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Evolutionary Game of Actors in China's Electric Vehicle Charging Infrastructure Industry

Mu Li [1,*], Yingqi Liu [1] and Weizhong Yue [2]

[1] School of Economics and Management, Beijing Jiaotong University, Beijing 100044, China
[2] Beijing Municipal Commission of Housing and Urban-Rural Development, Beijing 101160, China
* Correspondence: 21113083@bjtu.edu.cn

Abstract: China proposed a development direction of "new infrastructure" in 2020, due to the ongoing scientific and technological revolution and industrial transformation. The charging station industry is one of the seven industries of the "new infrastructure". Hence, it is of great importance to study China's electric vehicle charging infrastructure industry. Based on game theory, this study analyzes the game strategies for the evolution of actors in China's electric vehicle charging infrastructure industry. Firstly, the Chinese government has classified the industry according to the subsidy for charging piles and battery swapping stations. Then, the government, operators, and consumers constructed an evolutionary game model. The results show that: (1) under the investment subsidy mode, the purchase cost that consumers invest in purchasing traditional fuel-consuming vehicles has a positive impact on the operator's production enthusiasm. In addition, the government's subsidy amount has a positive impact on consumers' decision to purchase battery-swappable electric vehicles; and (2) under the operational subsidy mode, due to the government's strong supervision of the industry, there is a positive correlation between the word-of-mouth effect and the consumer's decision to buy rechargeable electric vehicles.

Keywords: game; electric vehicles; charging infrastructure industry; actors

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1. Introduction

The rapid growth of global energy demand and the increase in environmental pollution has attracted the global community's attention to energy transition and environmental protection. Due to the advantages of energy saving and environmental protection, electric vehicles (EVs) have become an effective solution for countries to implement strategies and plans for reducing energy and pollution. Recently, EVs have undergone exponential development. The EV industry is one of the ten key areas of the "Made in China 2025" initiative, serving as an important carrier for the development of electrification, intelligence, networking, and sharing in the automotive industry. The COVID-19 pandemic has exerted pressure on the construction and operation of public charging piles. On 14 February 2020, the 12th meeting of the Central Committee for Comprehensively Deepening Reform classified EV charging piles as one of the seven areas of China's "new infrastructure", and the government accurately and efficiently supports constructing and upgrading the EV charging piles. Under the context of China's industrial structure upgrading and kinetic energy conversion, for a period of time in the future, the "new infrastructure" will be the focus of the Chinese government. Progress in the EV charging industry not only develops and upgrades the EVs, but also provides developmental opportunities for emerging industries, such as smart micro grid and wireless smart charging. In the EV charging infrastructure industry, the actors experience important changes with the ongoing development of the industrial chain. A vital proposition is to analyze how actors compete and affect industrial development.

The EV industry is very complex since it depends not only on internal factors, such as technologies and the market, but also on the support of the government and other external factors [1]. Subsidy is one of the means for the government to effectively promote economic activities related to the EV industry. By formulating various subsidy policies, the government encourages industrial development and enterprise innovation [2,3]. The EV charging infrastructure faces problems, such as insufficient charging piles, poor operation, and weak profitability, which is one of the shortcomings in the EV industry, restricting the development of the industry. Today, the EV charging industry is in a critical phase of development. Hence, studying the game process and adopting the subsidy strategies play an important role in China's charging infrastructure industry and effectively promoting industrial development.

With the rapid development of the new energy industry, the EV charging industry has become a hot research topic, such as charging station layout optimization, charging facility demand forecast, and business models. A group of scholars have devoted themselves to solving the problem of charging pile location [4–10]. Wang et al. described the planning of charging station network as a mixed integer programming problem, and solved the modified flow-refueling location model (FRLM) using a branch-and-bound algorithm [11]. Similarly, He et al. used U.S. long-distance travel data to place charging stations and described the problem as a mixed integer program. Then, they employed a branch-and-bound algorithm to solve a modified FRLM [12]. Wang et al. established an expanded network structure to model the set of valid charging strategies for EV drivers, then formulated a variational inequality (VI) to capture the equilibrated route-choice and charging behaviors of EVs by incorporating an approximated queuing time function for a capacitated charging facility [13]. Shi proposed a hierarchical charging decision model to describe the charging decision behavior of electric vehicle users, and then used the queuing theory model to plan the charging station capacity allocation problem [14].

Another strand of studies has focused on the prediction of charging demand [15–17]. Arias and Bae used the data of historical traffic and weather in South Korea to formulate a forecasting model which estimates electric vehicle charging demand based on big data technologies [18]. Amini et al. presented an autoregressive integrated moving average method for the demand forecasting of conventional electrical load and charging demand of EV parking lots simultaneously, and the model takes daily driving patterns and distances as an input to determine the expected charging load profiles [19]. Majipour et al. forecasted the EV charging load based on the charging record of customers and the station record of charging piles [20]. Jia provided a dual-stage attention-based recurrent neural network model to predict the future trajectories of idle electric taxis and recommended the proper charging pile for the electric taxi [21].

Other researchers have conducted in-depth studies on the development of charging infrastructure industry. Ahman took the electric vehicle development in Japan as a research object and analyzed from the perspective of public finance the main factors supporting the construction of charging infrastructure are technological progress and policy support [22]. Schroeder and Traber conducted a case study on the expected return on estimated return on investment of a public fast charging station in Germany, finding that investment would be hardly profitable at low EV adoption rates, and the general EV adoption rate would be detected as a main risk factor for investment in public charging infrastructure [23]. Li et al. showed indirect network effects on both supply and demand sides of the EV market in the US and found a stronger network effect on the demand side [24]. Zhou and Li find that more than half of U.S. metropolitan statistical areas (MSAs) face critical mass constraints and that a subsidy policy targeting these critical-mass constrained MSAs could be much more effective in promoting EV adoption than the current uniform policy [25].

In addition, some studies focus on the subsidies for EVs [26–30]. In recent years, many local governments have issued subsidy policies for the construction and operation of charging piles, and researchers have studied the EV charging industry to provide relevant policy suggestions. Chen et al. reported that only a high subsidy can promote EV acceptance among consumers [31]. Statharas et al., taking Greece as an example, proposed that publicly financed infrastructure deployment is important for the first years, but in the mid-term, subsidization of the costs of charging points is necessary to positively influence the uptake of private investments [32]. Baumgarte et al. studied the profitability of fast charging infrastructure (FCI) along the German freeway. The results showed that investment subsidies or the exemption from the electricity tax do not contribute significantly to a widespread expansion of FCI, and the profitability of FCI strongly depends on the location's surrounding charging facilities and population characteristics [33]. Huang and Liu established a policy evaluation system. By comparing the effects of the charging facility and vehicle purchase subsidy modes, they found that charging station and purchase-related subsidies significantly affect the promotion of EVs. In the subsidy decline period, subsidies for charging infrastructure are an important policy direction for the promotion of EVs [34]. Chen et al. studied the synergistic impacts of the subsidy fall-off period and the "double credit" policy on developing the EV industry. The "double credit" policy was an adequate substitute for subsidies [35]. Regarding the characteristics of charging infrastructure, Zhang et al. explored the government's investment, financing, and fiscal policies and proposed policy suggestions based on the government's experience in charging infrastructure construction [36]. Despite expressive achievements in the policy research on charging infrastructure in recent years, few researchers have presented in-depth discussions on the game relationships among the government, charging station operators, and consumers for the cases of EV charging piles and battery swapping stations.

Our research follows the previous studies to investigate (1) the interactions of government, charging station operators, and consumers; (2) the effect of the government's subsidy policy on their game relationships; and (3) the starting points for future government subsidies. This study aims to obtain optimal effects of subsidy policies and promote the development of the charging infrastructure industry.

2. Policies Related to Development of the Charging Infrastructure Industry in China

The construction of charging piles was first proposed in *Energy Saving and New Energy Vehicle Industry Development Plan (2012–2020)* issued by The State Council in 2012 [37]. In 2013, The State Council suggested establishing a 500,000 EV charging infrastructure system by 2015 [38]. In October 2015, The General Office of the State Council issued *The Guideline on Speeding Up the Construction of Electric Vehicle Charging Infrastructure*, which clarified the policy direction of the charging pile industry for the first time [39]. Then, the promotion subsidy policy for new energy vehicles changed from subsidizing new energy vehicles to subsidizing charging infrastructure [40]. *The Government Work Report* covered charging piles for the first time in 2020, as supporting facilities for the promotion of new energy vehicles which became one of the seven major industries of "New Infrastructure Construction" [41]. *New Energy Vehicle Industry Development Plan (2021–2035)* predicts that pure electric vehicles will become the mainstream of new sales vehicles by 2035. Hence, policymakers should promote financing the construction of charging piles as public facilities [42]. This section summarizes the relevant policies which China issued for EV charging infrastructure construction from 2012 to 2020. The policies are notices, announcements, measures, and opinions of the government and regulatory authorities. We also include legal documents and strategic plans for industrial development. Totally, the policies on EV charging infrastructure have three categories, including subsidies and incentives, regulations and standards, and strategic plans. Figure 1 shows the number of policies that China has issued each year.

Figure 1 displays that the number of policies related to the EV charging infrastructure industry continuously increased in China from 2012 to 2020, especially after 2014. In 2014 and 2015, China released government policies on the incentives for constructing charging facilities and the promotion of EVs. These policies have not only played an essential role in promoting the development of China's charging infrastructure industry, but also contributed to the formulation and release of subsequent industrial policies.

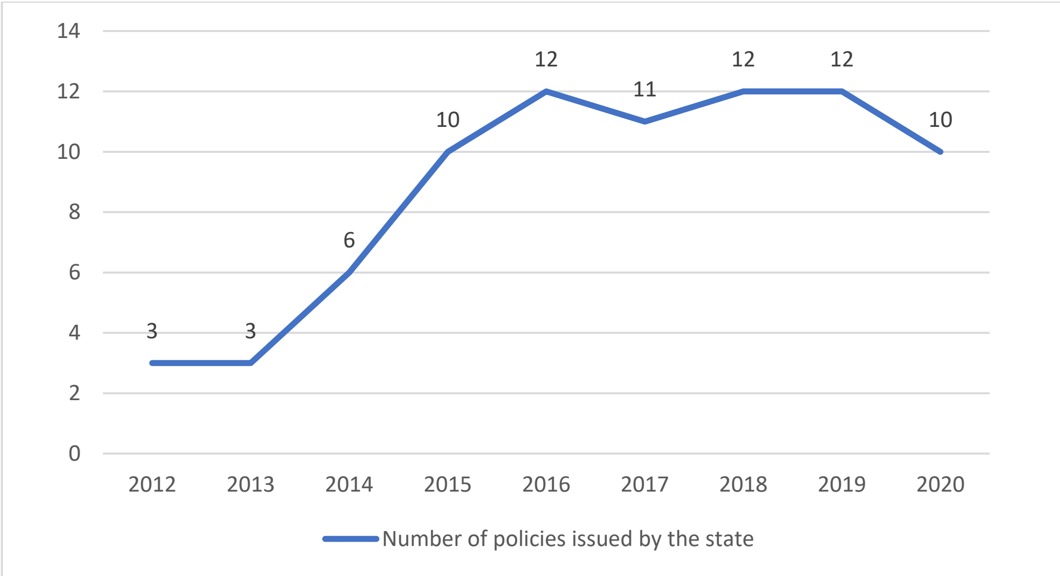

Figure 1. Number of policies related to charging infrastructure construction from 2012 to 2020 (at the national level). Data Source: public policy documents of the government.

In terms of the policy content, early policies on charging infrastructure are mainly based on the EV industry policy, not particularly for the development of charging infrastructure. For instance, the Ministry of Science and Technology formulated a special plan for the scientific and technological development of EVs in 2012, which described the significance of the EV industry and its development and technical path. This plan briefly explains the design specifications, technical standards, communication protocols, and charging interfaces in 2015. At that time, the construction of charging infrastructure was only regarded as a supporting facility for developing the EV industry. In 2015, releasing a special guideline for charging pile infrastructure launched a new era for developing EVs. Since then, China has released a series of policies on charging infrastructure construction, and notably formulated corresponding guidelines in 2015 to encourage the public-private partnership model in the process of charging infrastructure construction. Moreover, this country promotes the social capital for developing and stimulating the EV industry, which constructs an adequate pricing model under the market-oriented mechanism and accelerates the construction of charging piles in major cities in China.

3. China's EV Charging Infrastructure Market

According to the China Association of Automobile Manufacturers, the production and sales of new EVs reached 3.545 and 3.521 million, respectively, a 160% year-on-year increase in 2021 [43]. Public charging infrastructure has 71.7% share in Guangdong, Jiangsu, Shanghai, Zhejiang, Beijing, Hubei, Shandong, Anhui, Henan, and Fujian [44]. China has introduced a series of policies to encourage constructing EV charging piles. Moreover, many local governments have adopted implementation policies, including development plans and guidelines, and the construction of charging piles in residential areas and public places. These policies effectively promote developing China's charging infrastructure industry. Coordinating multiple departments of the central ministries and commissions solves the problems, such as the capital source, construction scheme, urban planning and layout, electricity pricing mechanism, and unifying the infrastructure standards of charging infrastructure, which provides key support for the development of the charging infrastructure industry.

During the charging infrastructure construction and promotion, different regions have issued several detailed regulations regarding their own characteristics. These regulations provide standards and guidelines for the construction and operation of local charging infrastructure, which promotes the operation on a market-oriented and standardized track. For instance, the *14th Five-Year Energy Development Plan of Beijing* shows that Beijing has built a total of 256,000 charging piles by the end of December 2021, expected to reach 700,000 by 2025 [45]. Shanghai offered 30% of financial subsidies for the charging infrastructure manufacturers and operators, and provided a subsidy of 600 and 300 Yuan/kW, respectively, pursuant to different direct and alternating current infrastructure [46]. These subsidies encourage people for purchasing EVs, reducing environmental pollution, and construction of charging infrastructure. The *14th Five-Year Innovative Department Plan for Intelligent and EVs of Guangzhou* issued in Guangdong Province announced that the new residential communities in Guangzhou should completely implement the construction of charging piles for fixed parking spaces or reserve installation conditions for the construction of charging piles during the14th Five-Year Plan [47]. Jiangsu Province issued the *14th Five-Year Industrial Development Plan for EVs of Jiangsu* Province at the end of 2021. This plan predicts building over 800,000 charging piles in Jiangsu, including 200,000 public charging piles and a total of 500 battery swapping stations, as well as reasonably distributing the charging and battery swapping network [48]. In 2022, Chengdu City in Sichuan Province issued *The Action Plan for Air Pollution Prevention and Control of Chengdu* which proposed that the number of new charging (or battery swapping) stations and the charging piles should, respectively, be over 350 and 20,000 in 2022 [49]. In 2021, the charging and battery swapping infrastructure developed rapidly in Chongqing, and scientists built 14,500 new charging piles, a 40.96% annual increase [50]. Figure 2 shows that the construction scale of public charging piles presents an annually stable and rapid growth trend in China with various policies. Figure 3 presents the difference in the number of the newly built public charging stations of different provinces in China.

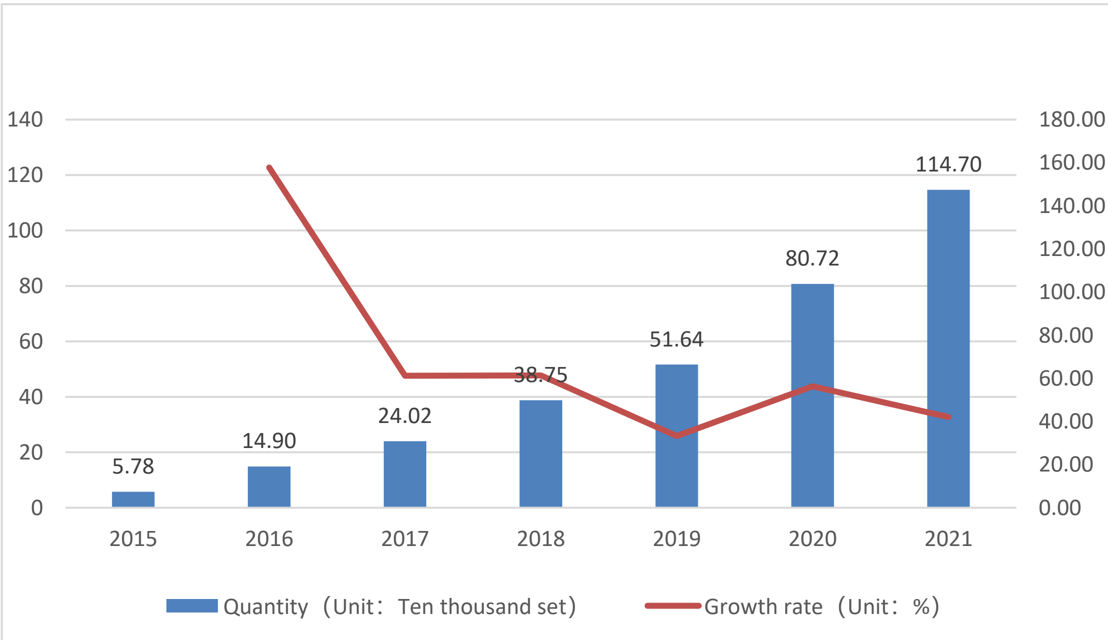

Figure 2. Number of public EV charging piles in China from 2015 to 2021. Data source: China Electric Vehicle Charging Infrastructure Promotion Alliance.

In terms of the charging infrastructure construction in different regions and administrative levels, the charging infrastructure has a large proportion (>70%) in economically developed cities. Currently, the charging capacity is relatively concentrated in Guangdong, Shanghai, and Jiangsu. Particularly, the main charging demands are from private vehicles and buses, while sanitation vehicles and taxis seldom use charging piles. Our results show that the current distribution of charging piles is reasonable, and its frequent use is ceaselessly increasing in China.

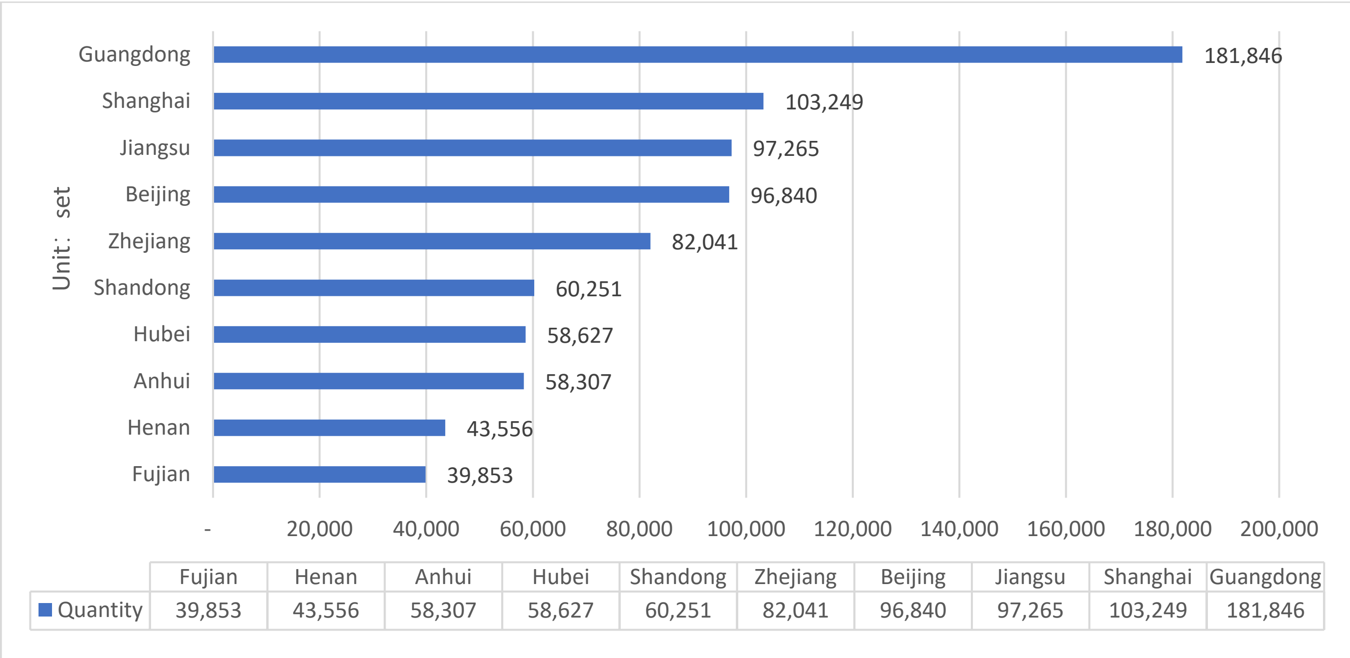

Figure 3. Ranking the public charging piles in China in 2020. Data Source: China Electric Vehicle Charging Infrastructure Promotion Alliance, China ASKCI Industry Research Institute.

From the perspective of charging infrastructure operators, nine operators mainly manage China's charging piles. Figure 4 represents the number and market share of charging piles owned by each operator.

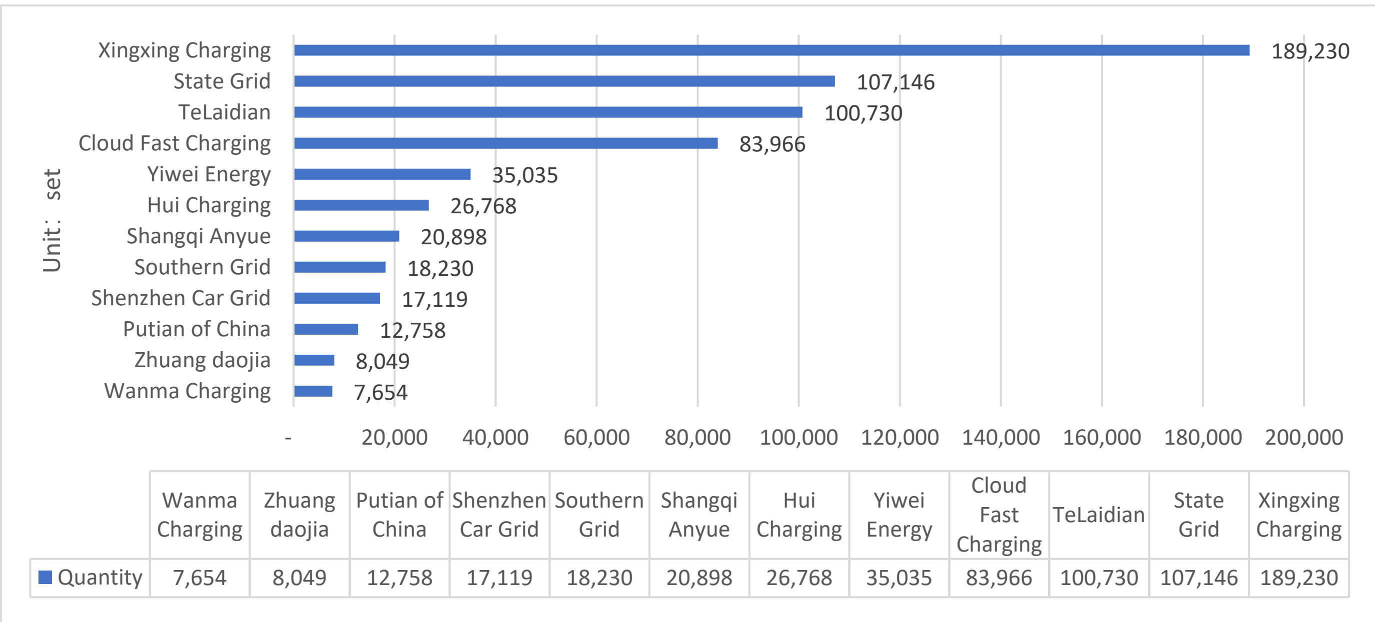

Figure 4. Ranking the market share of charging pile operators in China in 2021. Data source: Public policy documents of the government.

By the end of 2021, three operators had more than 10,000 charging piles, of which Star Charge ranked the first, with 189,000 charging piles. Figure 3 displays the charging piles owned by the top 12 operators, which have more than 90% of the charging piles in China.

4. Methodology

Game means that one or several people or teams with absolute rational thinking choose and implement their own behaviors or strategies, and obtain corresponding results or benefits from them under certain conditions while obeying certain rules. The behavior subjects with limited rationality (participants in game problems) are called "bounded rational" game players. Evolutionary game theory is the product of combining classical game theory with evolutionary physics. To reflect this characteristic of evolutionary physics, evolutionary game theory abandons the hypothesis of the completely rational individual in classical game theory, but assumes that the individual is bounded rationally. Individual bounded rationality appropriately represents the influence of evolutionary dynamics on the game results, reflected in a series of behavior patterns of players, such as how to learn successful strategies and how to make decisions by using experience. Evolutionary game is a theory to study the predicted and actual behaviors of decision-making individuals. Therefore, many scholars use this tool, most of them consider two-party game subjects, and few study tripartite game subjects. Bowles et al. employed an agent-based simulation model according to the concept of homogeneous group structure population and analyzed the coevolution dynamics of individual behavior and group behavior [51]. Trauslen et al. analyzed the difference and connection between the deterministic evolution dynamics of an infinite population and the stochastic evolution dynamics of a finite population, and extended the stochastic evolution dynamics of a finite population from low to high dimension [52]. Huang and Wang applied evolutionary game theory to simulate the different and bounded rational bidding strategies of generator companies, and quantitatively evaluated the model through practical examples [53].

Game theory solves multi-party decision-making problems, evaluates the players' strategies in the game under specific conditions, implements counterstrategies, and obtains an equilibrium among the players [54]. Researchers use the game theory to study the strategies in the game between the government and new energy vehicle enterprises, yielding remarkable achievements. Wang and Liao used a two-stage game to investigate the behavioral strategies of the government and enterprises in the R&D subsidies for EVs. Particularly, researchers studied the strategic selections of all parties under the condition of information asymmetry and presented policy suggestions [55]. Wang discussed the game between government subsidies and business operations in the EV market in stages based on the industrial life cycle theory [56]. Zhong and Du employed the signal transmission game model to explore the adverse selection problem of the government and vehicle manufactures [57]. Zhao and Zheng developed a dynamic game model according to the dynamic system theory to analyze the impact of different subsidies on vehicle manufactures [58]. Sun and Lv built an evolutionary game model of government and manufactures to simulate their behavioral choices as various factors change. According to the results, the government and vehicle manufactures maximize their own interests regarding the manufactures' decisions and subsidy changes [59]. Li et al. considered the market of three primary players, the new energy vehicle manufacturer, the fuel vehicle manufacturer, and government, to formulate non-cooperative game models which consider the battery recycling rate and consumers' environmental awareness [60]. Yu et al. introduced a sequential game model for the interactions between an EV charging station (EVCS) investor and electric vehicle (EV) consumers to show that the market solution underinvests EVCSs, leading to slower EV diffusion [61].

With the continuous development of game theory and the evolution of new energy vehicle industry in recent years, more and more scholars have used evolutionary game theory to analyze the impact of government subsidy policies on the development of the new energy vehicle industry. Gao et al. used evolutionary game theory to conclude that subsidies should be within a reasonable range, and found that reducing production costs, improving production efficiency, and bravely breaking technical bottlenecks are the key points for the development of new energy automobile industry [62]. Based on their modeling analysis on the evolutionary game model, Cao et al. found that government purchase would promote the expansion and development of the new energy industry to a certain extent, but only under a sound regulatory punishment mechanism could it help to optimize the industrial structure [63]. Ji et al. applied evolutionary game theory to examine the interaction mechanism of complex behaviors between local governments and automobile manufactures and proposed that subsidy policy phase-outs can help to develop the new energy vehicle industry [64]. Gu et al. adopted Stackelberg game theory to understand how government subsidies should be allocated in order to maximize total profit of the whole supply chain (consisting of government, an electric/gasoline vehicle manufacturer, a retailer, and consumers) [65]. Cheng et al. developed a newsvendor game model of a two-stage EV supply chain to study the optimal decisions of EV manufacturers and EV sellers by considering the subsidy reduction policy and stochastic demand of the EV market [66]. Chakraborty et al. used a game-theoretic approach and studied how using a combination of subsidy on EV and green-tax on conventional gasoline vehicles (GV) affected overall social welfare, environmental impact, and vehicle stock in monopoly and duopoly forms of market structures [67]. Liu et al. built an evolutionary game model between automobile manufacturers and governments to analyze the effects of governmental emission taxations and subsidies on the decision making of automobile manufacturers and on the dynamic tendency of the EV industry. Moreover, they divided the evolutionary stable strategy of the evolutionary game between governments and auto manufacturers [68]. In addition, they established an evolutionary game model between governments and vehicle producers (including electric vehicles and fuel vehicles) and analyzed the mechanism of government incentive policy (government subsidies and carbon tax) influence on vehicle producers' decision-making [69]. Zhou et al. proposed a system dynamics-based evolutionary game theoretical analysis to examine the impact of policy incentives (including price subsidy and taxation preference) on EVs industry development [70]. Sun et al. considered the limited rationality of governments, new energy vehicle (NEV) enterprises and consumers, and studied the subsidy policy of the China NEV market using the evolutionary game and system dynamics methods [71].

Previous studies show that game theory is a relatively mature and effective research method in the field of new energy automobile industry. This research builds an evolutionary game model for stakeholders of China's new energy vehicle charging infrastructure industry, explores the game relationships among the government, operators, and users, and provides theoretical guidance for policy formulation and industry development.

5. Construction and Analysis of Evolutionary Game Model

5.1. Model Description and Assumptions

This study considers three game-participants, including government, operators, and consumers in an evolutionary game model. All the three players maximize their own interests and adjust the strategies based on their rewards. Each player has two strategies in the evolutionary game model. The government's strategies are "subsidy" and "no subsidy", operators' strategies are "active" and "passive", and consumers' strategies are "purchasing EVs" and "purchasing traditional fuel-consuming vehicles". Researchers studied the behavioral interaction among the three players and analyzed the evolutionary stable state of the system under different circumstances and the factors affecting the evolutionary stable state.

This study has the following assumptions for the dynamic game relationship among the government, operators, and consumers.

1. The game consists of three participants, including government, operators, and consumers. Players aim to maximize their own interests. The set of players is N = {1,2,3}, where 1 represents the government, 2 shows the charging pile/battery swapping station operators, and 3 denotes the consumers.
2. The game is evolutionary and belongs to the dynamic game category. The participants of the game follow a certain game order, which is government-operators-consumers, and all players share the reward information of each player.

3. The charging pile/battery swapping station operators follow the government's policy guidance, and the government obviously knows the investment, operating costs, and benefits of the operator. In addition, the operators and the government have an obvious understanding of consumers' purchase and usage information, usage cost, and consumption cost. In addition, the consumers know the government policies and the operators' services. Hence, the information is symmetrical among the government, operators, and consumers.
4. According to existing policies, policy directions, and the development trend of the industry, the government tends to shift the original subsidy for vehicle purchases to the construction and operation of charging infrastructure. Thus, this study assumes that the government no longer offers subsidies to consumers and only gives subsidies to charging pile operators and battery swapping operators.
5. In the trilateral game among the government, operators, and consumers, x_H is the proportion of the investment subsidy mode, x_C is the proportion of the operational subsidy mode, y_H is the proportion of the battery swapping stations cooperating with the government's subsidy policy and implementing active production, y_C is the proportion of the charging pile operators cooperating with the government's subsidy policy and implementing active production, z_H is the proportion of consumers purchasing the battery swappable EVs, and z_C is the proportion of consumers purchasing the battery swappable EVs ($0 \le x_H, x_C, y_H, y_C, z_H, z_C \le 1$).

As the driver and supervisor of the EV charging infrastructure industry, the government plays a key role in maintaining market stability, reducing vicious competition, and reasonably allocating resources. The government financially supports R&D, production and sales of EVs and ensures the smooth production and sales of EVs with the active subsidy policies. S_C and S_H are operational and investment subsidy amounts. To evaluate whether the EV charging infrastructure industry meets the relevant industrial standards, the government supervises its development, and the supervision cost is Cg. Governmental supervision enhances consumers' purchase confidence and produces a positive social word-of-mouth effect G_1. Qualified charging piles and battery swapping stations bring positive social and environmental benefits G_2. The government finds operators producing and selling unqualified charging piles and battery swapping stations with an amount of T after consumers purchase their products. The government subsidizes consumers purchasing EVs in vehicle purchase tax and value-added tax. The subsidy amount is M, which stimulates the demand for EVs and develops the EV charging infrastructure industry.

Operators have an initial cost of C to produce charging piles or battery swapping stations. Based on the initial cost C, operators adopt active production strategies and introduce charging and battery swapping production technologies, with the investment costs of ΔC_{C1} and ΔC_{H1}, and the income after sales are P_{C1} and P_{H1}, respectively. ΔC_{C2} and ΔC_{H2} are the investment costs of operators adopting passive production strategy ($\Delta C_{C2} < \Delta C_{C1}$ and $\Delta C_{H2} < \Delta C_{H1}$), and P_{C2} and P_{H2} are the income after sales, respectively. In addition, E_2 is a disposal cost of the government, due to the environmental problems brought by maintenance and disposal of unqualified charging piles and battery swapping stations resulting from the passive production strategy.

If consumers purchase traditional fuel-consuming vehicles, the purchase cost is C_0 and the value of the physical asset is V. If they purchase EVs, the purchase cost is C_C. If they receive good charging services, they get a physical asset of V, and an additional utility of U_{C1}. If they do not enjoy a good charging or battery swapping service, the additional utility is U_{C2} ($U_{C2} < U_{C1}$). If the consumers purchase battery swappable EVs, the purchase cost is C_H ($C_H < C_C$), and the lease cost is C_R. If they receive good battery swapping services, they get a physical asset of V and an additional utility of U_{H1}. If they do not receive good charging or battery swapping services, the additional utility is U_{H2} ($U_{H2} < U_{H1}$).

5.2. Strategy Analysis under Different Subsidy Policies

5.2.1. Analysis under the Operational Subsidy Mode

1. Government's strategy

In China, people consider the EV industry as a strategic emerging industry, so the government has the responsibility to guide its development and offer certain financial subsidies and policy guidance to promote the healthy and rapid development of the industry. In the early stage of development, the new energy industry is restricted in many aspects, such as the market and products, so the government needs to offer support and subsidies to promote industrial development. When offering subsidies, the government has to make flexible adjustments for conforming to the actual development of the industry regarding its own benefits and investment. The government's benefits mainly include environmental and economic paybacks.

When the government offers operational subsidies, the main subsidized party is charging pile operators. We assume that the utilization rate of a single charging pile and the power of charging piles are constant, and the number of charging piles correlates with the subsidy amount. Hence, the government strategy reflects the subsidy strength for charging pile operators.

2. Operator's strategy

If government subsidies are operational mainly for operators, and all charging stations can maintain a certain power, the main strategy for charging pile operators is to increase the number of charging piles to obtain more revenue. Operators refer to the enterprises involved in the construction and operation of charging piles. Since constructing the charging piles requires substantial findings, investment returns are costly and require a long time, which restricts the development scale of charging piles. If the government offers corresponding subsidies or policy support, it fully develops the industry. These subsidies alleviate the capital pressure of enterprises, improve the speed of their capital turnover, and reduce investment and operational risks, helping them get through the initial difficult time. If enterprises can receive financial subsidies, and the amount of government subsidies is based on the operation and number of charging piles, the enterprises can only get more subsidies by producing more charging piles. Therefore, pile operators have two types two of charging strategy: "active" and "passive" production.

3. Consumer's strategy

Charging pile operators provide charging services to consumers who need to charge their EVs. The more advanced the development of the charging pile industry, the greater the consumers' charging experience. Compared with the consumers using the battery swapping method, the charging consumers need to pay the purchase price of the full vehicle, and the charging method often takes a much longer time, thus, consumers have a certain time cost. The purchase number of EVs mainly reflects the consumer's strategy. Consumers have two purchasing strategies: charging EVs and traditional fuel-consuming vehicles.

5.2.2. Analysis under the Investment Subsidy Mode

1. Government's strategy

When the government adopts the investment subsidy mode, it mainly provides the subsidy to the operators of the battery swapping stations, and the construction investment has a positive correlation with the subsidy amount. In this case, the government's strategic selection reflects the investment subsidy strength.

2. Operator's strategy

When the subsidy mode is investment subsidy for operators of the battery swapping stations, i.e., the enterprises that participate in the operation and construction of the battery swapping stations, the risk level is relatively high, and the government subsidy encourages developing the battery swapping stations. This effect is the result of the relatively high fixed cost. The battery swapping stations provide battery replacement services, and the battery swap time is typically very short, which reduces the consumer's consumption cost and enables the consumers to obtain good services. The main strategy of the battery swapping stations is the investment amount. If the battery swapping stations have a complete layout, consumers enjoy charging services more conveniently. In addition, the battery swapping stations manage the battery while bringing battery recycling benefits through effective battery management. Thus, the battery swapping operators have two strategies: active and passive production.

3. Consumer's strategy

In the early stage, the government gave consumers purchase subsidies. With developing the industry, the government began to adjust the subsidy policy. The purchase subsidies for consumers gradually declined and are gradually shifted to the charging field, which reduces the amount of direct subsidy received by consumers. For battery swapping consumers, battery rental companies provide battery rental services, battery replacement, and maintenance services for them. In this case, consumers do not have to purchase the battery, but only need to pay the rental fee, which relieves their economic burden. Consumers have two purchasing strategies: battery swappable EV and traditional fuel-consuming vehicle.

5.3. Reward Expectation Function Construction

In the evolutionary game among the government, operators, and consumers under the investment subsidy mode, the government has two possible decisions: to subsidize and not to subsidize. The probabilities are x_H and $1 - x_H$. Operators have two possible decisions: active and passive production, respectively, y_H and $1 - y_H$. The consumer's strategy set includes purchasing battery-swappable EVs and purchasing traditional fuel-consuming vehicles, and the probabilities are z_H and $1 - z_H$, respectively. Table 1 shows the reward matrix for the government, operators, and the consumers under the investment subsidy mode.

Table 1. Reward matrix in the evolutionary game among the government, operators, and consumers under the investment subsidy mode.

		Operators	
		Active Production y_H	**Passive Production $1 - y_H$**
Government	**To subsidize, x_H**	$G_1 + G_2 - S_H - C_g - M$	$G_1 - S_H - C_g - E_2 + T - M$
		$P_{H1} + S_H - C - \Delta C_{H1}$	$P_{H2} + S_H - T - C - \Delta C_{H2}$
		$U_{H1} + V + M - C_H - C_R$	$U_{H2} + V + M - C_H - C_R$
	Not to subsidize, $1 - x_H$	G_2	$-E_2$
		$P_{H1} - C - \Delta C_{H1}$	$P_{H2} - T - C - \Delta C_{H2}$
		$U_{H1} + V + M - C_H - C_R$	$U_{H2} + V + M - C_H - C_R$
Government	**To subsidize, x_H**	$G_1 - S_H - C_g$	$G_1 - S_H - C_g$
		$S_H - C$	$S_H - C$
		$V - C_0$	$V - C_0$
	Not to subsidize, $1 - x_H$	$G_1 - C_g$	$G_1 - C_g$
		$-C$	$-C$
		$V - C_0$	$V - C_0$

Correspondingly, in the evolutionary game model among the government, operators, and consumers under the operational subsidy mode, the government has two possible strategies: to subsidize and not to subsidize, and the probabilities are x_C and $1 - x_C$, respectively. The operators have two strategies: active and passive production, and the probabilities are y_C and $1 - y_C$, respectively. The consumer's strategy set includes purchasing rechargeable EVs and purchasing traditional fuel-consuming vehicles; the probabilities are z_C and $1 - z_C$, respectively. Table 2 represents the reward matrix in the game among the government, operators, and consumers under the operational subsidy mode.

Table 2. Reward matrix in the evolutionary game among the government, operators, and consumers under the operational subsidy mode.

		Operators	
		Active Production y_C	**Passive Production $1 - y_C$**
Government	**To subsidize x_C**	$G_1 + G_2 - S_C - C_g - M$	$G_1 + G_2 - S_C - C_g - M$
		$P_{C1} + S_C - C - \Delta C_{C1}$	$P_{C2} + S_C - T - C - \Delta C_{C2}$
		$U_{C1} + V + M - C_C$	$U_{C2} + V + M - C_C$
	Not to subsidize $1 - x_C$	G_2	$-E_2$
		$P_{C1} - C - \Delta C_{C1}$	$P_{C2} - T - C - \Delta C_{C1}$
		$U_{C1} + V + M - C_C$	$U_{C2} + V + M - C_C$
Government	**To subsidize x_C**	$G_1 - S_C - C_g$	$G_1 - S_C - C_g$
		$S_C - C$	$S_C - C$
		$V - C_0$	$V - C_0$
	Not to subsidize $1 - x_C$	$G_1 - C_g$	$G_1 - C_g$
		$-C$	$-C$
		$V - C_0$	$V - C_0$

E_{H11} and E_{H12} are the expected rewards of the government choosing to subsidize and not to subsidize the investment amount, respectively.

$$\begin{aligned} E_{H11} = y_H z_H (G_1 + G_2 - S_H - C_g - M) + (1 - y_H) z_H (G_1 - S_H - C_g - E_2 + T - M) \\ + y_H (1 - z_H)(G_1 - S_H - C_g) \\ + (1 - y_H)(1 - z_H)(G_1 - S_H - C_g) \end{aligned} \tag{1}$$

$$E_{H12} = y_H z_H G_2 + (1 - y_H) z_H (-E_2) + y_H (1 - z_H)(G_1 - C_g) + (1 - y_H)(1 - z_H)(G_1 - C_g) \tag{2}$$

The average expected reward of the government for the investment subsidy strategy is as follows.

$$\overline{E_{H1}} = x_H E_{H11} + (1 - x_H) E_{H12} \tag{3}$$

The expected rewards of the battery swapping station operators using active production E_{H21} and passive production E_{H22} are as follows.

$$\begin{aligned} E_{H21} = x_H z_H (P_{H1} + S_H - C - \Delta C_{H1}) + (1 - x_H) z_H (P_{H1} - C - \Delta C_{H1}) \\ + x_H (1 - z_H)(S_H - C) + (1 - x_H)(1 - z_H)(-C) \end{aligned} \tag{4}$$

$$\begin{aligned} E_{H22} = x_H z_H (P_{H2} + S_H - T - C - \Delta C_{H2}) + (1 - x_H) z_H (P_{H2} - T - C - \Delta C_{H2}) \\ + x_H (1 - z_H)(S_H - C) + (1 - x_H)(1 - z_H)(-C) \end{aligned} \tag{5}$$

The average expected reward of the operators is as follows.

$$\overline{E_{H2}} = y_H E_{H21} + (1 - y_H) E_{H22} \tag{6}$$

The expected rewards of the consumers purchasing battery-swappable EVs E_{H31} and the traditional fuel-consuming vehicles E_{H32} are as follows.

$$\begin{aligned} E_{H31} = x_H y_H (U_{H1} + V + M - C_H - C_R) + x_H (1 - y_H)(U_{H2} + V + M - C_H - C_R) \\ + (1 - x_H) y_H (U_{H1} + V + M - C_H - C_R) \\ + (1 - x_H)(1 - y_H)(U_{H2} + V + M - C_H - C_R) \end{aligned} \tag{7}$$

$$\begin{aligned} E_{H32} = x_H y_H (V - C_0) + x_H (1 - y_H)(V - C_0) \\ + (1 - x_H) y_H (V - C_0) + (1 - x_H)(1 - y_H)(V - C_0) \end{aligned} \tag{8}$$

In the battery swapping mode, the consumers' average expected reward is as follows.

$$\overline{E_{H3}} = z_H E_{H31} + (1 - z_H) E_{H32} \tag{9}$$

Similarly, E_{C11} and E_{C12} are the expected rewards of the government choosing to subsidize and not to subsidize the operation amount.

$$\begin{aligned} &E_{C11} = y_C z_C (G_1 + G_2 - S_C - C_g - M) \\ &+(1 - y_C) z_C (G_1 + G_2 - S_C - C_g - M) + y_C (1 - z_C)(G_1 - S_C - C_g) \\ &+(1 - y_C)(1 - z_C)(G_1 - S_C - C_g) \end{aligned} \tag{10}$$

$$E_{C12} = y_C z_C G_2 + (1 - y_C) z_C (-E_2) + y_C (1 - z_C)(G_1 - C_g) + (1 - y_C)(1 - z_C)(G_1 - C_g) \tag{11}$$

The government's average expected reward for the operational subsidy strategy is as follows.

$$\overline{E_{C1}} = x_C E_{C11} + (1 - x_C) E_{C12} \tag{12}$$

The expected rewards of the charging station operators using active production E_{C21} and passive production E_{C22} are as follows.

$$\begin{aligned} &E_{C21} = x_C z_C (P_{C1} + S_C - C - \Delta C_{C1}) \\ &+(1 - x_C) z_C (P_{C1} - C - \Delta C_{C1}) + x_C (1 - z_C)(S_C - C) \\ &+(1 - x_C)(1 - z_C)(-C) \end{aligned} \tag{13}$$

$$\begin{aligned} &E_{C22} = x_C z_C (P_{C2} + S_C - T - C - \Delta C_{C2}) \\ &+(1 - x_C) z_C (P_{C2} - T - C - \Delta C_{C1}) + x_C (1 - z_C)(S_C - C) \\ &+(1 - x_C)(1 - z_C)(-C) \end{aligned} \tag{14}$$

The operators' average expected reward is as follows.

$$\overline{E_{C2}} = y_C E_{C21} + (1 - y_C) E_{C22} \tag{15}$$

The expected rewards of the consumers purchasing rechargeable EVs E_{C31} and the traditional fuel-consuming vehicles E_{C32} are as follows.

$$\begin{aligned} &E_{C31} = x_C y_C (U_{C1} + V + M - C_C) + x_C (1 - y_C)(U_{C2} + V + M - C_C) \\ &+(1 - x_C) y_C (U_{C1} + V + M - C_C) \\ &+(1 - x_C)(1 - y_C)(U_{C2} + V + M - C_C) \end{aligned} \tag{16}$$

$$\begin{aligned} &E_{C32} = x_C y_C (V - C_0) + x_C (1 - y_C)(V - C_0) \\ &+(1 - x_C) y_C (V - C_0) + (1 - x_C)(1 - y_C)(V - C_0) \end{aligned} \tag{17}$$

In the charging mode, the consumers' average expected reward is as follows.

$$\overline{E_{C3}} = z_C E_{C31} + (1 - z_C) E_{C32} \tag{18}$$

5.4. Evolutionary Game Replication Dynamic Equation

The investment subsidy mode, according to the government, operator, and consumer's expected rewards, obtains the government's replication dynamic equation as follows

$$\begin{aligned} F(x_H) = \frac{dx_H}{dt} = \quad & x_H (1 - x_H)(E_{H11} - E_{H12}) \\ & = x_H (1 - x_H)\{[y_H z_H (G_1 + G_2 - S_H - C_g - M) + (1 - y_H) z_H (G_1 - S_H - C_g - E_2 + T - M) \\ & + y_H (1 - z_H)(G_1 - S_H - C_g) + (1 - y_H)(1 - z_H)(G_1 - S_H - C_g)] - [y_H z_H G_2 \\ & + (1 - y_H) z_H (-E_2) + y_H (1 - z_H)(G_1 - C_g) + (1 - y_H)(1 - z_H)(G_1 - C_g)]\} \\ & = x_H (1 - x_H)[-y_H z_H T + z_H (T - M + G_1 - C_g) - S_H] \end{aligned} \tag{19}$$

The battery swapping station operator's replication dynamic equation is as follows.

$$\begin{aligned} F(y_H) = \frac{dy_H}{dt} = \quad & y_H(1-y_H)(E_{H21}-E_{H22}) \\ & = y_H(1-y_H)\{[x_H z_H(P_{H1}+S_H-C-\Delta C_{H1})+(1-x_H)z_H(P_{H1}-C-\Delta C_{H1}) \\ & +x_H(1-z_H)(S_H-C)+(1-x_H)(1-z_H)(-C)]-[x_H z_H(P_{H2}+S_H-T-C-\Delta C_{H2}) \\ & +(1-x_H)z_H(P_{H2}-T-C-\Delta C_{H2})+x_H(1-z_H)(S_H-C)+(1-x_H)(1-z_H)(-C)]\} \\ & = y_H(1-y_H)[z_H(P_{H1}-P_{H2}-\Delta C_{H1}-\Delta C_{H2}+T)] \end{aligned} \tag{20}$$

The consumer's replication dynamic equation is as follows.

$$\begin{aligned} F(z_H) = \frac{dz_H}{dt} = \quad & z_H(1-z_H)(E_{H31}-E_{H32}) \\ & = z_H(1-z_H)\{[x_H y_H(U_{H1}+V+M-C_H-C_R)+x_H(1-y_H)(U_{H2}+V+M-C_H-C_R) \\ & +(1-x_H)y_H(U_{H1}+V+M-C_H-C_R)+(1-x_H)(1-y_H)(U_{H2}+V+M-C_H-C_R)] \\ & -[x_H y_H(V-C_0)+x_H(1-y_H)(V-C_0)+(1-x_H)y_H(V-C_0) \\ & +(1-x_H)(1-y_H)(V-C_0)]\} = z_H(1-z_H)[y_H(U_{H1}-U_{H2})+(U_{H2}+M-C_H-C_R+C_0)] \end{aligned} \tag{21}$$

Summarily, under the investment subsidy mode, the replication dynamic equation system of the government, operator, and consumer is as follows.

$$\left\{ \begin{array}{c} F(x_H) = x_H(1-x_H)[-y_H z_H T + z_H(T-M+G_1-C_g)-S_H] \\ F(y_H) = y_H(1-y_H)[z_H(P_{H1}-P_{H2}-\Delta C_{H1}+\Delta C_{H2}+T)] \\ F(z_H) = z_H(1-z_H)[y_H(U_{H1}-U_{H2})+(U_{H2}+M-C_H-C_R+C_0)] \end{array} \right. \tag{22}$$

Likewise, the operational subsidy mode, based on the government, operator, and consumer's expected rewards, obtains the government's replication dynamic equation.

$$\begin{aligned} F(x_C) = \frac{dx_C}{dt} = \quad & x_C(1-x_C)(E_{C11}-E_{C12}) \\ & = x_C(1-x_C)\{[y_C z_C(G_1+G_2-S_C-C_g-M)+(1-y_C)z_C(G_1+G_2-S_C-C_g-M) \\ & +y_C(1-z_C)(G_1-S_C-C_g)+(1-y_C)(1-z_C)(G_1-S_C-C_g)] \\ & -[y_C z_C G_2+(1-y_C)z_C(-E_2)+y_C(1-z_C)(G_1-C_g)+(1-y_C)(1-z_C)(G_1-C_g)]\} \\ & = x_C(1-x_C)[z_C(S_C+E_2)-y_C z_C(G_2+E_2)+(G_1+G_2-2S_C-C_g-M)] \end{aligned} \tag{23}$$

The charging pile operator's replication dynamic equation is as below.

$$\begin{aligned} F(y_C) = \frac{dy_C}{dt} = \quad & y_C(1-y_C)(E_{C21}-E_{C22}) \\ & = y_C(1-y_C)\{[x_C z_C(P_{C1}+S_C-C-\Delta C_{C1})+(1-x_C)z_C(P_{C1}-C-\Delta C_{C1}) \\ & +x_C(1-z_C)(S_C-C)+(1-x_C)(1-z_C)(-C)] \\ & -[x_C z_C(P_{C2}+S_C-T-C-\Delta C_{C2})+(1-x_C)z_C(P_{C2}-T-C-\Delta C_{C1})+x_C(1-z_C)(S_C-C) \\ & +(1-x_C)(1-z_C)(-C)]\} = y_C(1-y_C)[x_C z_C(S_C+\Delta C_{C1}-\Delta C_{C2})+z_C(P_{C1}-P_{C2}+T+C)] \end{aligned} \tag{24}$$

The consumer's replication dynamic equation is as follows.

$$\begin{aligned} F(z_C) = \frac{dz_C}{dt} = \quad & z_C(1-z_C)(E_{C31}-E_{C32}) \\ & = z_C(1-z_C)\{[x_C y_C(U_{C1}+V+M-C_C)+x_C(1-y_C)(U_{C2}+V+M-C_C) \\ & +(1-x_C)y_C(U_{C1}+V+M-C_C)+(1-x_C)(1-y_C)(U_{C2}+V+M-C_C)] \\ & -[x_C y_C(V-C_0)+x_C(1-y_C)(V-C_0)+(1-x_C)y_C(V-C_0)+(1-x_C)(1-y_C)(V-C_0)]\} \\ & = z_C(1-z_C)[y_C(U_{C1}-U_{C2})+(U_{C2}+M-C_C+C_0)] \end{aligned} \tag{25}$$

Summarily, under the operational subsidy mode, the government, operator, and consumer's replication dynamic equation system is as below.

$$\left\{ \begin{array}{c} F(x_C) = x_C(1-x_C)[z_C(S_C+E_2)-y_C z_C(G_2+E_2)+(G_1+G_2-2S_C-C_g-M)] \\ F(y_C) = y_C(1-y_C)[x_C z_C(S_C+\Delta C_{C1}-\Delta C_{C2})+z_C(P_{C1}-P_{C2}+T+C)] \\ F(z_C) = z_C(1-z_C)[y_C(U_{C1}-U_{C2})+(U_{C2}+M-C_C+C_0)] \end{array} \right. \tag{26}$$

5.5. Analysis of Evolutionary Stability Strategy

To solve the equilibrium of the evolutionary game under the investment subsidy mode, let

$$\begin{cases} F(x_H) = x_H(1-x_H)[-y_H z_H T + z_H(T - M + G_1 - C_g) - S_H] = 0 \\ F(y_H) = y_H(1-y_H)[z_H(P_{H1} - P_{H2} - \Delta C_{H1} + \Delta C_{H2} + T)] = 0 \\ F(z_H) = z_H(1-z_H)[y_H(U_{H1} - U_{H2}) + (U_{H2} + M - C_H - C_R + C_0)] = 0 \end{cases} \tag{27}$$

The solutions of the replication dynamic equation system constitute the boundary of the evolutionary game with the following equilibrium solution.

$$\begin{cases} z_H{}^*(-y_H{}^* T + T - M + G_1 - C_g) - S_H = 0 \\ z_H{}^*(P_{H1} - P_{H2} - \Delta C_{H1} + \Delta C_{H2} + T) = 0 \\ y_H{}^*(U_{H1} - U_{H2}) + (U_{H2} + M - C_H - C_R + C_0) = 0 \end{cases} \tag{28}$$

The solution is:

$$\begin{cases} x_H{}^* \in \forall, 0 \le x_H{}^* \le 1 \\ y_H{}^* = \frac{U_{H2}+M-C_H-C_R+C_0}{U_{H2}-U_{H1}} \\ z_H{}^* = \frac{S_H(U_{H1}-U_{H2})}{U_{H1}(1-M+G_1-C_g)+U_{H2}(1+M-G_1+C_g)+(M-C_H-C_R+C_0)} \end{cases} \tag{29}$$

Our results show whether or not the government implements investment subsidies, insignificantly impacts the evolutionary game among the government, and battery swapping station operators, and consumers.

As for the battery swapping station operators, the amount of subsidies by the government to consumers in terms of vehicle purchase tax and value-added tax has a significant positive impact on the operator's production enthusiasm. The higher the subsidies for consumers, the higher the demand for battery swappable EVs, and the more active the operators in production. Moreover, the purchase cost that consumers invest in purchasing traditional fuel-consuming vehicles also has a significant positive impact on operators' production enthusiasm. The higher the purchase cost of traditional fuel-consuming vehicles, the less the consumers are willing to purchase traditional fuel-consuming vehicles. Thus, the production enthusiasm of the battery swapping station operators increases to occupy a larger market share. In contrast, the purchase cost and leasing fee that consumers invest in a battery-swappable EV is negatively correlated with the operators' production enthusiasm. The higher the purchase cost of battery-swappable EVs and the cost of battery leasing, the less consumers are willing to spend for purchasing EVs. As a result, they pay more attention to traditional fuel-consuming vehicles, which affects the production enthusiasm of the operators.

From the consumers' perspective, the government's investment subsidy has a positive impact on the consumer's decision to purchase a battery-swappable EV. The higher the government's investment subsidy for battery swapping station operators, the higher the consumer's confidence in the purchase of EVs.

Correspondingly, to solve the equilibrium of the evolutionary game under the operational subsidy mode, let

$$\begin{cases} F(x_C) = x_C(1-x_C)[z_C(S_C + E_2) - y_C z_C(G_2 + E_2) + (G_1 + G_2 - 2S_C - C_g - M)] = 0 \\ F(y_C) = y_C(1-y_C)[x_C z_C(S_C + \Delta C_{C1} - \Delta C_{C2}) + z_C(P_{C1} - P_{C2} + T + C)] = 0 \\ F(z_C) = z_C(1-z_C)[y_C(U_{C1} - U_{C2}) + (U_{C2} + M - C_C + C_0)] = 0 \end{cases} \tag{30}$$

The solutions of the replication dynamic equation system constitute the boundary of the evolutionary game with the following equilibrium solution:

$$\begin{cases} z_C{}^*(S_C + E_2) - y_C{}^* z_C{}^*(G_2 + E_2) + (G_1 + G_2 - 2S_C - C_g - M) = 0 \\ x_C{}^* z_C{}^*(S_C + \Delta C_{C1} - \Delta C_{C2}) + z_C{}^*(P_{C1} - P_{C2} + T + C) = 0 \\ y_C{}^*(U_{C1} - U_{C2}) + (U_{C2} + M - C_C + C_0) = 0 \end{cases} \tag{31}$$

The solution is:

$$\begin{cases} {x_C}^* = \frac{P_{C1} - P_{C2} + T + C}{\Delta C_{C2} - \Delta C_{C1} - S_C} \\ {y_C}^* = \frac{U_{C2} + M - C_C + C_0}{U_{C2} - U_{C1}} \\ {z_C}^* = \frac{\left(2S_C + C_g + M - G_1 - G_2\right)(U_{C1} - U_{C2})}{(U_{C2} + M - C_C + C_0)G_2 + (U_{C1} + M - C_C + C_0)E_2 + (U_{C1} - U_{C2})S_C} \end{cases} \tag{32}$$

According to our results, due to the adoption of advanced charging technology, the higher the after-sales revenue of operators after introducing advanced charging technology, the higher their willingness to actively produce charging piles. Moreover, the government's operational subsidies have a positive correlation with the income in charging pile operators from the sale of EVs. In this case, the government increases the operational subsidy, giving operators the power and capital to continuously improve production technology, which develops the supply-side technologies. Moreover, the operator's initial cost of producing charging piles has a positive correlation with the government's operational subsidies. In other words, the higher the initial cost of producing charging piles, the higher is the government's operational subsidies, which encourage operators to carry out technical upgrading and provide financial support for the charging pile operators.

For the charging pile operators, the amount of subsidies by the government to consumers in terms of vehicle purchase tax and value-added tax has a significant positive impact on the operators' production enthusiasm. The higher the subsidies for consumers, the higher the demand for rechargeable EVs. Thus, the operators are more active in production. In addition, the purchase cost that consumers invest in purchasing traditional fuel-consuming vehicles has a significant positive impact on operators' production enthusiasm. The higher the purchase cost of traditional fuel-consuming vehicles, the less the consumers are willing to purchase traditional fuel-consuming vehicles. Thus, the production enthusiasm of the charging pile operators increases to occupy a larger market share. In contrast, the purchase cost that consumers invest in a rechargeable EV is negatively correlated with the operators' production enthusiasm. The higher the purchase cost of rechargeable EVs, the less the consumers are willing to spend for purchasing EVs. Hence, they pay more attention to traditional fuel-consuming vehicles, which affects the operators' production enthusiasm.

From the perspective of the consumers, the cost of government supervision of relevant industry standards has a positive impact on the consumer's decision to purchase rechargeable EVs because the government's strong supervision will enhance consumer's confidence in the purchase of EVs, such that more consumers are willing to buy EVs. Moreover, there is a positive correlation between the social word-of-mouth effect obtained by the government's strong supervision of the industry and the consumer's decision to purchase a rechargeable EV. The stronger the word-of-mouth effect, the higher the acceptance and popularity of EVs, and the more consumers will decide to buy rechargeable EVs.

6. Conclusions and Suggestions

6.1. Conclusions

With the ongoing development and evolution of China's EV charging infrastructure industry, the entire market is in an expansion phase. The game performance of the government, operators, and users under different government subsidy modes is as follows:

1. Under the investment subsidy mode

For the government, whether or not the government implements investment subsidies insignificantly impacts the evolutionary game among the government, the battery swapping station operators, and the consumers. For the battery swapping station operators, the amount of subsidies by the government to consumers in terms of vehicle purchase tax and value-added tax, and the purchase cost that consumers invest in purchasing traditional fuel-consuming vehicles, both have a significant positive impact on operators' production enthusiasm. In contrast, the purchase cost and leasing fee that consumers invest in a battery-swappable EV are both negatively correlated with the operators' production enthusiasm. For the consumers, the government's investment subsidy has a positive impact on the consumer's decision to purchase a battery-swappable EV.

2. Under the operational subsidy mode

For the government, the operational subsidies implemented by the government have a positive correlation with the income obtained from the sale of EVs after the charging pile operators actively introduce the advanced charging technology. For the charging pile operators, the amount of subsidies by the government to consumers in terms of vehicle purchase tax and value-added tax and the purchase cost that consumers invest in purchasing traditional fuel-consuming vehicles both have a significant positive impact on operators' production enthusiasm. In contrast, the purchase cost that consumers invest in a rechargeable EV is negatively correlated with the operators' production enthusiasm. For the consumers, the cost of government supervision of relevant industry standards and the social word-of-mouth effect obtained by the government's strong supervision of the industry are both positively correlated with the consumer's decision to purchase rechargeable EVs.

6.2. Suggestions

The research has some policy suggestions for the development of China's new energy vehicle charging infrastructure industry. If the government chooses to implement the investment subsidy policy for new energy vehicle charging infrastructure, it can increase the subsidy amount, and increase the purchase cost of traditional fuel consumption vehicles and reduce the purchase cost of rechargeable EVs appropriately. If the government chooses to implement the operating subsidy policy for the charging infrastructure of new energy vehicles, it can increase the subsidy amount of vehicle purchase tax and value-added tax, and strengthen the supervision of the industry, enhancing the social word-of-mouth effect, which promotes the steady development of China's charging infrastructure industry for new energy vehicles.

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