopted by the government for BEVs and CVs, which contain driving restrictions (*DR*) and license plate restrictions (*LPR*). These two policies are currently implemented only in CVs (LPR_{BEV} = 0, LPR_{CV} = 1; DR_{BEV} = 0, DR_{CV} = 1) in Beijing. Purchase subsidy policy variables are used for describing the incentive policy of subsidies implemented by the government to promote BEVs and CVs, including purchase tax (*PT*) exemptions and a purchase subsidy (*PS*). The purchase subsidy for BEVs is 15,000–50,000 CNY (2159.2–7197.4 USD) in Beijing; this paper takes its average value as 32,500 CNY (4678.3 USD) for modeling (PS_{BEV} = 32,500), and there is no subsidy for purchasing CVs (PS_{CV} = 0). The purchase tax rate is 10% for CVs (PT_{CV} = 10%) and is exempt from BEVs (PT_{BEV} = 0).

Table 1. Description of scenario variables. BEVs = battery electric vehicles, CVs = conventional vehicles, *CC* = charging convenience, *CR* = cruising range, *LPR* = license plate restrictions, *DR* = driving restrictions, *PT* = purchase tax, *PS* = purchase subsidy, *VUS* = vehicle use subsidy, and *BLDP* = bus line driving permit.

Category	Name	Type	Description	Values in Beijing's Real Situation	
				BEVs	**CVs**
Vehicle technique	*CC*	0–1	Whether the charging is convenient (1: yes, 0: no)	0 (no)	1 (yes)
	CR	0–1	Whether cruising range is long enough (1: yes, 0: no)	0 (no)	1 (yes)
Restriction policy	*LPR*	0–1	Whether a license plate restriction policy is implemented (1: yes, 0: no)	0 (no)	1 (yes)
	DR	0–1	Whether a driving restriction policy is implemented (1: yes, 0: no)	0 (no)	1 (yes)
Purchase subsidy policy	*PT*	Continuous	Purchase tax rate (%)	0 (%)	10 (%)
	PS	Continuous	Purchase subsidy	32,500 (CNY) (4678.3 USD)	0 (CNY)
Alternative incentive policy	*VUS*	Continuous	Vehicle use subsidy	0 (CNY/year)	0 (CNY/year)
	BLDP	0–1	Whether the bus line is permitted to drive (1: yes, 0: no)	0 (no)	0 (no)

As for the consideration of alternative incentive policies, based on the real situation of the BEV market in Beijing, this paper selects them according to the following rules: (i) In addition to stimulating BEV adoptions, its daily use frequency should also be promoted. (ii) BEV purchase intentions can continue to be stimulated and reach the original level.

Based on the above two rules, this paper proposes two alternative incentive policies: vehicle use subsidy (*VUS*) and bus line driving permit (*BLDP*). The vehicle use subsidy is the annual subsidy, mainly referring to the government's subsidy for parking, charging, congestion charges, etc. For the applicability of this study for different cities, only *VUS* is used here to unify all of them. Its amount is directly related to the vehicle use frequency, e.g., 0.5 CNY/km and 0.1 CNY/kWh (0.072 USD/km and 0.014 USD/kWh), which can promote the daily use of BEVs and then avoid the phenomenon of purchasing BEVs only for subsidies. The bus line driving permit refers to whether vehicles are allowed to travel in bus lanes. Under normal circumstances, the bus lane only allows buses to travel during peak congestion periods. In order to promote BEVs, some cities (e.g., Liuzhou, China) allow BEVs to travel in bus lanes during the promotion period as an incentive policy.

Among these scenario variables, *CC*, *CR*, *DR*, *LPR*, and *BLDP* are 0–1 variables, and *PT*, *PS*, and *VUS* are continuous variables.

The basic variables describe the basic information of potential consumers, which is used to explore impacts on BEV adoption intentions. They are divided into personal attribute variables and travel information variables, as described in Table 2. Personal attribute variables include age (*AGE*), education (*EDU*), and annual household income (*AHI*). Considering the impact of age on BEV adoption intentions may not be linear, age is divided into three groups, namely *AGE1*, *AGE2*, and *AGE3*, respectively, which are used to analyze the characteristics of different age groups. Travel information variables include vehicle ownership (*VO*), vehicle purchase demand (*VPD*), vehicle purchase budget (*VPB*), and daily travel distance (*DTD*). These basic variables are all 0–1 variables.

Table 2. Description of basic variables. *EDU* = education, *AHI* = annual household income, *VO* = vehicle ownership, *VPD* = vehicle purchase demand, *VPB* = vehicle purchase budget, and *DTD* = daily travel distance.

Category	Name	Type	Description
Personal attributes	*AGE1*	0–1	Whether the age is 18–25 years old (1: yes, 0: no)
	AGE2	0–1	Whether the age is 25–40 years old (1: yes, 0: no)
	AGE3	0–1	Whether the age is 40–60 years old (1: yes, 0: no)
	EDU	0–1	Whether the education level is postgraduate education (1: yes, 0: no)
	AHI	0–1	Whether the annual household income is more than 200,000 CNY (28,789.4 USD) (1: yes, 0: no)
Travel information	*VO*	0–1	Whether the respondent already owns a vehicle (1: yes, 0: no)
	VPD	0–1	Whether the respondent has urgent vehicle purchase demand (1: yes, 0: no)
	VPB	0–1	Whether the vehicle purchase budget is more than 200,000 CNY (28,789.4 USD) (1: yes, 0: no)
	DTD	0–1	Whether the daily travel distance is more than 40km (1: yes, 0: no)

According to the description of the above variables, since the value of the scenario variables is all different between BEVs and CVs, all scenario variables need to be included in both of the utility functions. For basic variables, due to their values being the same between BEVs and CVs, they only need to be considered in one of the utility functions between BEVs and CVs. In this paper, all basic variables are considered in the BEV utility function. Figure 3 shows the variables contained in the utility functions of CVs and BEVs in the BL model.

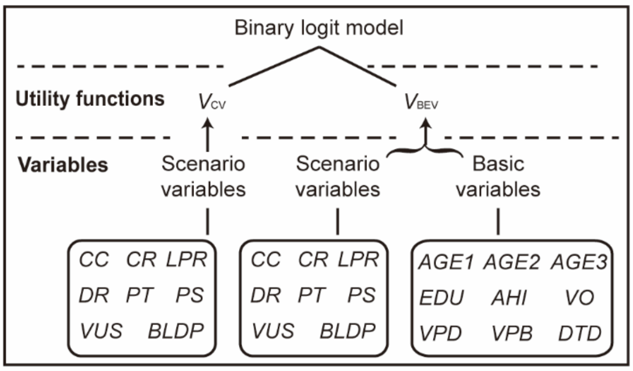


Figure 3. Variables contained in the utility functions of CVs and BEVs in the binary logit (BL) model.

3.3. Data Collection

In order to collect the data required for the above BL model, a web-based questionnaire about BEV adoption intentions was designed, and 900 respondents from Beijing participated in this survey during 15 March 2018–15 June 2018. Respondents were all Beijing residents with the intention to purchase a CV or BEV. The distribution of respondents' residences covered all districts in Beijing. Figure 4 shows the number of respondents in each district. They participated in the survey through two channels: (1) social media, an efficient way to do a survey, and we conducted this survey through WeChat, which is a mobile communication service application in China. (2) The data collection agency, which has a wide range of survey sources, can collect sufficient amounts of valid data in the short term.

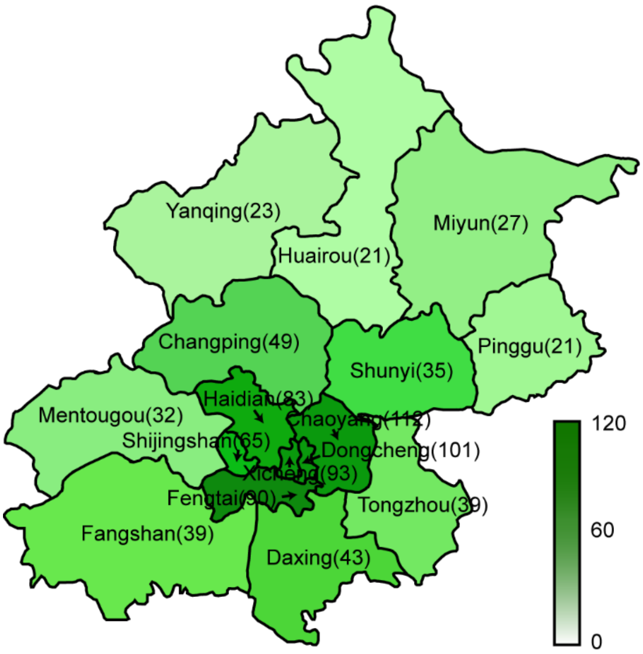


Figure 4. The distribution of respondents in Beijing.

The questionnaire content was divided into three parts, namely "personal attribute", "travel information", and "BEV adoption intention". (1) "Personal attribute" investigates age, education, family income, and place of residence. (2) "Travel information" investigates vehicle ownership, vehicle purchase demand, vehicle purchase budget, and daily travel distance. (3) "BEV adoption intention" collects the respondent's choice between a BEV and CV in different scenarios. In addition to the real situation of the BEV market in Beijing, there are eight other hypothetical scenarios considered in the model, including the future change of vehicle techniques, restriction policies, subsidy policies, and alternative incentive policies.

Table 3 shows the specific scenario designs. Among them, Scenario 0 is the real situation scenario with no change; scenarios 1, 2, 3, 4, 5, and 6 are hypothetical scenarios that change the existing conditions (vehicle techniques and subsidy policies); and scenarios 7 and 8 are alternative incentive policy change scenarios, both of which are new hypothetical scenarios. Scenario 7 is the vehicle use subsidy scenario after the purchase subsidy is canceled. In this survey, we assume the total period of vehicle use subsidy is six years, and its subsidy amount is related to the vehicle use frequency. This scenario includes three questions; the specific content of each question is as follows:

1. The annual subsidy limit is 2000 CNY/year (287.9 USD/year), e.g., the mileage subsidy 0.5 CNY/km (0.072 USD/km), subsidy distance limit 4000 km/year, or the electricity subsidy 0.1 CNY/kWh (0.014 USD/kWh), subsidy electricity limit 20,000 kWh/year.
2. The annual subsidy limit is 3000 CNY/year (431.8 USD/year), e.g., the mileage subsidy 0.5 CNY/km (0.072 USD/km), subsidy distance limit 6000 km/year, or the electricity subsidy 0.1 CNY/kWh (0.014 USD/kWh), subsidy electricity limit 30,000 kWh/year.
3. The annual subsidy limit is 4000 CNY/year (575.8 USD/year), e.g., the mileage subsidy 0.5 CNY/km (0.072 USD/km), subsidy distance limit 8000 km/year, or the electricity subsidy 0.1 CNY/kWh (0.014 USD/kWh), subsidy electricity limit 40,000 kWh/year.

Table 3. Survey scenario design.

Scenario Type	Scenario Name	Scenario Description	Variable Change
Real situation	0 No change	The current real situation in Beijing	None
Vehicle technique change scenario	1 Charging convenient (*CC*) change	BEV charging becomes convenient (the same as CV)	$CC_{\mathrm{BEV}} = 1$
	2 Cruising range (*CR*) change	BEV cruising range increased (the same as CV)	$CR_{\mathrm{BEV}} = 1$
Restriction policy change scenario	3 License plate restriction (*LPR*) change	BEV purchase becomes restricted (the same as CV)	$PR_{\mathrm{BEV}} = 1$
	4 Driving restriction (*DR*) change	BEV driving becomes restricted (the same as CV)	$DR_{\mathrm{BEV}} = 1$
Subsidy policy change scenario	5 Purchase tax rate (*PT*) change	BEV purchase tax rate becomes 3.5% (CV is 10%)	$PT_{\mathrm{BEV}} = 3.5$
		BEV purchase tax rate becomes 7.0% (CV is 10%)	$PT_{\mathrm{BEV}} = 7.0$
		BEV purchase tax rate becomes 10% (CV is 10%)	$PT_{\mathrm{BEV}} = 10.0$
	6 Purchase subsidy (*PS*) change	BEV purchase subsidy becomes 45000 CNY (6477.6 USD) (CV is 0)	$PS_{\mathrm{BEV}} = 45.0$
		BEV purchase subsidy becomes 20000 CNY (2878.9 USD) (CV is 0)	$PS_{\mathrm{BEV}} = 20.0$
		BEV purchase subsidy becomes 7500 CNY (1079.6 USD) (CV is 0)	$PS_{\mathrm{BEV}} = 7.5$
		BEV purchase subsidy becomes 0 (CV is 0)	$PS_{\mathrm{BEV}} = 0.0$
Alternative incentive policy change scenario	7 Vehicle use subsidy (*VUS*) change	BEV purchase subsidy becomes 0, and the vehicle use subsidy limit becomes 2000 CNY/year (287.9 USD/year) (CV is 0)	$VUS_{\mathrm{BEV}} = 2.0$ $PS_{\mathrm{BEV}} = 0.0$
		BEV purchase subsidy becomes 0, and the vehicle use subsidy limit becomes 3000 CNY/year (431.8 USD/year) (CV is 0)	$VUS_{\mathrm{BEV}} = 3.0$ $PS_{\mathrm{BEV}} = 0.0$
		BEV purchase subsidy becomes 0, and the vehicle use subsidy limit becomes 4000 CNY/year (575.8 USD/year) (CV is 0)	$VUS_{\mathrm{BEV}} = 4.0$ $PS_{\mathrm{BEV}} = 0$
	8 Bus line driving permit (*BLDP*) change	BEV purchase subsidy becomes 0, and BEV is permitted to drive on bus lane (CV is not permitted)	$BLDP_{\mathrm{BEV}} = 1$ $PS_{\mathrm{BEV}} = 0.0$

In order to ensure the accuracy of the data obtained by the survey, some rules for improving the accuracy of the survey result are applied as follows: (1) Additional information about the BEVs is provided in the questionnaire if the respondent needs, which could help the respondent fully understand the technical characteristics and related policies of the BEVs. (2) To eliminate the inductivity problem, the continuous inductive questions in scenarios like purchase tax changes (three questions of 3.5%, 7%, and 10%); purchase subsidy changes (four questions of 4,5000, 20,000, 7500, and 0 CNY, i.e., 6477.6, 2878.9, 1079.6, and 0 USD); or vehicle use subsidy changes (three questions of 2000, 3000, and 4000 CNY, i.e., 287.9, 431.8, and 575.8 USD) are assigned into three different questionnaire versions. (3) After the survey, we cleaned the data through some cleaning rules (inconsistent answers, contradictory answers, too-short answer time, and invalid IP address or residence); if any of these were met, the data was treated as invalid and removed.

Finally, a total of 900 questionnaires were collected, of which, 27 invalid questionnaires were removed, and 873 valid questionnaires were obtained. These provided data support for the estimation of the model parameters.

3.4. Statistical Analysis

Figure 5 shows the choice result statistics for each scenario in the survey. In Scenario 0, the BEV choice rate is 46.05% in Beijing, which is significantly higher than those in other cities, the main reason is that Beijing's various incentive policies have greatly improved the BEV choice probability. In Scenarios 1 and 2, BEV choice rates are increased to 82.82% and 81.10% when the charging convenience (e.g., advances in fast charging and battery replacement technology) and cruising range increase to the same level as CVs, respectively. In Scenarios 3 and 4, as the BEV license plate restriction and driving restriction policy becomes the same as CVs, the BEV choice rates are significantly lower than that in Scenario 0, which are 15.92% and 22.57%, respectively. Scenarios 5 and 6 are the scenarios under purchase subsidy policy changes. As the purchase tax rate increases or purchase subsidy decreases, the BEV choice rate decreases gradually. Scenarios 7 and 8 are the scenarios under alternative incentive policy changes; as the alternative incentive policy is gradually strengthened, the BEV choice rate rises gradually. These results indicate that changes in polices or vehicle techniques have significant impacts on BEV adoption preferences.

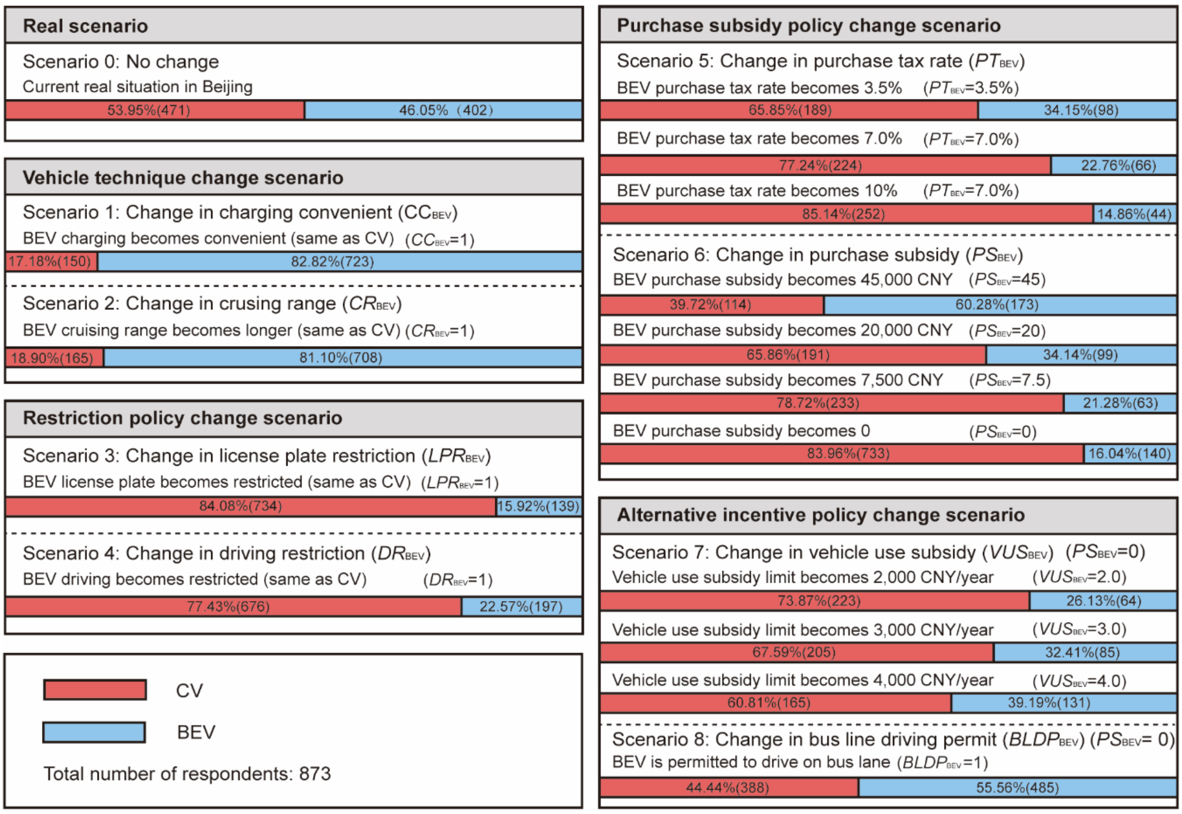


Figure 5. Choice result statistics for each scenario in the survey.

Figure 6 shows the statistics of personal attributes and travel information in the survey. For personal attributes, there is a high percentage of respondents 25–40 years old, their education level below a bachelor's degree, and an annual income over 200,000 CNY (28,789.4 USD). For travel information, such groups of respondents are the majority: no vehicles, having urgent vehicle purchase demand, purchase budget less than 200,000 CNY (28,789.4 USD), and daily travel distance less than 40 km. The above data covers all types of respondents required for the model used in this paper, and the sample size is sufficient, which can provide data support for subsequent model parameter estimations.

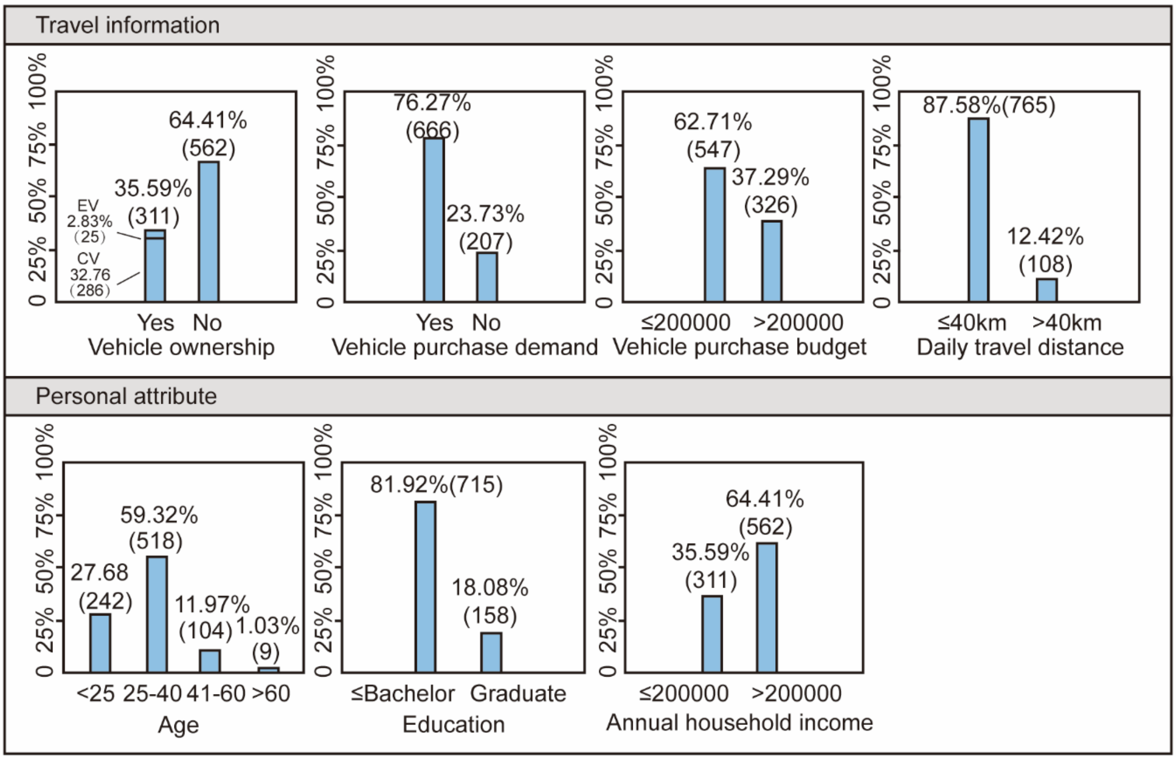


Figure 6. Statistics of basic information in the survey.

4. Results and Analysis

The parameters of the BL model are estimated in this section based on the above survey data, and the effects of each factor and alternative incentive policy on the BEV choice probability is analyzed based on the model results.

4.1. Parameter Estimation Results Analysis

The parameters of the BL model are estimated by the maximum likelihood estimation method, which can be implemented by some software. In this paper, we use the PythonBiogeme software [38] to perform BL model parameter estimations. Table 4 shows the parameter estimation results. In order to test the validity of the estimation results, a Student's t-test (t) is considered for verifying variable significance and the likelihood ratio test (ρ^2) for the goodness of fit. As can be seen from the table, except for *AGE3*, the significance levels of other variables are all under 5% ($|t| > 1.96$), which indicates that the parameter estimation results are statistically significant. $\rho^2 = 0.237$ indicates that the model's goodness of fit is acceptable.

To intuitively compare the effects of variables on BEV adoption intentions, the willingness-to-pay for parameter X (WTP_X) is defined as Equation (4):

$$WTP_X = Par_X / Par_{PS} \tag{4}$$

where Par_{PS} represents the parameter of the purchase subsidy (PS), and Par_X represents the parameter of variable X.

The rank in Table 4 indicates the sorting result according to the absolute value of each parameter, which is used to compare the effects of each variable on the BEV choice probability.

Table 4. Parameter estimation results of the BL model.

Category	Subcategories	Variable	Parameter (*Par*) BEV	Parameter (*Par*) CV	*t* value	WTP_X	Rank
Scenario variable	Vehicle technique	Charging convenience (*CC*)	1.23 ***	1.23 ***	7.24	27.8	5
		Cruising range (*CR*)	1.11 ***	1.11 ***	6.75	25.1	7
	Restriction policy	License plate restriction (*LPR*)	−2.11 ***	−2.11 ***	−12.14	−47.6	1
		Driving restriction (*DR*)	−1.67 ***	−1.67 ***	−10.69	−37.7	3
	Purchase subsidy policy	Purchase tax (*PT*) (%)	−0.150 ***	−0.150 ***	−10.95	−3.39	15
		Purchase subsidy (*PS*) (unit: 1000 CNY, i.e., 143.9 USD)	0.0443 ***	0.0443 ***	11.75	1.0	17
	Alternative incentive policy	Vehicle use subsidy (*VUS*) (unit: 1000 CNY/year, i.e., 143.9 USD/year)	0.293 ***	0.293 ***	8.16	6.61	12
		Bus line driving permit (*BLDP*)	1.72 ***	1.72 ***	11.2	38.8	2
Basic variable	Personal attribute	Age (*AGE1*) (<25)	1.54 ***	-	3.27	34.8	4
		Age (*AGE2*) (25–40)	1.16 **	-	2.47	26.2	6
		Age (*AGE3*) (41–60)	0.896 *	-	1.88	20.2	8
		Education (*EDU*)	0.190 **	-	2.22	4.29	14
		Annual household income (*AHI*)	−0.0972 **	-	−2.28	−2.19	16
		Daily travel distance (*DTD*)	−0.303 ***	-	−3.04	−6.84	11
	Travel information	Vehicle ownership (*VO*)	0.550 ***	-	7.66	12.4	9
		Vehicle purchase demand (*VPD*)	0.506 ***	-	6.27	11.4	10
		Vehicle purchase budget (*VPB*)	−0.229 ***	-	−2.92	−5.17	13
Constant			−5.68 ***	-	−8.17	−128	–
ρ^2			0.237				
Sample size			8730: 873 respondents × 10 questions				

* p <10%. ** p < 5%. *** p < 1%. Note: when the absolute t-value of the parameter is greater than 1.65, 1.96, and 2.58, the significance level is at 10%, 5%, and 1%, respectively. *WTP* = willingness-to-pay.

Next, the impact of each variable under the six different subcategories on BEV adoption is analyzed respectively based on the values of "Parameter", "WTP_X", and "Rank" shown above.

1. Vehicle technique parameters. The values of Par_{CC} and Par_{CR} are both positive, showing that the improvement of charging convenience and cruising range have strong promotion effects on BEV adoption intentions. It reveals that the improvement of the two in the future is crucial for potential consumers to purchase BEVs.
2. Restriction policy parameters. The values of Par_{LPR} and Par_{DR} are both negative, indicating that the license plate restriction and driving restriction policies for BEVs have strong negative effects on the BEV choice probability. The root cause of these results is that people's increasing demands for vehicles cannot be directly met. Besides, the absolute value of WTP_{LPR} is 47.6, and the rank of *LPR* is 1, which is the highest among all variables. It shows that the CV license plate restriction is the most significant factor in promoting BEV adoption.
3. Purchase subsidy policy parameters. The values of Par_{PT} and Par_{PS} are negative and positive, respectively, which indicates that as the BEV purchase tax rate increases or purchase subsidy decreases, the BEV choice probability will gradually decline. The value of WTP_{PT} is −3.39, which means that a 1% increase in the purchase tax rate has the same effect on the BEV choice probability as a reduction of 3390 CNY (488.0 USD) in the purchase subsidy. This value indicates that the attitude of potential consumers to these two policies depends not only on economic factors but also on the difference between their characteristics, which may include the following two aspects: On the one hand, the purchase tax is linearly related to the purchase price, while the purchase subsidy is less relevant. On the other hand, the tax exemption policy is a direct exemption which does not need the consumer to pay, while the purchase subsidy requires the consumer to pay first and then subsidizes the consumer.
4. Alternative incentive policy parameters. The values of Par_{VUS} and Par_{BLDP} are both positive, which show that the BEVs' vehicle use subsidy and bus line driving permit policy could increase the BEV choice probability. The value of WTP_{VUS} is 6.61, which means that the impact of the vehicle use subsidy increases by 1000 CNY/year (143.9 USD/year) (six years in total) on BEV

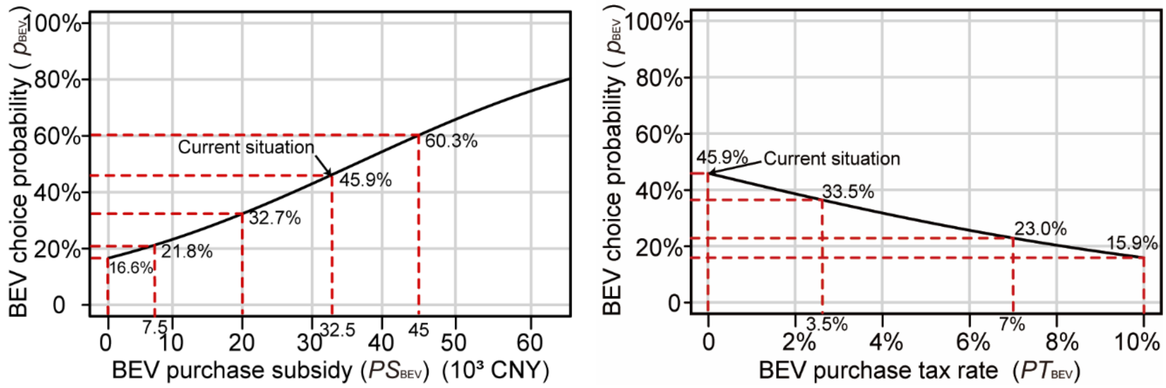
choice probability, equivalent to a purchase subsidy of 6610 CNY (951.5 USD). It shows that the potential consumers' perception differences between the purchase subsidy and vehicle use subsidy are not only in terms of the subsidy amount, but there may also be another reason: The purchase subsidy is a one-time subsidy when purchasing a vehicle. The vehicle use subsidy is a sub-annual subsidy, and its annual subsidy amount is related to the vehicle use frequency. The value of WTP_{BLDP} is 38.8, meaning that when the bus lanes allow BEVs to use them, their effects on BEV adoption is equivalent to a purchase subsidy of 38,800 CNY (5585.1 USD). The Rank of the *BLDP* is 2, revealing that the bus lane permission policy has a strong stimulating effect on BEV adoption intentions. The reason may be that severe traffic congestion during peak hours in Beijing prompts people to pay attention to this policy.

5. Personal attribute parameters. The values of the age (*AGE1*, *AGE2*, and *AGE3*) parameters are positive, which shows that the potential consumer under 60 years old is more likely to purchase a BEV, and the relationship between *AGE* parameter values is $Par_{AGE1} > Par_{AGE2} > Par_{AGE3}$, indicating that the younger the potential consumer, the more inclined to purchase a BEV. The ranks of *AGE1*, *AGE2*, and *AGE3* are 4, 6, and 8, respectively, which are the largest in the basic parameters. It indicates that, for potential consumers' personal attributes, age is the most significant factor affecting the BEV choice probability. The value of Par_{EDU} shows that potential consumers with a graduate degree are more inclined to purchase a BEV than others. The value of Par_{AHI} is negative, which indicates that potential consumers with annual household incomes below 200,000 CNY (28,789.4 USD) are more likely to purchase a BEV. These parameters illustrate that BEVs are more prevalent among potential consumers who are younger, with higher educations or lower household incomes. It reveals that the problem of how to improve BEV adoption intentions for potential consumers with different attributes needs to be further explored.
6. Travel information parameters. The value of Par_{DTD} is negative, which shows that the potential consumer whose daily travel distance is less than 40 km is more likely to purchase a BEV. It reveals that BEVs are more suitable for short-distance travel needs in the context of the shortcomings of its cruising range and charging convenience. The value of Par_{VO} is positive, indicating that potential consumers who already own vehicles are more likely to purchase a BEV. The reason for this phenomenon may be that the majority of vehicle ownership in Beijing is of CVs, whose driving restriction policy has a stimulating effect on BEVs, so users are more willing to purchase a BEV as a supplement to their travel needs. The value of Par_{VPD} is positive, which indicates that potential consumers with an urgent vehicle purchase demand are more likely to purchase a BEV, mainly because Beijing's license plate restriction policy makes CV adoptions extremely difficult. The value of Par_{VPB} parameter is negative, showing that potential consumers with a vehicle purchase budget below 200,000 CNY (28,789.4 USD) are more inclined to purchase a BEV. This is most likely due to the more significant incentives of the BEV purchase subsidy and tax exemption policy for low-purchase budget consumers.

Therefore, it can be concluded that the current BEV technical characteristics and incentive policies make them more suitable for the consumer who meets the conditions of "short-distance travel demand", "already own vehicle", "urgent vehicle purchase demand", or "low purchase budgets". This indicates that, in the future, it is necessary to explore the BEV purchase needs of potential consumers with different travel characteristics.

4.2. Alternative Incentive Policy Analysis

Based on the parameter estimation results, this section explores how to develop alternative incentive policies against the purchase subsidy policies' phase-out. To develop the specific alternative incentive policies, we first analyze the sensitivity of the purchase subsidy policies, including purchase tax and purchase subsidy (Figure 7). Keeping the values of other variables in the model fixed, the impacts of purchase subsidy and purchase tax rate on BEV choice probability are analyzed respectively.



(**a**) BEV purchase subsidy (**b**) BEV purchase tax rate

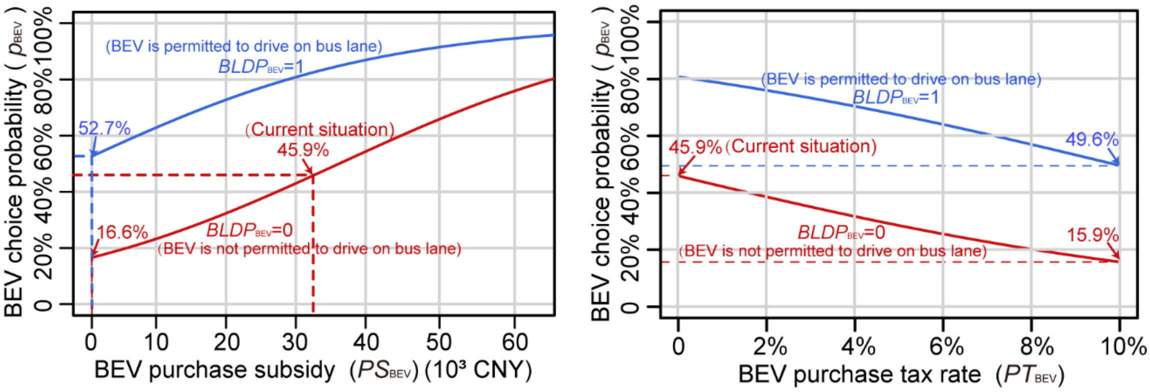
Figure 7. Sensitivity analysis of the BEV purchase subsidy and purchase tax rate.

In Figure 7a, there is a positive correlation between values of the BEV purchase subsidy and BEV choice probability. When the BEV purchase subsidies are 45,000, 32,500, 20,000, 7500, and 0 CNY (6477.6, 4678.3, 2878.1, 1079.6, and 0 USD), the BEV choice probabilities are 60.28%, 45.94%, 32.73%, 21.78%, and 16.62%, respectively. In Figure 7b, there is a negative correlation between the values of the BEV purchase tax rate and the BEV choice probability. When the purchase tax rates are 0, 3.5%, 7%, and 10%, the BEV choice probabilities are 45.94%, 33.46%, 22.93%, and 15.94%, respectively. The results of these two figures reveal that the phase-out of whether the purchase subsidy policy or tax exemption policy has greater impacts on the BEV choice probability, which also illustrates the necessity of implementing alternative incentive policies when purchase subsidy policies are canceled.

In order to develop a specific alternative incentive policy to determine the alternative relationship between the alternative incentive policy and the purchase subsidy policy, the impact of alternative incentive policies of the bus line driving permit (Figure 8) and vehicle use subsidy (Figure 9) on the BEV choice probability are analyzed under different purchase subsidy policies changes, which provide a quantitative reference for the formulation of alternative incentive policies.

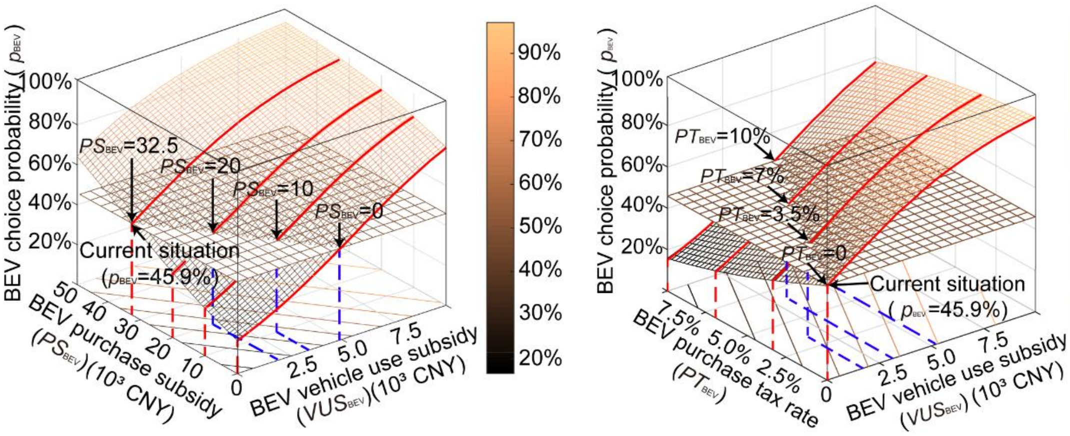
In Figure 8, the value of bus lane permission is positively correlated with the value of BEV choice probability. When the purchase subsidy or purchase tax exemption is canceled ($PS_{\mathrm{BEV}} = 0$ or $PT_{\mathrm{BEV}} = 0$), if the bus line driving permit policy is implemented on BEVs ($BLDP_{\mathrm{BEV}} = 1$) at this time, the BEV choice probability will become 52.67% and 49.56%, respectively, which are both higher than the original probability of 45.94%. This reveals that bus lane permission is an effective policy against the purchase subsidy policy phasing out. When the purchase subsidy policy or tax exemption policy phases out, the bus line driving permit policy for BEVs could be used to maintain and increase the original BEV choice probability.

In Figure 9, the curved surface represents the value of the BEV choice probability with changes in both the purchase subsidy policy (purchase subsidy or purchase tax exemption) and the vehicle use subsidy; the plane represents the BEV choice probability in the current situation ($p = 0.459$), and the curve intersecting the plane and the surface represents the alternative relationship between the subsidy policy (purchase subsidy or tax exemption) and vehicle use subsidy in order to maintain the original BEV choice probability. In Figure 9a, when the PS_{BEV} decreased to 20,000, 10,000, and 0 CNY (2878.9, 1439.5, and 0 USD), the VUS_{BEV} needed to be set at 1887, 3393, and 4962 CNY/year (271.6, 488.4, and 714.3 USD/year) to maintain the original BEV choice probability. In Figure 9b, when the PT_{BEV} increased to 3.5%, 7%, and 10%, the VUS_{BEV} needed to be set at 1940, 3596, and 5130 CNY/year (279.3, 517.6, and 738.4 USD/year) to maintain the original BEV choice probability.



(**a**) BEV purchase subsidy (**b**) BEV purchase tax rate

Figure 8. Alternative effects of the bus line driving permit (BLDP) against purchase subsidy policy phase-outs.



(**a**) BEV purchase subsidy (**b**) BEV purchase tax rate

Figure 9. Alternative effects of the vehicle use subsidy (VUS) against purchase subsidy policy phase-outs.

When the purchase subsidy policy or the tax exemption policy is canceled, the total six years (assumption of the survey) of the vehicle use subsidy are 29,772 and 30,780 CNY (4285.6 and 4430.7 USD), respectively, which are lower than the current purchase subsidy amount (32,500 CNY, i.e., 4678.3 USD). This difference may be due to the following reasons: (1) the fact that BEVs are becoming more popular in the future, and people's BEV adoption intentions will gradually increase under the same conditions, and (2) the fact that BEV users could still get higher vehicle use subsidies through their reasonable use in the context of purchase subsidies will phase out in the future. Therefore, people will be more willing to accept vehicle use subsidies in the future, although the total amount of vehicle use subsidies may be lower than the original purchase subsidies.

Besides, since the vehicle use subsidy is related to the annual usage frequency of BEVs, the actual subsidy amount of the vehicle use subsidy will be lower than the maximum subsidy amount. So, the implementation of the vehicle use subsidy policy could reduce the financial burden of the government under the premise of maintaining the original BEV choice probability. More importantly, it will stimulate the usage frequency of BEVs, which could promote the development of BEVs. Therefore, the vehicle use subsidy could play a good alternative role during the transition period of the purchase subsidy policy phase-out.

5. Conclusions and Discussion

5.1. Conclusions

Taking the Beijing BEV market as an example, a survey is conducted about potential consumers' basic information and BEV adoption intentions in different scenarios. Based on the survey data, the impacts of various factors on BEV adoption intentions are analyzed through establishing a BL model, especially the incentive policy factors. The major conclusions are summarized as follows:

1. According to the model results related to subsidy policies, the intensity of the alternative incentive policies against the subsidy decrease is quantified, including the vehicle use subsidy and bus lane permission. The results show that the alternative incentive policies have better economic and incentive effects than the subsidy policy, so they could play a good transition role during the period of subsidy policy decrease. When the purchase subsidy or purchase tax exemption policy is canceled, the BEV choice probability will be reduced from the original 45.94% to 16.62% and 16.15%. In this case, the implementation of the bus line driving permit policy would increase the BEV choice probability to 52.56% and 49.56%, respectively, which are higher than the original level of 45.94%. For the vehicle use subsidy policy, it needs to be set at the level of 4962 CNY/year and 5130 CNY/year (714.3 USD/year and 738.4 USD/year), respectively, to maintain the original choice probability.
2. This paper analyzed the impact of Beijing's unique restriction policies, including license plate restrictions and driving restrictions. The results showed that these two policies have significant negative effects on BEV adoption intentions. Notably, the license plate restriction policy is the most significant factor compared with other factors. Therefore, restriction policies for CVs, especially the license plate restriction policy, are the effective measures to promote the development of BEVs.
3. In terms of basic factors, the results show that BEVs are more acceptable among people who meet the following criteria: young, high education level, already owning vehicles, urgent vehicle purchase demand, lower income, short travel distance, and lower vehicle purchase budget. In terms of vehicle technical factors, charging convenience and cruising range have significant positive impacts on BEV adoption intentions, which show that these two factors urgently need to be improved for the BEV choice probability.

5.2. Discussion

According to the statistical analysis and results analysis of this paper, the purchase subsidy has a strong stimulating effect on BEV adoption intentions and has a good incentive effect. This result is consistent with the conclusions of some studies [24–29]. However, for the current BEV market in many cities, there are few related studies on the purchase subsidies gradually phasing out, especially regarding countermeasures and alternative incentive policies. In response to this problem, this paper proposes two alternative incentive policies (i.e., vehicle use subsidy and bus lane driving permit) against purchase subsidy phase-out and proves the feasibility of these two alternative policies. The results provide references for future policy developments.

In terms of other BEV incentive policies, many researchers have carried out related research, such as special lane driving permits, parking incentives, charging infrastructure development, road toll fee waivers, and licensing incentives [31,32]. However, few studies have focused on China's unique restriction polices. This paper quantifies the incentive effect of restriction policies (license plate restrictions and driving restrictions) on BEV purchase intentions. The results show that the incentive effect of restriction policies is much higher than other incentive policies and provide a reference for the development of restriction policies in Beijing and other regions in the future.

Future related research should focus on the specific forms of alternative incentive policies (e.g., parking fee discount, charging cost subsidy, and congestion charge discount) applicable to different regions, since different forms of policies may have different effects on BEV adoption intentions in a specific city. This paper treated all these policies as the vehicle use subsidy policy, which can give guidance on policy formulation at the macro level, but when it is specifically implemented in different countries, it is necessary to determine its specific form based on actual conditions. Besides, this paper only studied the behavior and related polices of BEV choices, and further analysis of their environmental benefits is lacking. Future research should also pay attention to the role of BEV development in emission reductions under different scenarios of incentive policies. Based on studies on travelers' BEV purchase behaviors, usage behaviors, footprints, etc. [6,39], the impact of BEVs' roles in emission reductions can be quantified and used as a reference for the development of future emission reductions.

Author Contributions: Conceptualization, T.L.; data curation, T.L.; funding acquisition, E.Y.; investigation, F.J. and L.P.; methodology, T.L. and E.Y.; software, F.J.; supervision, E.Y.; validation, T.L. and F.J.; writing—original draft, T.L.; and writing—review and editing, E.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Fundamental Research Funds for the Central Universities (No. 2019YJS106).

Conflicts of Interest: The authors declare no conflicts of interest.

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