TU Delft OPEN

EJTIR

Issue 23(2), 2023, pp. 1-23

https://doi.org/10.18757/ejtir.2023.23.2.6666

ISSN: 1567-7141

http://ejtir.tudelft.nl/

Dynamic analysis of the investment decision of electric vehicle charging facilities and the promotion effect measurement for electric vehicles

Lefeng Shi
shilefeng@foxmail.com
National Center for Applied Mathematics in Chongqing, Chongqing Normal University, China
School of Economic and Management, Chongqing Normal University, China

Guanhong Chen
cgh15208957602@163.com
School of Economic and Management, Chongqing Normal University, China

Song Wang*
wang-song@foxmail.com
School of Economic and Management, Chongqing Normal University, China

Keywords

electric vehicles
bass model
charging facility
incentive policy

Publishing history

Submitted: 10 August 2022
Accepted: 21 April 2023
Published: 1 May 2023

Cite as

Shi, L., Chen, G., & Wang, S. (2023). Dynamic analysis of the investment decision of electric vehicle charging facilities and the promotion effect measurement for electric vehicles. European Journal of Transport and Infrastructure Research, 23(2), 1-23.

This paper aims to analyze the deep reason why there exists hesitation when investors decide whether invest in EV charging facilities (ECFs). To this end, a series of theoretic models are built and derived, and some enlightening results are got. The main results confirm that charging facility investors are insufficiently motivated to follow a moderately aggressive investment strategy in the early stages of EV development. For stimulating ECFs' investment, the marginal conditions in which the investors choose active or conservative investment strategies to lay out charging facilities are analyzed, and the effects under different ECFs investment strategies are quantized in terms of driving the market development of EVs. Based on the findings, relevant policy suggestions are proposed. Finally, to verify the gained results, a case study in the context of China is given.

* corresponding author

1 Introduction

Along with the worldwide concerns about energy and environmental issues, in the fields of production and lifestyle, choosing the appropriate energy-saving and emission-reduction ways has increasingly become the common pursuit of countries (Anjos et al., 2020). Within this transforming process, transportation electrification, mainly represented by the diffusion of electric vehicles (EVs), has become one of the focuses (Eisenbarth et al., 2021; Golab et al., 2022). Many nations regard EVs as idealistic alternatives to existing conventional combustion vehicles (CVs) due to their zero direct emission of tail gas and the benefits of comprehensive energy consumption (Chen et al., 2016; He et al., 2013; Shi et al., 2020). These merits, in addition to the impact of the increasing price of oil as well as the significant progress of some key relevant technologies such as battery pack technologies and electric motor technologies, make EVs more and more popular recently, even in some obviously unfavorable situations (Sovacool et al., 2019). For instance, one research performed by "Sweden EV-volumes.com" indicated that although COVID-19 caused the decline of the total sales of automobiles by one-fifth in 2020, the global sales of EVs still obtained a headwind growth at the same time, reaching 3.24 million units which increased 980,000 units compared with 2019 and got a year-on-year increase of 43.36% (EV-Volumes, 2021). Taking China as an example, its pure EV ownership in China reached 4 million by 2020, accounting for 81.32% of the national sale of new energy automobiles (The Ministry of Public Security of the People's Republic of China, 2021a); by March 2021 alone, the volume of EV’s ownership increased to 4.49 (The Ministry of Public Security of the People's Republic of China, 2021b).

In this inspiring context, nevertheless, some inharmony factors still dampen this transport electrification momentum. One of the most salient is the insufficient supply of EV charging facilities (ECFs) (Badia et al., 2020; Srivastava et al., 2022; Zhao et al., 2020); yet the deeper reason is the insufficiency of enough investment enthusiasm for ECFs stakeholders, especially to public ECFs (Shi et al., 2021). For this problem, the majority of relevant studies attributed it to the low-profit expectation of ECFs due to the limited EV amount (Baumgarte et al., 2021; Huang et al., 2022; Lee & Choi, 2021; Nityanshi et al., 2021), which causes a typical egg-chick paradox. The paradox is that the further development of EVs needs more ECFs, whereas the investors will lay out ECFs only when the volume of EVs achieve their expectation.

Therefore, how to disentangle this paradox has become the chief issue on the road of EV development. In order to resolve it, the Chinese government attempted to resort to administrative means to stimulate the construction of ECFs, for instance, with the proposal of the ideology of the "moderately forward" development of ECFs. On May 20, 2019, the Ministry of Transport and other 12 ministries jointly issued the Green Travel Action Plan (2019–2022), proposing accelerating the construction of a moderately advanced charging network system. Next to that, on November 2, 2020, the New Energy Automobile Industry Development Plan (2021–2035), released by the General Office of the State Council, explicitly requires the Ministry to speed up the layout of EV charging networks with the intention of forming a joint policy to break through the predicament of charging for EVs. However, from the current effects, the object of these policies has not been achieved.

At present, the academic community focuses more on the analysis of the factors affecting EV charging demand and the design of relevant ECF planning schemes (Shi et al., 2021; Tian et al., 2021; Wu et al., 2021; Yang et al., 2020), not directly touching on the analysis of the participation motivation of ECF investors. To address this issue and provide corresponding solutions, this paper aims to analyze the dynamic investment motivation mechanism of ECF investors. Compared with the existing research, the main contributions of this paper are summarized as follows:

(1) Building a set of theoretic models to describe the dynamic development relationship between EVs and ECFs;

(2) Gaining the boundary conditions that ECF investors own adequate motivation to participate in ECF construction;

(3) Proposing the corresponding policies for breaking the aforementioned paradox.

The main content is organized as follows. Firstly, the interdependent relationship between EVs and ECFs is described in Section 2. Then in Section 3, the classic Bass model is improved to characterize the influence of ECFs on EV diffusion. Accordingly, the relevant investment functions of ECF are constructed in Section 4. Next, in Section 5, the investment decision process of ECF's investors is analyzed in theory, and some propositions are got. To further corroborate these propositions, a case study is presented in the context of China in Section 6, which respectively analyzes the preconditions for making the ECF investors actively participate in EFC investment and compares the effects of some typical policies set forth by the different cities of China; The simulation results are further discussed in Section 7. Section 8 gives the conclusion of this paper.

2 Context outline

EVs and ECFs are usually viewed as an integral whole by the market (Gnann & Plötz, 2015; Harrison & Thiel, 2017; Reid & Spence, 2016). Without any one, their function will not be played out fully. Thus, the development of both sides needs close coordination among their related stakeholders. In an ideal situation, EVs' continued technological progress would not only attract a number of consumers to buy EVs but also motivate more investors to engage in the construction of ECFs to grasp this prospective commercial opportunity caused by EVs; meanwhile, the increasing ECFs would further relieve the worry of charging inconvenience on potential buyers, thereby increasing the market-acceptance rate of EVs in turn.

In terms of the market, the increasing emergence of EV adopters would cause more consumers to become potential buyers of EVs. Following this trajectory, both EVs and ECFs will step into a very smooth state: the more complete the network of ECFs is, the more fast and convenient the ECFs will be, and the higher the incentive effect on the purchase of potential EV users and the ECF construction of ECF investors will be (Taalbi & Nielsen, 2021). However, due to a lack of the first push, their development often struggle in the egg-chicken dilemma: the buyers who intend to purchase EVs wait for a complete ECF network before making a real purchase decision; the ECF investors are unable to spend more capital to build ECFs in the context of a small scale of EVs. Thus how to break out of this bind is critical to the path of EV market diffusion.

From the perspective of technological features, compared with EVs, the technologies related to ECFs are more mature. So during the EV's specific technology-development stage, improving the charging convenience of EVs beforehand through laying out ECFs in advance, could be conducive to maximizing the potential market demand for EVs. Therefore, to some extent, the active degree of ECF investors determines the development of EVs. For the purpose of portraying the active degree, this paper sets that there are two kinds of ECF investors: one is a passive investor, and the other is an active investor. Passive investors adhere to a conservative investment strategy (referred to as the C investment strategy herein). Active investors, otherwise, obeying an active and optimistic perspective, conduct a moderately advanced investment strategy, aiming to satisfy the charging demand of EVs in the future (labeled as the F investment strategy herein). In order to express it concisely, this paper sets D to represent the investment strategy of ECF investors, where $D \in \{C, F\}$.

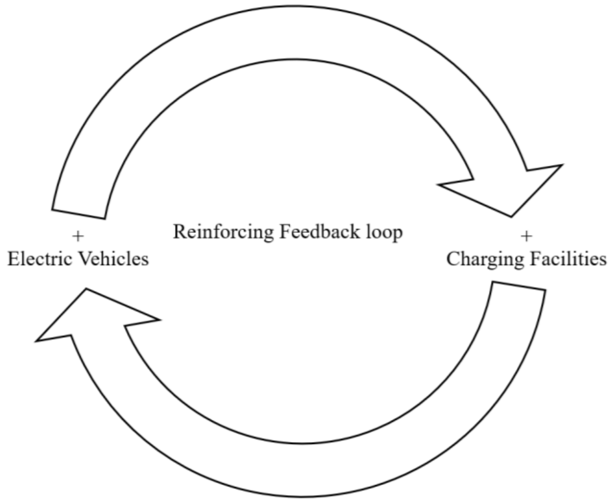

Figure 1. Mutual reinforcing relation between EVs and ECFs

3 EV developing model

From Section 1, we know that EV diffusion is mainly affected by multiple factors, yet there is no model capable of encompassing them and describing their internally interactive relationship as well as their causal relationship within EV market diffusion. To address this issue, this section first selects a model (i.e., the Bass model) as the fundamental model, based on which the factors influencing EV adoption are functioned and added to the basic model, thereby constructing a set of the coordination development models of EVs and ECFs.

3.1 Basic model

The academic community usually refers to some biological models to describe the market diffusion process of new products, analogizing the process as a natural selection process by the market. In relevant research, the classic Bass model is often chosen (Hao et al., 2019) as it can better describe the market diffusion characteristics of new products, in which the adopters of new products are divided into "innovators" and "imitators" (Jha & Saha, 2020; Tang et al., 2019). The formers make the purchase decision based on their own judgment about the new product itself; the imitators are mainly affected by the influence of the social network formed by the innovators. The expression of the classic Bass model is:

$$n(t) = p \times [M - N(t)] + q \times \frac{N(t)}{M} \times [M - N(t)] \quad (1)$$

In Equation (1), $n(t)$ denotes the increment of the described new product in period t; $N(t)$ denotes the cumulative total amount of the product by the end of period t; p is the innovation influence coefficient reflecting the influence from the endogenous factors of the product itself such as the maximum driving range, cost per kilometer, operating performance and others associated with EV technologies (Sierzchula et al., 2014); q is the exogenous imitation coefficient reflecting the influence of others who have purchased the product; and M is the total potential market of new products.

As exhibited by Equation (1), though the Bass model considers both the endogenous factors and the exogenous factors into the model (Li et al., 2020; Qiu et al., 2021). Yet for special products like EVs whose function depends closely on the supply of other complementary products or services like EV charging services (not only by the factors directly related to the new product itself), the general Bass model is not able to accurately describe the impact of charging services. To make up for this deficiency, therefore, in this paper, charging factors are introduced on the basis of the original model to reflect the influence of ECFs on EV market diffusion, as shown in Equation (2):

$$n(t) = p \times [M - N(t)] + q \times \frac{N(t)}{M} \times [M - N(t)] + g \times [M - N(t)] \tag{2}$$

In Equation (2), $n(t)$ denotes the increment of EVs in t period; $N(t)$ denotes the number of EVs by the end of t period; p is the technological influence coefficient reflecting the influence from automobile technology level on the market acceptance rate of EVs (Shi et al., 2020); q is the social influence coefficient reflecting the impact of the existing number of EVs on the development of EVs in the future (Peres et al., 2010); g is the complementary influence coefficient reflecting the impact of charging convenient degree on the market number of EVs (Shi et al., 2018; Sun et al., 2018); and M is the market ownership of EVs when EVs saturate.

Combining the ECF investment strategies ($D \in \{C, F\}$), the number of EVs in a certain period can be expressed as:

$$N(t+1) = N(t) + n^D$$

where $N(t+1)$ is the number of EVs in the $t+1$ period after the ECF investor chooses the D strategy; n^D is the increment of EVs under the investment strategy D.

3.2 Extended model

The Bass model is effective in terms of outlining dynamic relationships between researched new products and the external environment, but its efficacy is insufficient when exploring the more subtle influence of some concrete factors. Hence, to investigate the deeper relationships among EV market development, EV relevant technologies, social influence, and ECF investment, as well as other detailed factors, in this section, the coefficients of Equation (2) will be further functionated, thereby obtaining an extended Bass model as the foundation of the next analysis.

Influence of ECFs

The convenience of EV charging does not just hinge on the number of ECFs but is also related to the location of ECFs (Yang et al., 2017) To express this influence, we use the ratio of charging piles to EVs to represent the adequate degree of ECF supply and consider the average distance between ECFs and workplaces, communities, and other population clustering areas to represent the influence of ECF location. In this case, the influence of ECFs, g could be expressed as follows:

$$g = g^D = \frac{Q^D}{N\frac{d}{L}} \cdot r^{-\delta} (g^D > \lambda) \tag{3}$$

where g^D (h) denotes the charging convenience coefficient under investment strategy D of ECFs, that is the aggregated time consumption for EV owners from departing for charging to finish charging, which is composed of three parts. The first part is the numerator Q^D, representing the number of charging piles. The second part is the denominator Nd/L, representing the number of EVs that need to be charged of unit day, where N represents the number of EVs in the researched area and period, d (km) is the average traveling range of each EV per day, and L (km) is the EV's average distance per charge. The third part is $r^{-\delta}$ in which r (km) denotes the average distance between ECFs and population clustering areas; δ is the preference parameter representing the preferring degree of consumers to ECF location. Besides, λ represents the maximum endurance time that EV users are willing to wait for charging.

Q^D is functionated further:

$$Q^D = \frac{\gamma(N + n^D) d \cdot S}{100 P_e \beta} \tag{4}$$

Notably, the perceived charging convenience often is reflected in rush hour when most EVs choose to charge. Hence in Equation (4), γ (%) denotes the ratio of EVs choosing to charge in rush hour;

n^D denotes the incremental number of EVs under the investment strategy D; S (kW•h) is the average electricity consumption of each EV per 100 kilometers; P_e (kW) represents the output power of charging pile; and β denotes the charging conversion efficiency of charging pile, namely the actual working efficiency of the charging pile.

Influence of EV-technology

Although logically, all EV-related technologies can pose influences on the EV market acceptance, their specific efficacy is different. Some studies argued that the market's evaluation to one new product is often based on subjective perception which is usually decided by its crucial and easily recognizable technology (Anjos et al., 2020; Globisch et al., 2018). For EVs, the driving range is often viewed as the key indicator of the EV's technology progress by the market's subjective perception (Globisch et al., 2018). Considering that the driving range links closely with the EV battery technologies, hence, the influence of EV-technology is expressed:

$$p = p^D = \alpha\varepsilon \frac{K}{1+\frac{K-k^D}{k^D}e^{-\phi}} \quad (5)$$

where p^D denotes the technological innovation coefficient of EVs when investment strategy D is implemented; otherwise, α (%) represents the market perception to the different the EV's technological level (Axsen et al., 2017); ε (kWh/km) is the unit energy consumption of EVs per kilometer (Woo & Magee, 2020); the third component, $\frac{K}{1+\frac{K-k^D}{k^D}e^{-\phi}}$ (km) represents the EV's driving range per charge. For simplicity, in the following content, the driving range is represented as L^D, that is $L^D = \frac{K}{1+\frac{K-k^D}{k^D}e^{-\phi}}$, to reflect the technological development level of EVs, where K (km) denotes EV's theoretical maximum driving range (km); k^D (km) denotes the common driving range under the investment strategy D of ECFs; $e^{-\phi}$ denotes the technologically progressive rate of EVs, in which ϕ is the technologically progressive coefficient.

Influence of society

Social influence largely comes from the psychology of herd mentality, in which consumers usually choose the product they frequently see in the market (Yang et al., 2017). As to EVs, the social influence from purchased EVs is not associated with the absolute ownership amount but with the probability that they see EVs, namely relating with the consumer's subjective perception (Sun et al., 2022). In view of this (Silvia & Krause, 2016; Yu et al., 2019), we functionate the social influence coefficient, q, as the following functions:

$$q = \frac{H_E}{H} \cdot \frac{T_d}{T_w} \quad (6)$$

where q (%) is defined as the market impact factor of EVs, denoting the ratio of the existing EVs observed by market consumers in a given period; H_E denotes the number of EVs on the road within the observation time; and H denotes the total number of car in the researched area; T_w (h) is the observation time ; T_d (h) is the time of one day.

Combined model

Combined with Equations (2) -- (6), the extended Bass model can be obtained:

$$n^D = (M-N)\left(\varepsilon\alpha L^D + \frac{H_E}{H}\frac{T_d}{T_w}\frac{N}{M} + \frac{Q^D L^D}{dN} r^{-\delta}\right) \quad (7)$$

4 Investment decision model of ECFs

For ECF investors as subjects of profit-seeking, the primary object of investing ECFs is to persuit profit. If not, they would abandon the investment plan. In this section, the profit function of ECF investors will be constructed based on the measurement function of EV charging demand and the investment cost function of ECFs.

4.1 Service demand of ECFs

ECF investor' revenue is not only related to the number of EVs it serve, but also to the amount of electricity which each EV can charge each year:

$$E = T\frac{d}{L^D} \times L^D \times \frac{S}{100} \tag{8}$$

where T represents the equivalent-effective working days of the charging facility in one year, and the other letters have the same meanings as the prior equations. Equation (8) can be simplified as follows:

$$E = 0.01TdS \tag{9}$$

Considering the total amount of EVs, $N + n^D$, the annual electricity ECFs service can be expressed as: $(N + n^D) \times 0.01TdS$.

4.2 Cost items of ECFs

The cost items of ECFs in this paper encompass constructing cost and operating cost, all which could be express as following equation:

$$C^D = \frac{Q^D C_p + N_l C_l}{m} + I^D E P_b N + \frac{C_o}{m} \tag{10}$$

where C^D denotes the aggregated cost each ECF per year on average under the ECF investment strategy D, which includes two cost items: the annual amortized construction cost $\frac{Q^D C_p + N_l C_l}{m}$ of one ECF; and the corresponding annual average operation cost $I^D E P_b N + \frac{C_o}{m}$. As to concrete symbols, C_p (\$) denotes the cos t of each EV charging pile; N_l(㎡) denotes the land area EV charging pile covers; C_l (\$) is the related unit cost of the land; C_o (\$) denotes other relevant fees; m denotes the normal working years of one ECF; I^D denotes the market attraction of the ECF, that is, how many EVs could choose this ECF to charge every year; P_b (\$) is the purchasing price of electricity from utility company.

Remarkably, there exists a dynamically interactive relationship between ECFs and EVs. On the one hand, EVs' diffusion needs the forced support of ECFs. The higher the penetration level of ECFs (e.g., professional charging stations), the more convenient the charging of EVs will be, and the better the publicity and demonstration function it will play to potential users who have not purchased EVs but show a certain interest in them (Shi et al., 2021). On the other hand, the higher the number of EVs, the higher the profit expectation for ECF investors (Jha & Saha, 2020). Thus, for an ECF investor, constructing its ECFs in the areas with the highest market attraction is a very rational choice.

Thus, in the planning and construction of ECFs, this paper mainly considers the interaction between ECFs and EVs. Set that the attraction degree $I^D$is proportional to the attraction constant, the level of ECFs, and the vehicles served by charging stations, and inversely proportional to the square of the distance between users and charging stations.

4.3 Profit gain of ECFs

Set P_s (\$) to represent the charging price that the ECF investor charge EV drivers. Combined with the above analysis, it can be obtained the annual profit gain for one ECF investor under the two investment strategies:

$$V^C = I^C(N + n^C) \times P_s \times 0.01TdS - \frac{Q^C C_p + N_l C_l + C_o}{m} - 0.01TdSI^C P_b(N + n^C) \tag{11}$$

$$V^F = I^F(N + n^F) \times P_s \times 0.01TdS - \frac{Q^F C_p + N_l C_l + C_o}{m} - 0.01TdSI^F P_b(N + n^F) \tag{12}$$

where V^C denotes the profit of the ECF investor when investment strategy C is chosen; $V^F$is the profit of the ECF investor when investment strategy F is chosen.

5 ECF investment decision analysis

This section will analyze marginal conditions when ECF investors have the motivation to actively construct ECFs based on the above settings. Accordingly, the impact of different investment strategies (C or F) on the development of EVs is measured further, based on which the corresponding incentive policy is designed to guide ECF investors to choose the strategy F so as to facilitate the diffusion of EVs.

5.1 ECFs investment decision

Boundary conditions of ECF investment

Only when the profit is positive, will ECF investors choose to invest ECFs. Through the profits under the different strategies, the following Proposition can be obtained:

Proposition 1: The boundary condition for ECF investors to choose investment strategy C is $N + n^C > \frac{Q^C C_p + N_l C_l + C_o}{0.01TdSI^C(P_s - P_b)m}$, while the boundary conditions of investment strategy F is $N + n^F > \frac{Q^F C_p + N_l C_l + C_o}{0.01TdSI^F(P_s - P_b)m}$.

Different stages of ECF investment

Proposition 1 indicates that the existing amount of EVs will affect whether the ECF investors invest ECFs. For further analyzing this influence, the EV's development trajectory is described firstly:

Proposition 2: There are three critical time points in the development process of EVs, namely: initial phase $t_1 = \frac{1}{\alpha\varepsilon L^D + \frac{H_E T_d}{HT_w} + \frac{Q^D L^D}{dN} r^{-\delta}}\left[ln\frac{\frac{H_E T_d}{HT_w}}{\alpha\varepsilon L^D + \frac{Q^D L^D}{dN} r^{-\delta}} - ln(2 + \sqrt{3})\right]$, rapid expansion phase $t^* = \frac{1}{\alpha\varepsilon L^D + \frac{H_E T_d}{HT_w} + \frac{Q^D L^D}{dN} r^{-\delta}} ln\frac{\frac{H_E T_d}{HT_w}}{\alpha\varepsilon L^D + \frac{Q^D L^D}{dN} r^{-\delta}}$ and mature phase $t_2 = \frac{1}{\alpha\varepsilon L^D + \frac{H_E T_d}{HT_w} + \frac{Q^D L^D}{dN} r^{-\delta}}\left[ln\frac{\frac{H_E T_d}{HT_w}}{\alpha\varepsilon L^D + \frac{Q^D L^D}{dN} r^{-\delta}} + ln(2 + \sqrt{3})\right]$, which divide the diffusion process of EVs into three stages as shown in Fig.2.

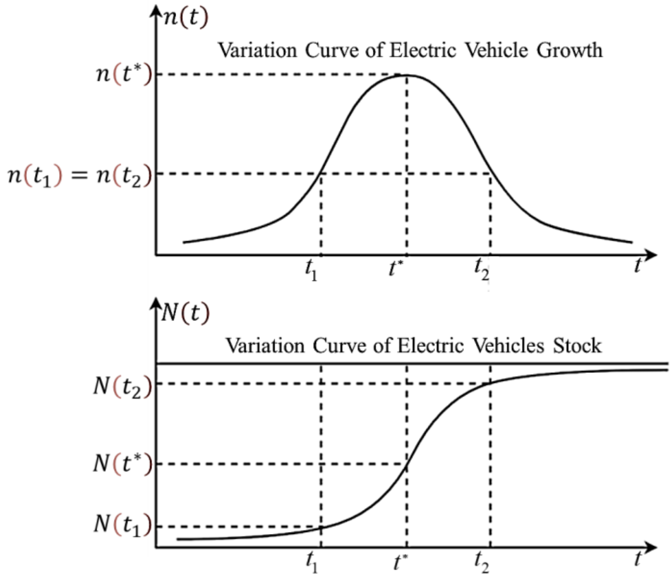

Figure 2. Three phase of EV diffusion

Based on Proposition 2, the following corollary 1 could be gained:

Corollary 1: Before the development of EVs to the time $t^* = \frac{1}{\alpha\varepsilon L^D + \frac{H_E T_d}{HT_w} + \frac{Q^D L^D}{Nd}} ln \frac{\frac{H_E T_d}{HT_w}}{\alpha\varepsilon L^D + \frac{Q^D L^D}{dN} r^{-\delta}}$, the increment of EVs increases with the increasing of the number of existing EVs. After the time $t^* = \frac{1}{\alpha\varepsilon L^D + \frac{H_E T_d}{HT_w} + \frac{Q^D L^D}{Nd}} ln \frac{\frac{H_E T_d}{HT_w}}{\alpha\varepsilon L^D + \frac{Q^D L^D}{dN} r^{-\delta}}$, the effect is reversed.

The reason behind Corollary 1 is that in the early phase, due to the demonstration effect, purchasing EVs would drive other extra purchases; while in the latter stage EVs almost saturated the market, the growth rate of EVs would slows down. Regarding Corollary 1, it means the charging network should not extend unlimitedly too. To this point, the following Proposition gives a quantization answer.

Proposition 3: When the charging facility investor adopts the C investment strategy, if the attraction degree of ECFs, I^C is greater than the critical value$\frac{NC_p}{0.01TS(M-N)L^C r^{-\delta}(P_s - P_b)m}$, the profit of the ECFs would increase with the increase of the number of charging piles. If not, the profit would decrease. On the other side, when the charging facility investor chooses the F investment strategy, if the attractiveness of the charging facility I^F is greater than the critical value$\frac{NC_p}{0.01TS(M-N)L^F r^{-\delta}(P_s - P_b)m}$, the profit of the ECFs would increase with the increase of the number of charging piles, and vice versa.

Proposition 3 explains the impact of the market attraction (i.e., market share) of the invested ECFs on their profits under a fixed charging price. However, in realistic operations, the charging price is influenced by many factors, including the local government's regulations, market competition, and especially investment costs. However, if returning to the essence of making a price tariff (that is a price strategy would be mostly determined by the overall investment cost), the relation between the boundary charging price of ECFs and the different ECF investment strategies could be derived, based on Equations (11) and (12).

Proposition 4: If the investors of ECFs chooses the investment strategy *F*, then the lowest boundary charging price condition P_s should be greater than $\frac{C_p(Q^F-Q^C)}{0.01TdS\left\{(I^F-I^C)\left(N+\frac{N H_E T_d}{M\, HT_W}\right)+(M-N)\varepsilon\alpha(I^F L^F-I^C L^C)+\frac{M-N}{dN}r^{-\delta}(I^F L^F Q^F-I^C L^C Q^C)\right\}m}+P_b$.

$$Q^C=\frac{\gamma\left[N+(M-N)L^C\varepsilon\alpha+\frac{H_E T_d}{HT_W}\frac{N(M-N)}{M}\right]SdN}{100P_e\beta N-\gamma(M-N)SL^C r^{-\delta}}$$

$$Q^F=\frac{\gamma\left[N+(M-N)L^F\varepsilon\alpha+\frac{H_E T_d}{HT_W}\frac{N(M-N)}{M}\right]SdN}{100P_e\beta N-\gamma(M-N)SL^F r^{-\delta}}$$

Proposition 4 gets the lowest charging price when the ECFs investors choose the *F* strategy. However, from the perspective of pushing forward the development of electric cars, another boundary condition must be satisfied, i.e., the driving cost per 100km of EVs shall be less than that of oil-fueled cars, so that users will enjoy a comparative advantage in buying electric cars at the same price. In real scenarios, the market has motivation to purchase EVs to displace oil-fueled cars only when the boundary condition$P_s\times S<P_g\times f$ is satisfied, whereas P_g ($\$/\mathrm{L}$) represents the unit price of oil.

In the other case that both investment strategies could get a positive profit, the marginal condition of choosing which strategy for the investors is determined by the following corollary.

Corollary **2**: When the attraction degree of the invested ECFs meets the condition: $I^F>\frac{dNC_p}{0.01TdS(P_s-P_b)(M-N)L^F r^{-\delta}m}$, ECFs investors would choose *F* strategy.

Corollary **3**: Given the precondition of Corollary 2, as long as overall EV charging demand rises, ECF investors will opt for the more aggressive *F* strategy, even if future EV technology advancements will reduce unit EV charging demand.

Proposition 5: In the dynamic development of EVs, compared with the investment strategy *C* of ECFs, the investment strategy *F* will help to push forward more EVs with an increase margin:

$$(M-N)\left[\varepsilon\alpha\left(\frac{K}{1+\frac{K-k^F}{k^F}e^{-\phi^F t}}-\frac{K}{1+\frac{K-k^C}{k^C}e^{-\phi^C t}}\right)+\frac{r^{-\delta}}{dN}\left(\frac{K}{1+\frac{K-k^F}{k^F}e^{-\phi^F t}}Q^F-\frac{K}{1+\frac{K-k^C}{k^C}e^{-\phi^C t}}Q^C\right)\right]$$

As described previously, in a harmonious state, ECFs investments and EVs purchases could stimulate each other. Rationally, investing more ECFs could advance the development of EVs. However, it is hard to explain the present "egg-chick" stalemate situation, where each side waits for the other's action. To explain this question, Proposition 6 is given:

Proposition 6: When the development of EVs is in its initial stage, charging facility investors have less incentive to choose the F investment strategy to invest in ECFs than in other stages.

5.2 ECF investment incentives

The discussed Proposition 6 indicates that it is hard to incentivize ECF investors to choose the relatively aggressive *F* strategy without any coordinated schemes. Thus, from the goal of facilitating EV development better, designing an appropriate incentive policy for ECF investors is necessary, especially in the initial stage of EV development. In order to achieve this goal, relevant countries mainly formulate three types of related policies: subsidizing ECFs based on a certain percentage, subsidizing based on the number of ECFs, and subsidizing based on the installed power of ECFs. However, the effects of these policies have not been measured so far. In this section, the policies will be modelled and theoretically compared with each other.

(1) Subsidy based on a certain percentage:

$$V^D=I^D(N+n^D)\times P_s\times 0.01TdS-\frac{Q^D C_p+N_l C_l+C_o}{m}-0.01TdSI^D P_b(N+n^D)+G\left(Q^D C_p+N_l C_l+C_o\right) \quad (13)$$

In Equation (13), G represents the subsidy proportion of the total investment in one ECF, and the other letters have the same meanings as above.

(2) Subsidy based on the number of ECFs:

$$V^D = I^D(N + n^D) \times P_s \times 0.01TdS - \frac{Q^D C_p + N_l C_l + C_o}{m} - 0.01TdSI^D P_b(N + n^D) + XQ^D \tag{14}$$

In Equation (14), X represents the subsidy amount for each charging pile according, and the meaning of the other letters is the same as above.

(3) Subsidy based on the installed power of ECFs:

$$V^D = I^D(N + n^D) \times P_s \times 0.01TdS - \frac{Q^D C_p + N_l C_l + C_o}{m} - 0.01TdSI^D P_b(N + n^D) + YQ^D P_e \tag{15}$$

In Equation (15), Y represents the subsidy amount per kilowatt of the installed power of each charging pile. The meanings of the other letters are the same as above.

Through a series of algetic deriving of Eqs. (13), (14) and (15), the following Proostion could be got:

Proposition 7: The subsidy policy based the installed power of ECFs is most effective.

6 Case study

6.1 Basic setting

According to the report released by the IEA, to 2030, the estimated volume of global charging piles will reach 245 million units; the total charging power will reach 1800GW; and the charging capacity will reach 820TWh.; globally the average cost of each public ECF in 2030 and in 2020 would be 30,000 Chinese yuan/unit and 18417.4 Chinses yuan/unit respectively. For the sake of analysis, this paper takes the price of charging pile as 2,0000 Chinses yuan/unit. The government generally sets the service fee of EV charging at 1.6 to 1.9 yuan/kWh. Learning from the study of Zhang et al. (Zhang et al., 2018), this paper sets the charging fee P_s at 1.6 yuan/kWh and the extra service fee at 0.6 yuan/kWh. The price of electricity purchased by the charging facility investors from the power grid P_b is 1 yuan/kWh. As the car market of China is not saturated, set the private car increases to saturation at a rate of $\theta = 0.15 - 0.012t$ ear by year (Yu et al., 2019).

According to the *Annual Report on the Development of China's Charging Infrastructure for 2019-2020* ("Annual Report") released by the China EV Charging Infrastructure Promotion Alliance in February 2020, the average power of new public DC charging piles in China continuously grew from 69.23 kW in 2016 to 115.76 kW in 2019, following an annual increase rate of 67.2%. At present, the charging power of existing public DC charging piles on the market can basically meet the charging demand of EVs. In order to facilitate calculation and take into account the *Annual Report* into account, the output power of a charging pile P_e is set to 120kW. Based on the research of Guo (Guo, 2019), the charging conversion efficiency of each charging pile β is set to 0.9. The average daily driving distance of one EV d is set to 50km according to the study by Wang et al. (Wang et al., 2019). The average electricity consumption of each EV per 100 kilometers is set to 15 kW•h (Yu et al., 2019). The maximum endurance time that EV users are willing to wait for charging is set to 20 minutes (Li et al., 2022). Besides, for analysis convenience, the author sets the effective life of each ECF as 10 years without regard to the residual value. Upon the premise of not affecting the conclusion, assume that all EVs are charged via the public DC charging piles.

Through the above settings, the parameter values as shown in Tab. 1 can be obtained:

Table 1. Parameter values

Parameter	Value	Parameter	Value	Parameter	Value
T (day)	365	H_e (Vehicles)	50	C_l (yuan)	5000
d (km)	50	H (Vehicles)	100	C_o (yuan)	5000
I^C	0.3	T_d (hour)	24	C_p (yuan)	20000
I^F	0.4	T_w (hour)	8	P_s (yuan/kWh)	1.6
ε (kWh/km)	0.001	r (km)	1.1	P_b (yuan/kWh)	1
β	0.9	δ	2	γ	0.5
K (km)	600	α	0.3	G	0.3
m (year)	10	P_e (kW)	120	X (yuan)	500
N (vehicles)	900	N_l (m2)	300	Y (yuan)	200

Based on the above parameter values, the following simulation results can be obtained. See the following sections for details.

6.2 *Marginal condition analysis*

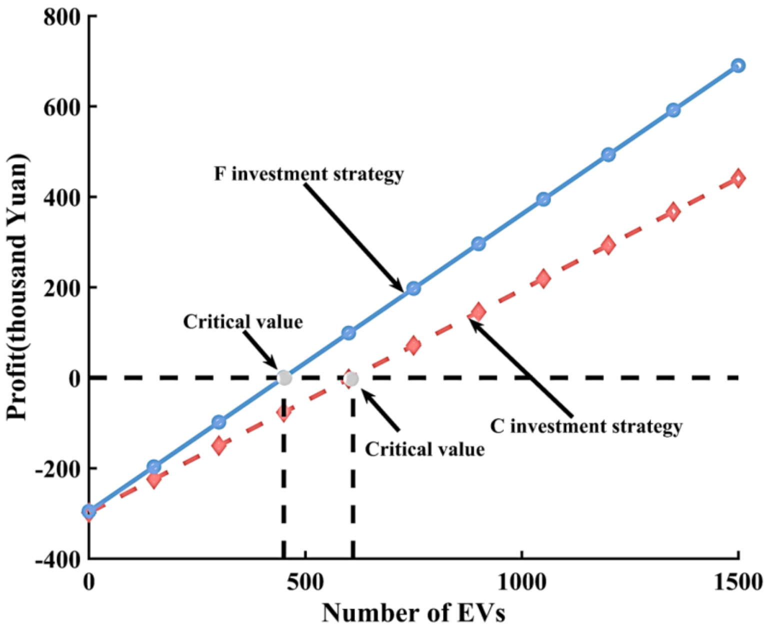

Figure 3. ECF-investment profit changes with number of EVs

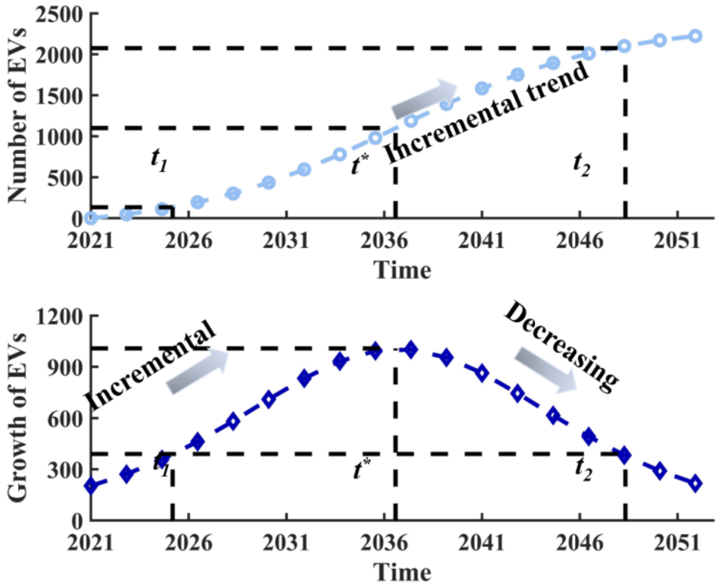

Figure 4. Development process of EV

As can be seen from Fig. 3, if charging facility investors choose investment strategy C to invest ECFs, the profit should be greater than zero, and the EV ownership should meet the boundary conditions $N+n^C > \frac{Q^C C_p + N_l C_l + C_o}{0.01 T d S I^C (P_s - P_b) m}$. In contrast, if the charging facility operator chooses investment strategy F, the profit should be greater than zero, and the EV ownership should meet the boundary conditions $N+n^F > \frac{Q^F C_p + N_l C_l + C_o}{0.01 T d S I^F (P_s - P_b) m}$. Proposition 1 is proved.

As can be seen from Fig. 4, there are three critical time points in the development process of EVs: the take-off point of growth rate is the t_1 moment, the maximum point of growth rate is the t^* moment, and the maturity point of growth rate is the t_2 moment. Proposition 2 is proven.

Fig. 3 shows the dynamic change of ECF investor's profit along with the number of EVs. However, the simulation is built on the basis of a fixed charging price setting. To analyze the corresponding change under different charging price, next, this setting is relaxed, based on which the Fig.5 is got.

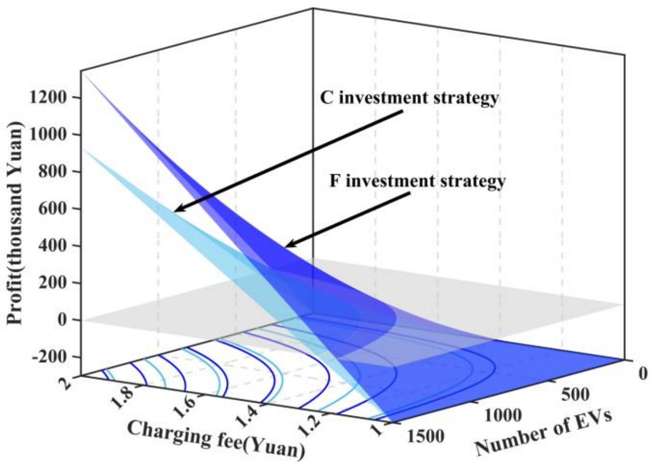

Figure 5. ECF-investment profit changes with the charging fee and number of EVs

As shown by Fig. 5, the profits of ECF investors are in proportion to the increasing of charging price and the number of EVs. In addition, it can be seen from Fig. 5 that the profits can only achieve positive values when the charging price and the number of EVs reach a certain number, indicating that with regards to the scale of EVs as well as potential profit rate which is decided by the charging price setting, there exist the marginal condition for the investors to participate the construction of ECFs.

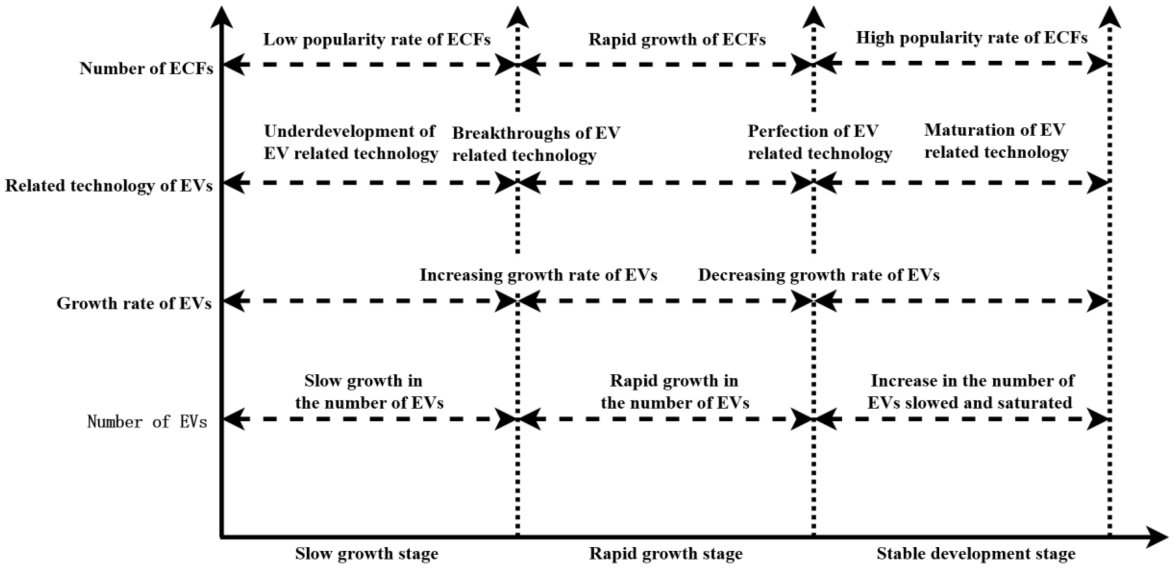

Figure 6. Characteristics of different stages in the development of EVs

According to the three time points in Fig. 4 and the characteristics of each period, the development process of EV can be divided into three stages. As shown in Fig. 6, Stage 1 is a slow growth stage characterized by underdeveloped EV-related technology and a low popularity rate of EVs. Stage 2 is a rapid growth stage characterized by developed EV-related technology, a significant increase in the EV purchase rate and ECFs. Stage 3 is a stable development stage characterized by the saturation of the EV market. The above stages and the change of each stage are described clearer by Fig. 7. Remarkably, Fig. 7 also fully demonstrates how the market stock of electric vehicles will stimulate future electric vehicle purchases.

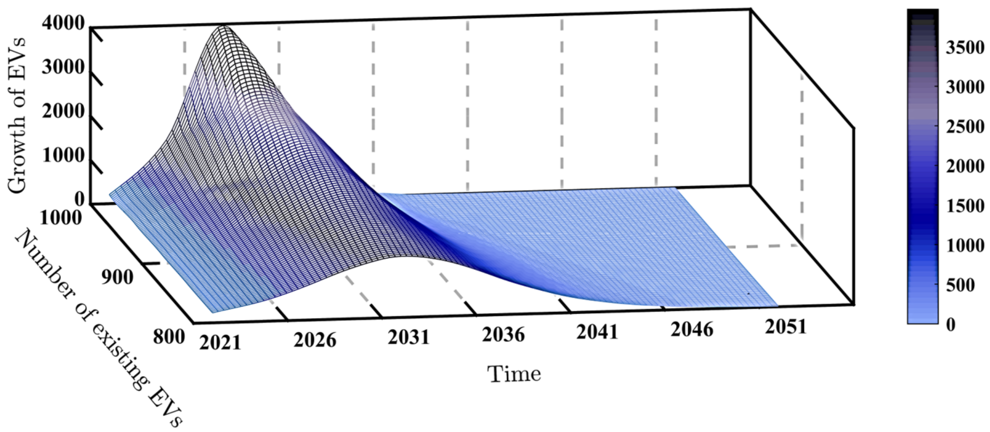

Figure 7. ***Growth of EVs changes with the number of existing EVs***

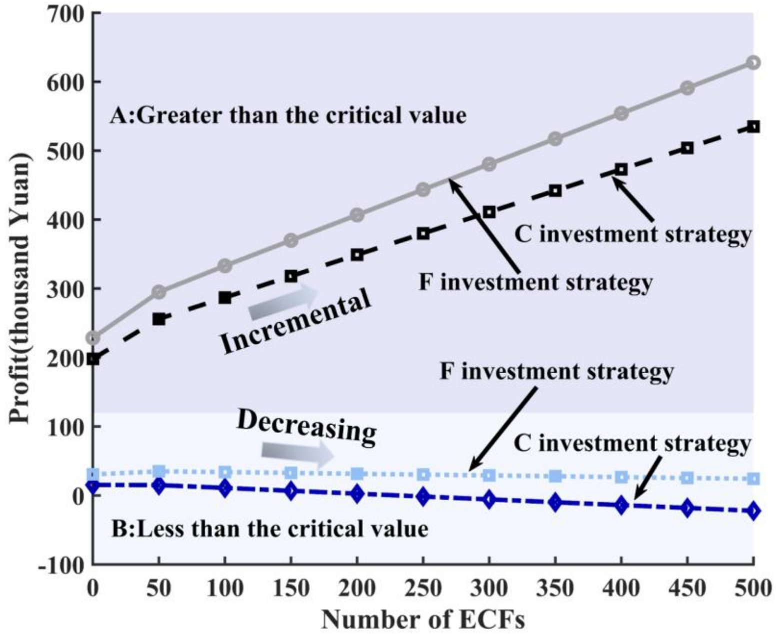

Figure 8. ECF-investment profit changes with the number of ECF

As seen from Fig. 8, when the ECF investor chooses the investment strategy C and the attractiveness I^C is greater than the critical value $\frac{NC_p}{0.01TS(M-N)L^C r^{-\delta}(P_s-P_b)m'}$, i.e., area A, the profit of the investor increases with the increase of the number of ECFs. Besides, when charging facility investors choose investment strategy F and the attractiveness I^F is greater than the critical value $\frac{NC_p}{0.01TS(M-N)L^F r^{-\delta}(P_s-P_b)m'}$, i.e., area A, the profit of the charging facility operator increases with the increase in the number of ECFs. So Proposition 3 is proven.

6.3 *Marginal stage analysis*

As a typical new-technology product, some research argued that the trajectory of EV's development is similar to that of other high-tech products—— showing a "S" shaped development track (Zhou et al., 2017). As shown in Fig. 9, with the continuous development of EV technology and the construction of ECFs, EV will show a development trend of "slow, fast and steady" (Shi et al., 2020), which is consistent with the conclusion of Proposition 2 in this paper. To more accurately map the interactive development relationship between EVs and ECFs, we perform a simulation and get Fig. 10.

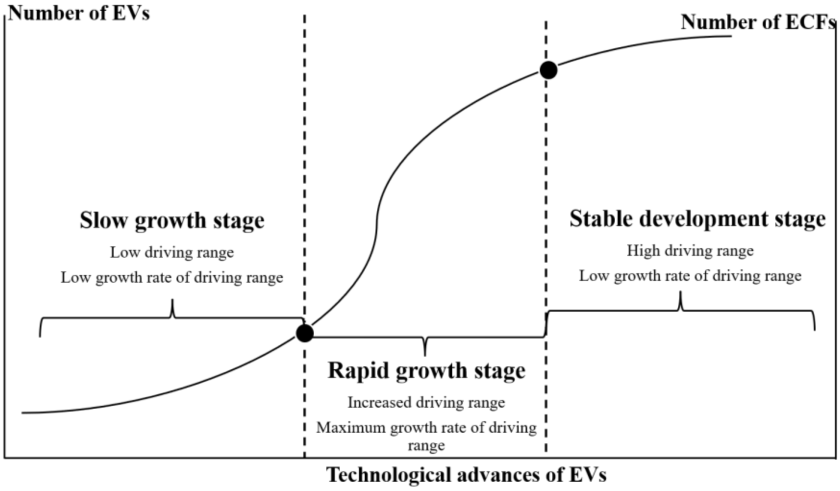

Figure 9. ***Three stages of EV technology development***

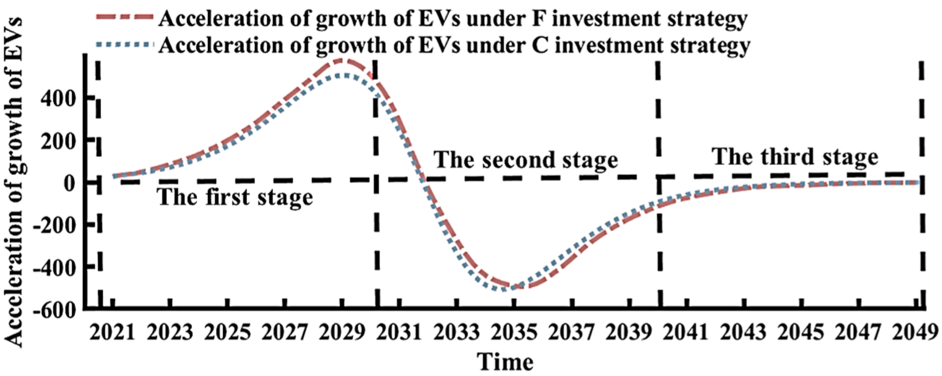

Figure 10. *Three stage growth change of EV*

As shown by Fig. 10, in the first stage, EVs show an accelerating- growth tendency; yet after that stage, both in the secondary stage and the third stage, the accelerating growth would slow down, and even decelerate after 2032. Nevertheless, the effects of different ECF investment strategies is different. Obviously, the stimulation effect of the more aggressive strategy *F* on the EV's market diffusion would better than the conservative strategy *C*.

6.4 *Incentive policy analysis*

To analyzes the effects of different incentive policies on the incentive to ECF investors, the representative policies are gathered and selected in China, as shown in Tab. 2:

Table 2. Three cities policy

City	Policy	Content
Beijing City	Interim provisions of Beijing Development and Reform Commission on the administration of government investment	Subsidizing the 30% of the total ECFS investment
Shanghai City	Interim Measures of Shanghai Municipality on promoting the interconnection and orderly development of electric vehicle charging (swapping) facilities	Subsidizing 500 Chinese yuan/ pile
Shenzhen City	Shenzhen new energy vehicle charging infrastructure management Interim Measures	Subsidizing 200 Chinese yuan/ kW

In the base of Tab.2, a simulation is performed, as shown Fig.11. Obviously, according to the simulation results, the scheme of Shenzhen is better in terms of enhancing the profit expectation of ECF investors in each developing stage of EVs under different investment strategies. It means that this incentive policy is more effective in incenting ECF investors to layout ECFs actively, thus stimulating the regional development of EVs indirectly. This result verifies Proposition 7.

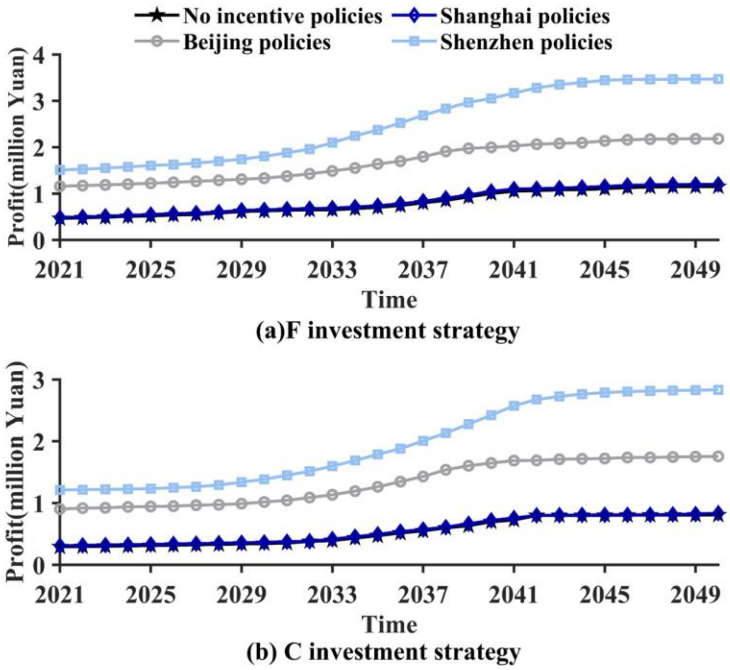

Figure 11. *ECF-investment profit changes with different policies*

6.5 Result robustness test

The prior analysis of the case study has corroborated the main results of this paper basically. In order to validate their robustness (that is, the gained results whether have the capability of generalization) further, in this section, an extra simulation analysis is performed, in which some core parameters (e.g., the market perception parameter α that represents the market perception to the different the EV's technological level, the peak charging parameter γ that represents the ratio of EVs choosing to charge in rush hour, and the preference parameter δ that represents the preferring degree of consumers to ECF location) are adjusted, in the background of the introduced three cities. As shown in Fig. 12, the results are still stable. This verifies the results' robustness.

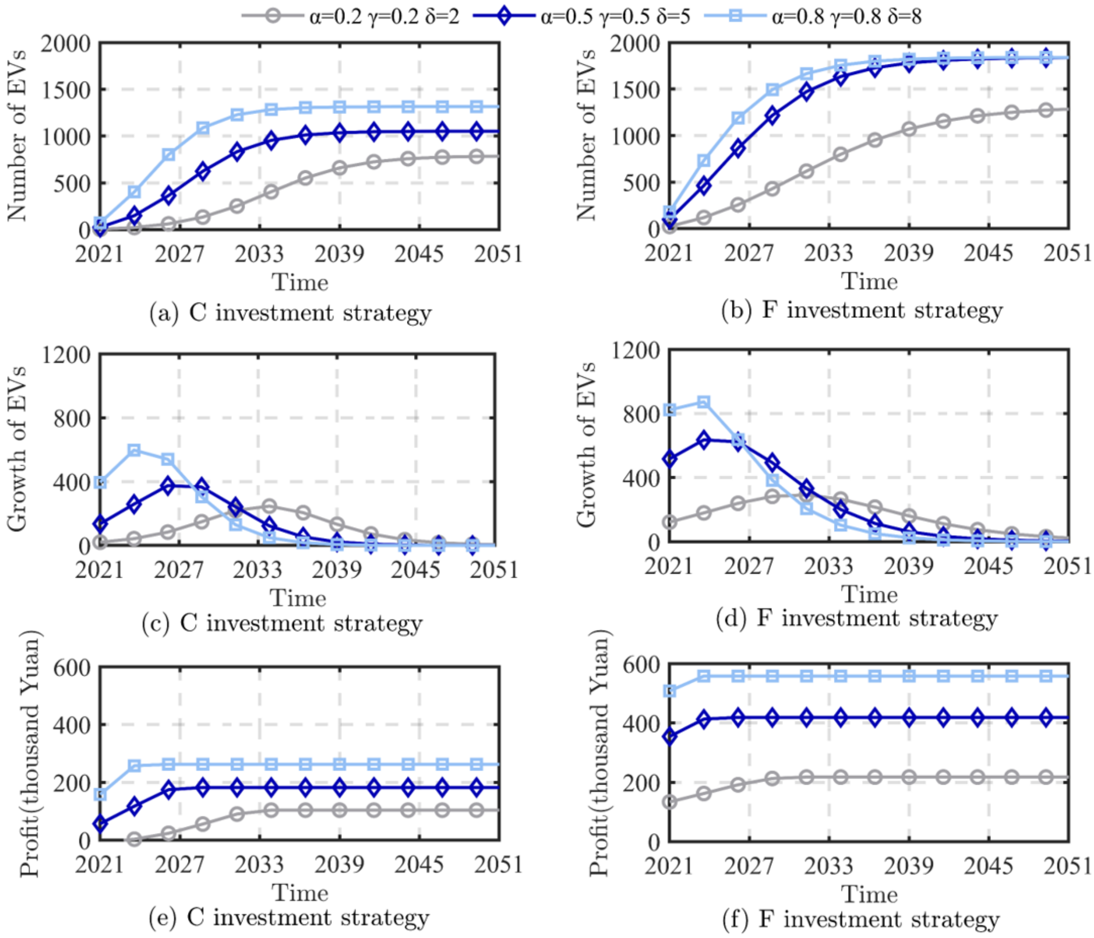

Figure 12. Number of EVs and growth of EVs and profit changes with α and γ and δ

7 Discussions

The above sections have perform a systematic analysis to the issue of the investment motivation of ECF investors. Overall, a central conclusion can be drawn that ECF investors' investment profit expectations determine their investment strategies. The investment profits, however, are closely related to the investment environment. According to our research, the development of EVs can be divided into three stages, in which the investment choices of ECF investors are different.

In the initial stage of EVs' development, due to the existence of a number of uncertainties, e.g., the market scale of EVs, ECF investors usually choose a conservative investment strategy. Yet, this choice is not favorable to the further development of the EVs market, because there are not adequate ECFs, which may cause charging anxiety, hence hindering the purchase of EVs. To break this predicament, an appropriate macro incentive policy should be formulated. Around this point, the paper further summarizes the incentive policies of some other countries (referring to the summary of Tab.3), and after comparing them with China's incentive policies, it is found that the incentive policies can still be divided into three types as shown in Tab.2. Therefore, the proposed ECF subsidy scheme based on installed charging capacity, that is, the scheme of Shenzhen city in China, is generalized. This is also consistent with the findings of Fang et al. (Fang et al., 2020) and Kumar et al. (Kumar et al., 2021). To some degree, this result could provide an explication of why Shenzhen has a high population rate of EVs and even nurture the emerging EV brand "BYD".

After the initial stage, the EVs would drive into a fast-diffusing stage. In this phase, the influence of EVs' market scales would become not important, while the factors of the spatial cost would affect the investment decision of the investors more. This is consistent with the findings of Zhang et al. (Zhang et al., 2019). Notably, the spatial factors not just refer to the cost of land usage for building ECFs, but also include others, for example, the retrofit costs for the power systems for avoiding to impact of EVs' peak-charging-load period (Wu & Pang, 2023; Yin et al., 2023). From a holistic perspective, therefore, at this stage, it is important to plan the layout of charging facilities in order to take into account the charging convenience of EVs and the minimization of the overall investment cost. This is consistent with the opinion of Shi et al. (Shi et al., 2021).

Table 3. Summary of incentive policy for ECFs in different countries

Country	Content	Source
China	Subsidizing the 30% of the total ECFS investment Subsidizing 500 Chinese yuan/ pile Subsidizing 200 Chinese yuan/ kW	(Shi et al., 2023)
United States	70%-80% grant on hardware cost Grant of up to 10,000-70,000 $/station	(California Energy Commission, 2020) (Austin Energy, 2019) (Montana Department of Environmental Quality, 2019) (Michigan Department of Environment, 2019)
France	40% grant on supply and installation cost	(European Alternative Fuels Observatory, 2020)
Finland	30% grant on purchasing and installing cost	(International Energy Agency, 2018)
Sweden	50% grant on investment	(Swedish Environmental protection agency, 2020)
South Korea	Grant of about HK$16,000 - HK$23-000/station	(Legislative Council Secretariat, 2020)
Japan	100% subsidy for hardware purchase cost of commercial facilities	(Legislative Council Secretariat, 2020)

8 Conclusion

To explore the internal motivation mechanism of ECF investors, when deciding whether to invest ECFs, as well as to measure the influence of different investment strategies of the investors on the market development of EVs, this paper firstly constructs a series of theoretic models to describe the interactive relationships, e.g., between the investment decision of the investor and the regional EVs market development. Based on the models, some enlightening propositions are gained. Then, to further corroborate the main results, a case study is performed in the background of China. The main results are summarized as follows.

First of all, it is hard to make ECF investors choose an active or even aggressive investment strategy in terms of laying out ECFs in the initial phase of EV development, due to the limited market volume of EVs. Rather, in this stage, investors would be hesitant to take part in the construction of ECFs, due to the high cost of investing in them, a lower-than-expected cost recovery rate, and significant risk.

Obviously, in a long run, the conservative investment strategy of ECFs is not favorable to EV market development. Therefore, formulating and enacting an incentive policy to incentivize the investment of ECF investors is necessary. After comparing the three typical policies, the subsidy policy according to installed charging power is suggested.

Overall, the developing relationship between electric vehicles and charging facilities is stage-specific. Of all stages, the most thorny is the first stage, as mentioned above. Besides, in order to enhance the operationality of the results, in this paper, the boundary of the stages and the effects on EV development under the different investment strategies of ECF investors all are quantified.

Acknowledgements

This paper is financially supported by the Chongqing National Natural Science Foundation of China (NO.cstc2020jcyj-msxmX0808), Humanities and Social Sciences Research Project of Chongqing Municipal Education Commission (NO. 23SKGH081).

References

Anjos, M F., Gendron, B., & Joyce-Moniz, M. (2020). Increasing electric vehicle adoption through the optimal deployment of fast-charging stations for local and long-distance travel. *European journal of operational research*, 285(1), 263-278.

Austin Energy (2019). Plug-in austin electric vehicles: rebates, resources, and fun for EV drivers and riders, https://austinenergy.com/ae/green-power/plug-in-austin.

Axsen, J., Langman, B., & Goldberg, S. (2017). Confusion of innovations: Mainstream consumer perceptions and misperceptions of electric-drive vehicles and charging programs in Canada. *Energy Research & Social Science*, 27, 163-173.

Badia, B., Berry, R A., & Wei, E. (2020). Investment in EV charging spots for parking. *IEEE Transactions on Network Science and Engineering*, 7(2), 650-661.

Baumgarte, F., Kaiser, M., & Keller, R. (2021). Policy support measures for widespread expansion of fast charging infrastructure for electric vehicles. *Energy Policy*, 156, 112372.

California Energy Commission (2020). Central coast incentive project | CALeVIP. Center for sustainable energy, https://calevip.org/incentive-project/central-coast.

Chen, T D., Kockelman, K M., & Hanna, J P. (2016). Operations of a shared, autonomous, electric vehicle fleet: Implications of vehicle & charging infrastructure decisions. *Transportation Research Part A: Policy and Practice*, 94(C), 243-254.

Eisenbarth, M., Wegener, M., Scheer, R., Andert, J., Buse, D S., Klingler, F., Sommer, C., Dressler, F., Reinold, P., & Gries, R. (2021). Toward smart vehicle-to-everything-connected powertrains: Driving real component test benches in a fully interactive virtual smart city. *IEEE Vehicular Technology Magazine*, 16(1), 75-82.

European Alternative Fuels Observatory (2020). Incentives and legislation - France, https://www.eafo.eu/countries/france/1733/incentives.

Fang, Y., Wei, W., Mei, S., Chen, L., Zhang, X., & Huang, S. (2020). Promoting electric vehicle charging infrastructure considering policy incentives and user preferences: An evolutionary game model in a small-world network. *Journal of Cleaner Production*, 258, 120753.

Globisch, J., Dütschke, E., & Schleich, J. (2018). Acceptance of electric passenger cars in commercial fleets. *Transportation Research Part A: Policy and Practice*, 116, 122-129.

Gnann, T., & Plötz, P. (2015). A review of combined models for market diffusion of alternative fuel vehicles and their refueling infrastructure. *Renewable & Sustainable Energy Reviews*, 47, 783-793.

Golab, A., Zwickl-Bernhard, S., & Auer, H. (2022). Minimum-Cost Fast-Charging Infrastructure Planning for Electric Vehicles along the Austrian High-Level Road Network. *Energies*, 15(6), 2147.

Guo, G. (2019). Load calculation and influence factors of electric vehicle charging station. *Electrical Engineering*, 20(3), 93-97.

Hao, F., Wang, T., & Zhao, C. (2019). New product announcements and stock investor reactions:A behavioral model based on Bass model. *Management Review*, 31(1), 48-61.

Harrison, G., & Thiel, C. (2017). An exploratory policy analysis of electric vehicle sales competition and sensitivity to infrastructure in Europe. *Technological Forecasting & Social Change*, 114, 165-178.

He, F., Wu, D., Yin, Y., & Guan, Y. (2013). Optimal deployment of public charging stations for plug-in hybrid electric vehicles. *Transportation Research Part B: Methodological*, 47, 87-101.

Huang, X., Lin, Y., Lim, M K., Zhou, F., Ding, R., & Zhang, Z. (2022). Evolutionary dynamics of promoting electric vehicle-charging infrastructure based on public–private partnership cooperation. *Energy*, 239, 122281.

International Energy Agency (2018). Finland - policies and legislation | IA-HEV, http://www.ieahev.org/assets/1/7/Report2019_Finland.pdf.

Jha, A., & Saha, D. (2020). Forecasting and analysing the characteristics of 3G and 4G mobile broadband diffusion in India: A comparative evaluation of Bass, Norton-Bass, Gompertz, and logistic growth models. *Technological Forecasting & Social Change*, 152, 119885.

Kumar, R R., Chakraborty, A., & Mandal, P. (2021). Promoting electric vehicle adoption: Who should invest in charging infrastructure? *Transportation Research Part E: Logistics and Transportation Review*, 149, 102295.

Lee, S., & Choi, D. (2021). Dynamic pricing and energy management for profit maximization in multiple smart electric vehicle charging stations: A privacy-preserving deep reinforcement learning approach. *Applied energy*, 304, 117754.

Legislative Council Secretariat (2020). Policies and Measures on Promoting the Use of Electric Vehicles in Selected Places. Legislative Council of the Hong Kong special administrative region of the peoples republic of China, p. 28, https://www.legco.gov. hk/research-publications/english/1920fs01-polices-and-measures-on-promoting-the-use-of-electric-vehicles-in-selected-places-20200610-e.pdf.

Li, H., Xia, Y., Yu, S., Zhao, X., Fang, C., Feng, D., & Zhou, Y. (2022). Research on capacity expansion and planning for urban electric vehicle charging station based on user-side active charging guidance. *Proceedings of the CSEE*, 1-17.

Li, X., Yang, J., & Liu, Y. (2020). Impact of technological progress on the demand of new energy vehicles——empirical evidence from 15 countries. *Soft Science*, 34(10), 12-17.

Michigan Department of Environment (2019). Great Lakes, and Energy, 2019. EGLE offers grants of up to $70,000 for EV fast chargers, https://www.michigan. gov/egle/0,9429,7-135-3308-515146–,00.html.

Montana Department of Environmental Quality (2019). Funding opportunity for electric vehicle charging
stations. montana department of environmental quality, http://deq.mt.gov/Energy/transportation/VW
-Settlement-Page.

Nityanshi., Mathur, T., Tikkiwal, V A., & Nigam, K. (2021). Feasibility analysis of a solar-assisted electric vehicle charging station model considering differential pricing. *Energy Storage*, 3(4), e237.

Peres, R., Muller, E., & Mahajan, V. (2010). Innovation diffusion and new product growth models: A critical review and research directions. *International Journal of Research in Marketing*, 27(2), 91-106.

Qiu, B., Yu, R., Liu, Y., Zhao, D., & Song, J. (2021). A comparative study on economy of battery and fuel cell electric vehicles of different application scenarios based on learning rate. *Automotive Engineering*, 43(2), 296-304.

Reid, S., & Spence, D B. (2016). Methodology for evaluating existing infrastructure and facilitating the diffusion of PEVs. *Energy Policy*, 89, 1-10.

Shi, L., Hao, Y., Lv, S., Cipcigan, L., & Liang, J. (2021). A comprehensive charging network planning scheme for promoting EV charging infrastructure considering the Chicken-Eggs dilemma. *Research in Transportation Economics*, 88, 100837.

Shi, L., Liu, C., Dong, J., & Liana, C. (2020). External benefits calculation of sharing electric vehicles in case of Chongqing China. *Utilities Policy*, 64, 101021.

Shi, L., Lv, S., & Lv, T. (2021). Transaction incentive mechanism design in V2G market considering dynamic loss aversion. *Journal of Industrial Engineering and Engineering Management*, 35(02), 233-242.

Shi, L., Lv, S., Liu, C., Zhou, Y., Liana, C., & L, A T. (2020). A framework for electric vehicle power supply chain development. *Utilities Policy*, 64, 101042.

Shi, L., Lv, T., & Wang, Y. (2018). Vehicle-to-grid service development logic and management formulation. *Journal of Modern Power Systems and Clean Energy*, 7(4), 935-947.

Shi, L., Wang, S., & Lv, S. (2023). lnteraction mechanism between charging facility operators' investment decision and the development of electric vehicles. *Management Review*, 35(01), 243-256.

Sierzchula, W., Bakker, S., Maat, K., & van Wee, B. (2014). The influence of financial incentives and other socio-economic factors on electric vehicle adoption. *Energy Policy*, 68, 183-194.

Silvia, C., & Krause, R M. (2016). Assessing the impact of policy interventions on the adoption of plug-in electric vehicles: An agent-based model. *Energy Policy*, 96, 105-118.

Sovacool, B K., Rogge, J., Saleta, C., & Masterson-Cox, E. (2019). Transformative versus conservative automotive innovation styles: Contrasting the electric vehicle manufacturing strategies for the BMW i3 and Fiat 500e. *Environmental Innovation and Societal Transitions*, 33, 45-60.

Srivastava, A., Kumar, R R., Chakraborty, A., Mateen, A., & Narayanamurthy, G. (2022). Design and selection of government policies for electric vehicles adoption: A global perspective. *Transportation Research Part E: Logistics and Transportation Review*, 161, 102726.

Sun, K K., He, S Y., & Thøgersen, J. (2022). The purchase intention of electric vehicles in Hong Kong, a high-density Asian context, and main differences from a Nordic context. *Transport Policy*, 128, 98-112.

Sun, X., Sun, R., & Tu, A. (2018). Network effects, emerging industries evolution and niche cultivation: An agent-based modeling simulation from electric vehicle industry. *Journal of Management Sciences in China*, 21(11), 1-17.

Swedish Environmental protection agency (2020). St¨od till Publika Laddningsstationer. Swedish Environmental protection agency, https://www.irs.gov/pub/irs-pdf/i8911. pdf.

Taalbi, J., & Nielsen, H. (2021). The role of energy infrastructure in shaping early adoption of electric and gasoline cars. *Nature Energy*, 6(10), 970-976.

Tang, H., Liu, L., Yu, H., & Cui, J. (2019). Research into Demand Diffusion for Sequels Integrating Bass Model with Three-Stage Process Model. *Operations Research and Management Science*, 28(1), 166-175.

The Ministry of Public Security of the People's Republic of China (2021a). In 2020, there will be 33.28 million newly registered motor vehicles and 4.92 million new energy vehicles in China, https://www.mps.gov.cn/n2254314/n6409334/c7647242/content.html.

The Ministry of Public Security of the People's Republic of China (2021b). In the first quarter of 2021, 9.66 million newly registered motor vehicles were registered, a record high for the same period, https://www.mps.gov.cn/n2254314/n6409334/c7829324/content.html.

Tian, M., Tang, B., Yang, X., & Xia, X. (2021). Planning of electric vehicle charging stations considering charging demands and acceptance capacity of distribution network. *Power System Technology*, 45(2), 498-506.

EV-Volumes (2021). A global electric vehicle research company, https://www.ev-volumes.com/.

Wang, H., Zhang, Y., & Mao, H. (2019). Charging load forecasting method based on instantaneous charging probability for electric vehicles. *Electric Power Automation Equipment*, 39(03), 207-213.

Woo, J., & Magee, C L. (2020). Forecasting the value of battery electric vehicles compared to internal combustion engine vehicles: the influence of driving range and battery technology. *International Journal of Energy Research*, 44(3), 1-19.

Wu, S., & Pang, A. (2023). Optimal scheduling strategy for orderly charging and discharging of electric vehicles based on spatio-temporal characteristics. *Journal of Cleaner Production*, 392

Wu, X., Feng, Q., Bai, C., Lai, C S., Jia, Y., & Lai, L L. (2021). A novel fast-charging stations locational planning model for electric bus transit system. *Energy*, 224, 120106.

Yang, J., Wu, F., Yan, J., Lin, Y., Zhan, X., Chen, L., Liao, S., Xu, J., & Sun, Y. (2020). Charging demand analysis framework for electric vehicles considering the bounded rationality behavior of users. *International Journal of Electrical Power & Energy Systems*, 119, 105952.

Yang, W., Xiang, Y., Liu, J., & Li, Y. (2017). Multi-agent modeling for the scale evolution of plug-in electric vehicles. *Power System Technology*, 41(7), 2146-2154.

Yin, W., Wen, T., & Zhang, C. (2023). Cooperative optimal scheduling strategy of electric vehicles based on dynamic electricity price mechanism. *Energy*, 263, 125627.

Yu, H., Yan, Z., & Pan, A. (2019). Medium- and long-term evolution model of charging load for private electric vehicle. *Automation of Electric Power Systems*, 43(21), 80-87.

Yu, H., Zhang, Y., & Pan, A. (2019). Medium- and Long-term Evolution Model of Charging Load for Private Electric Vehicle. *Automation of Electric Power Systems*, 43(21), 80-87.

Zhang, L., Yang, M., & Zhao, Z. (2019). Game analysis of charging service fee based on benefit of multi-party participants: A case study analysis in China. *Sustainable Cities and Society*, 48, 101528.

Zhang, L., Zhao, Z., Xin, H., Chai, J., & Wang, G. (2018). Charge pricing model for electric vehicle charging infrastructure public-private partnership projects in China: A system dynamics analysis. *Journal of Cleaner Production*, 199, 321-333.

Zhao, Y., Guo, Y., Guo, Q., Zhang, H., & Sun, H. (2020). Deployment of the electric vehicle charging station considering existing competitors. *IEEE Transactions on Smart Grid*, 11(5), 4236-4248.

Zhou, H., Liu, J., Liu, Y., Xiang, Y., Dai, S., & Li, T. (2017). Analysis and simulation of electric vehicles scale evolution based on system dynamics. *Proceedings of the CSU-EPSA*, 29(08), 1-7.