Department of Human and Engineered Environmental Studies
Graduate School of Frontier Sciences
The University of Tokyo

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Master’s Thesis

A study on different subsidy policies for the Chinese electric vehicle industry with an agent-based model
(エージェントベースモデルを用いた中国電気自動車産業の補助金政策に関する研究)

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Adviser: Professor Yu Chen (seal)

Student ID Number 47196793

伍 紹同

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Time always flies but leaves behind precious memories and experiences. These two years will surely shine like gold in my life. My growth and progress cannot be achieved without the support of every person.

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Content

Chapter 1 Introduction

In the current age, global warming, carbon emissions, and oil dependence govern research agendas. The transition to low carbon emission techniques is becoming increasingly important. Electric vehicles (EVs) are one such a promising solution. Their zero emissions and their capability to be powered by renewable energy can help navigate a path to a sustainable and hopeful future.

Subsidies are used widely as policy tools to promote the diffusion of new technologies and new products in various areas, including electric vehicle markets. According to the different targets of subsidies, they are divisible into consumer subsidies and manufacturer subsidies. Among the manufacturer subsidies, there are subsidies for R&D processes according to various purposes. Depending on the criteria for receipt of subsidies, they can also be divided into selective and automatic subsidies. In China, to promote the diffusion of electric vehicles, the national government has promulgated consumer subsidies emphatically to drive EVs out of a niche phase quickly.

However, consumer subsidies can be more effective in promoting the diffusion of EVs in earlier stages because of remarkable price discounts. Manufacturer subsidies can augment investment into R&D processes directly, which can improve EV efficiency and curb their costs. Which of these two subsidies is the more effective? Could the advantages of these subsidies of two types be combined and complemented to form a new, more effective form of subsidy? That question will be addressed as the main topic of this study.

This chapter is organized as follows. Sections 1.1 and 1.2 respectively describe the history of electric vehicles and the current state and adopted policies in China. Section 1.3 presents a literature review. Section 1.4 includes discussion of the motivations and objectives of this research. Section 1.5 presents an outline to readers.

1.1 Electric vehicle development

1.1.1 History of electric vehicles

Electric vehicles might seem like a recent discovery in our society as a reaction to pressing issues related to carbon emissions and climate change. However, their development began with the first use of automobiles. The history of the electric vehicles has since been turbulent [1].

1.1.1.1 1834–1915

In 1834, an American inventor invented the world's first truly electric car, powered by a battery encased in a simple glass jar. In 1839, Scottish scientists transformed a four-wheeled carriage into the world's first vehicle powered by electricity by fitting it with a battery and an electric motor. In 1881, French engineers assembled an electric vehicle powered by lead–acid batteries, making it the world's first vehicle to be powered by rechargeable batteries.

The electric vehicle did not immediately replace personal horse-drawn carriages. However, in the mass transit sector, electric trams replaced horse-powered trams almost completely within 14 years after their first occurrence in 1888 [2]. The popularity of electric trams raised enthusiasm about electricity. During this period, electric vehicles became popular and entered commercialization. By 1912, there were about 34,000 registered electric cars in the U.S. This period was also the heyday of electric vehicles in the early stage. However, the invention of electric starters for fuel vehicles by Kettering in 1911 made fuel vehicles more popular and led to dramatic reduction in fuel prices and vehicle prices, which hastened the disappearance of electric cars.

1.1.1.2 1915–1990

Hoyer provides an overview of the development of electric vehicles during 1915–1990 [3]. During World War I, European interest in electric vehicles increased temporarily because petroleum products were needed as war supplies. However, when World War I ended, the nascent companies were bankrupted. Another cycle ended with the stock market crash in 1929, bankrupting electric vehicle firms once again. The same scenario was repeated during World War II, similarly, because of demand for gasoline at the war front. Interest dropped again after the war.

In the 1960s, 70s, and 80s, the rise of environmental movements again wrote alternative energy sources into the political agenda. Electric vehicles were once again attracting attention. At this time, many manufacturers designed and produced prototypes that never came into full production. Batteries were very expensive, making them uncompetitive with gasoline engines. Their performance remained unstable.

1.1.1.3 1990–Now

Since the 1990s, research and development of electric vehicles have become active again under the dual pressures imposed by energy necessity and environmental protection. Benefited by the rapid development of various scientific technologies, many technical difficulties of electric vehicles have been resolved. These include a joint push by vehicle manufacturers and battery producers to promote the commercialization of electric vehicles. Governments have also implemented various beneficial policies to promote the diffusion of electric vehicles.

1.1.2 Reflection

As explained in earlier sections, it is apparent that all past attempts at reintroducing electric vehicles to the market have been short-lived. Every revival of electric vehicles failed once the initial stimulating impetus was removed. During the two world wars, electric vehicles only had the chance to be resurrected in markets when petroleum supplies were threatened or unavailable. It seems that no single stimulus condition can lead EVs to win the market. Only multi-perspective beneficial conditions can advance the market diffusion of EVs similarly to that of gasoline vehicles. Furthermore, now is perhaps the best chance for the development and diffusion of electric vehicles because of opportunities in technology, social environments, and political perspectives.

1.2 Current state of electric vehicles and adopted policies in China

1.2.1 Current state in China

The Chinese government has set ambitious targets for EV diffusion. For instance, the market share of EVs is targeted to reach 20% of all annual vehicle sales by 2025 [4]. However, the country's sales of EVs reached only 5.5% of annual vehicle sales in 2020. In addition to the abolishment of purchase subsidies for electricity from 2022, the EV market is expected to face great challenges and turbulence [5].

Li provided an overview of barriers to EV diffusion in China at microscopic and macroscopic levels [6]. At a micro-level, when manufacturers are facing great uncertainty about technological advances and limited market demand, large investments are necessary to expand electric vehicle production capacity. They have heretofore preferred to invest in the conventional vehicle market to maintain their dominant position [7]. There also exist several factors affecting consumer preferences for EVs. These factors include (1) financial factors such as high purchase prices and maintenance costs, (2) technological factors such as long charging times and a limited cruising range, and (3) infrastructure factors such as only slight access to charging facilities [8]. At a macro-level, some political factors can hinder the implementation of effective policies to overcome micro-level barriers such as fragmented authority and local protectionism. Regarding fragmented authority, in China, the powers responsible for policy formulation and implementation are distributed among various agencies of governments at different levels. Furthermore, no formal definition or scope of authority exists at these institutions. Instead, policy decisions are usually based on a consensus reached by these institutions through extensive discussions. Until a consensus is established, conflicting interests and reconciliation can greatly delay a final policy plan. For example, during the construction of charging infrastructure, urban planners are more concerned about the nature of charging infrastructure, whereas public utilities might see charging infrastructure as an opportunity for higher revenues. The result of these conflicts is a marked delay in the development of charging infrastructure [9]. Another factor is local protectionism. The Chinese government has given local governments autonomy to develop and implement EV subsidy measures: the central government has provided only broader guidelines. This approach can help local governments adjust policies flexibly, but it also provides a scope for local governments to interpret policy guidelines in ways that contribute to local interests. Local protectionism is prevalent in public procurement. Because of this fact, most public fleet vehicles have been purchased from local automakers [7]. Local protectionism severely hinders fair market competition, leading to uneven development of electric vehicles in all regions.

1.2.2 Review of EV policy incentives in China

The Chinese government has introduced policy measures and financial incentives to promote electric vehicles in alignment with its advanced industrial development, such as pilot demonstration, research and development (R&D) subsidies, EV purchase subsidies, tax reductions and exemptions, easy market access, infrastructure construction and Corporate Average Fuel Consumption (CAFC) credits regime, and New Energy Vehicle (NEV) credit regime [10]. China implemented the three-step strategy for electric vehicle development. The process is divisible into three phases. The adopted policies for 2009–2020 are presented clearly in Fig. 1.

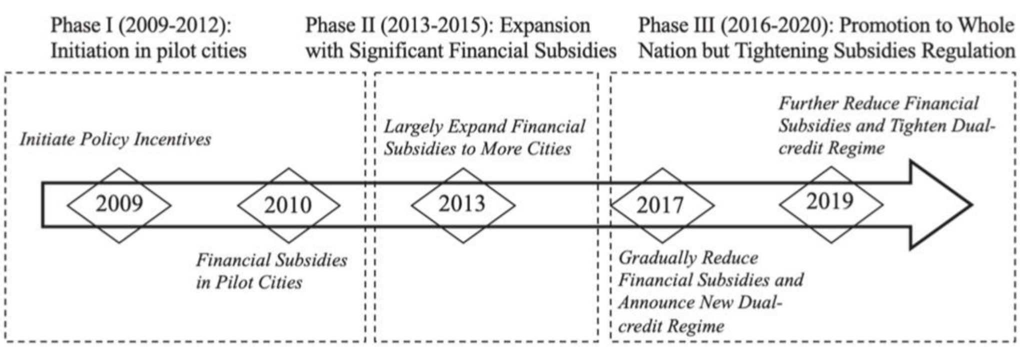


Fig. 1. Milestones of national EV policy incentives in China (Wu et al., 2021).

The first phase of the policy started from pilot projects in several key cities. Most cities chose hybrid electric vehicles as demonstration projects. Financial subsidies during this phase specifically emphasized public transportation and were aimed at stimulating investment, driving industry growth and shortening the initiation period. At this stage, electric vehicles were in the very early stages of industrialization. These demonstration projects were hampered by imperfect infrastructure and technological readiness. The national project of "Ten Cities and Thousands of EVs" lagged the original target: only around one-third of the original target was reached by October 2011 [11]. However, Phase I gave relevant experience and a foundation for subsequent Phase II and III policies.

Compared to Phase I, the policy of Phase II gradually extended the EV pilot to more regions. Financial subsidies were provided to both the public and private transportation sectors. During this phase, consumers were able to purchase electric vehicles at prices comparable to those of conventional vehicles. Large subsidies from the central government led to a rapid increment in the diffusion of EVs [12]. However, in light of rampant subsidy scandals and malfeasance, the central government began to consider introduction of stricter constraints for financial subsidies.

In Phase III, the industrial chain of EVs was established and upgraded at the national level. After financial subsidies from the central government increased gradually, government intervention was implemented to promote technological innovation and to improve energy efficiency. Aside from policies guiding financial subsidies, the Chinese government introduced alternative policies such as "Measures for the Parallel Management of Average Fuel Consumption and EV Credits for Passenger Car Companies" issued in September 2017 [13]. Corporate Average Fuel Consumption (CAFC) credits and production of New Energy Vehicle (NEV) credits were assessed using a system of "dual credits." This policy is also widely known as "Dual-credits Policy." By adopting a "Dual-credits policy" to control manufacturers' emissions levels and product performance, manufacturers are required to adjust their production patterns when the credit becomes negative. They can generate additional positive credits through the adjusted production pattern. Consequently, it can encourage vehicle manufacturers to bring highly energy-efficient products to market.

1.3 Literature review

1.3.1 Subsidy effects

Public subsidies are used widely as a crucially important policy instrument for the support of emerging industries. According to for the target for providing subsidies, public subsidies are classified conventionally into two broad categories: consumer and manufacturer subsidies [14]. According to manufacturer subsidy schemes, subsidies are classified into selective and automatic schemes [15]. Manufacturer subsidies are a kind of supply side instrument aimed at improving product competitiveness through subsidizing production or innovation activities of firms such as R&D subsidies that subsidize research and development activity [16]. Market demand is the dominant influential factor of technological innovation. However, consumer preferences are usually locked in traditional technologies because of path dependence, resulting in limited development space for new technologies [17]. Therefore, consumer subsidies are advocated by governments to relieve this difficulty. However, consumer subsidies are useful to create niche markets, protecting new technologies from competition with traditional technologies. By offering a positive policy signal, a consumer subsidy is expected to alleviate market uncertainty about new technologies and induce innovation investment by firms [18]. Selective R&D subsidies are a form of the merit-based subsidy scheme in which firms are selected to be subsidized through assessment of certain technical indicators by experts. In addition, selective schemes provide recipients with certification of the quality of their innovative projects, which is not provided by automatic schemes. In turn, this certification effect helps address information asymmetries that might have otherwise precluded access to external financing and other resources by these firms [15].

1.3.1.1 EV industry research subsidy

For the EV industry, many studies have specifically examined subsidy policies. Existing studies have sufficiently demonstrated the positive effects of subsidy in the EV industry [19–21]. Kong et al. argue that abolishment of consumer subsidies would affect EV diffusion. They propose the application of carbon emissions trading and licensing restriction policies to promote the long-term development of

EVs [22]. Zuo et al. proposed a novel decision model to help decision-makers select appropriate R&D subsidy targets to avoid waste of public resources and subsidy fraud in the EV market [23]. Liu et al. use the perspective of subsidy policy characteristics and apply generalized propensity score matching (GPS) to estimate the effects of different subsidy policy intensities on a change in consumer demand for EVs. Moreover, they find an interval to optimize [24]. Fan et al. analyzed the role of shared electric vehicles for promoting the acceptance of electric vehicles. They argued that distributing subsidies among car-sharing firms and consumers according to a certain percentage can better motivate people to use electric vehicles [25]. According to Wang et al., manufacturer subsidies can be expected to fulfill protective and incentive functions. On the one hand, subsidy funds provided by government can temporarily protect uncompetitive EV firms from bankruptcy and support the development of new entrants. On the other hand, a manufacturer subsidy provides EV incumbents additional funds to speed up R&D progress and expand the production scale, thereby improving new product quality and production efficiency. The market share of EV firms can be expanded [26].

Several studies are related to this research. Sun et al. designed a model that captured manufacturers and consumers in the vehicle market through an agent-based model approach. Based on robustness tests, the findings suggest that consumer subsidies are more effective than manufacturer subsidies for promoting the popularity and technological breakthrough of electric vehicles. Song et al. developed a system dynamics (S.D.) model to describe the feedback relation among subsidy policies, EV sales, and the uptake of EVs. The findings suggest that a policy portfolio of manufacture subsidy and purchasing subsidy can improve the efficiency of government funds for promoting EV industry development [28]. Zhang et al. developed a model that compared efforts for consumer subsidies, R&D subsidies, and combined subsidies. The findings suggest that, in an emerging market, where the EV infrastructure is inadequate and where manufacturers have insufficient technical capacity to produce EVs, it is better to adopt the R&D subsidy program first to increase the manufacturer's technology capacity. Then a consumer subsidy program can be used to promote EV sales [29]. Wang et al. developed a system dynamics model of China's EV adoption, running up to 2030, to analyze the effectiveness of EV policies. The findings forecast the diffusion conditions after abolishment of consumer subsidies and presented suggestions for EV-related policy reform after 2020 [5].

1.3.1.2 Evaluation of subsidy research

Much work has been undertaken to elucidate effects of consumer subsidies and manufacturer subsidies. Subsidies of both types are recognized as playing an important role in shaping the dynamics of innovation, which is particularly important in the EV industry. *Nevertheless, no report describes a study specifically examining selective R&D subsidies (a specific type of manufacturer subsidies) and their effect on the EV industry*. Colombo et al. demonstrated that selective R&D subsidies have a positive effect on the productivity of a sample of high-tech Italian recipient firms, whereas automatic incentives do not [30].

Numerous studies have compared effects of consumer subsidies and manufacturer subsidies. Controversy lies in which is the more effective. Results of some studies show, based on the output of their models, that consumer subsidies are more effective than manufacturer subsidies [27]. Other studies show that comparing the effects of these two types of subsidies requires consideration of the manufacturer's technology level. Effects of diverse subsidies differ when manufacturers are at different levels of technology [29]. However, before these conclusions are reached, these studies ignore the validity of the model itself, i.e., whether the model has been validated and calibrated, and whether the output is valid. Only from a model that has been validated and calibrated can convincing results be obtained.

Confirming the existence of differential effects among policies, related studies have emphasized the importance of a balance between demand-pull and technology-push measures within the policy mix, especially for emerging industries with advanced-generation technologies that compete with conventional products. Support schemes for emerging industries should explicitly examine policies targeted at both consumers and manufacturers to promote technology diffusion and innovation activities. Otherwise, the policy mix might impose high costs on the entire community without achieving the expected positive effects in terms of new technology development and social benefits.

Therefore, elucidating the effects of each subsidy type and making a comparison based on a reliable model are of great value. Then the effects of different policy mixes can be explored.

1.3.2 Methodology of EV industry research

Studies based on statistical analyses: Sierzchula et al. [31] used a multiple linear regression method to evaluate financial incentives and other factors related to EV adoption in 30 countries. They concluded that charging infrastructure was the most strongly related. From their linear municipal-level models, Mersky et al. [32] found that access to battery electric vehicle charging infrastructure had the greatest predictive power to measure BEV adoption in Norway, whereas toll exemptions and the right to use bus lanes seem to have little predictive power. Plötz et al. [33] analyzed data of plug-in electric vehicle sales from 30 European countries from 2010–2016, applying panel data regression models. They found that both direct and indirect subsidies influence PEV adoption positively.

Studies based on consumer surveys: Through a survey conducted in 20 countries, Lieven [34] found that a charging network on the freeway was of absolute importance. A four-paradigm model used by Li et al. [35] based on questionnaire data was used to analyze the consumers` evaluation of each policy. Results show that subsidization, technical support, and infrastructure policies in China must be improved urgently. Bjerkan et al. [36] invited nearly 3400 BEV owners in Norway to do a survey. Their conclusions revealed that exemptions from purchase taxes and value-added taxes were fundamentally important incentives. However, many BEV owners decided to buy an EV merely because of exemption from road tolls or the granting of special bus lane access. It is noteworthy that stated preference data of consumers are usually not in accordance with reality.

Studies based on simulation methodology: Wang et al. [5] analyzed the outlook for the EV market after repeal of consumer subsidies using a system dynamic model. They analyze different policies to help restore the EV market. Noori et al. [36] considered their respective inherent uncertainties. Vehicle attributes are evaluated for different vehicle types, including internal combustion engines, gasoline hybrid vehicles, and three other electric vehicle types. In addition, they designed an agent-based model to identify the market shares of the respective studied vehicles. Sheffield et al. [37] developed an agent-based model to study the market share evolution of passenger vehicles in Iceland, a country rich in domestic renewable energy. The model considers internal combustion engine vehicles that are currently dominant in the market and electric vehicles that are likely to enter the market in the future. Agent-based models are powerful tools for linking micro-scale behaviors to macro-scale phenomena in a class of complex adaptive systems that can capture behaviors and dynamics of consumers and manufacturers. They can facilitate studies of various subsidy effects.

1.4 Research motivations and objectives

Section 1.2.1.2 provided a brief overview of issues that are not being reported in the literature describing current studies.

China is slated to abolish consumer subsidies after 2022, but existing studies generally consider the abolishment of consumer subsidies after 2020 because of the renewal and timeliness of the policy. Consequently, it is necessary to predict again the future development and diffusion trend of electric vehicles based on the latest policy. The roles of selective R&D subsidies in the electric vehicle industry have not been emphasized in recent research, but theoretical studies have amply demonstrated its role and value. Existing studies propose different policy mix scenarios without fully considering the roles of different subsidies, which can lead to misjudgment by policymakers and waste of public funds.

Agent-based computational modeling is regarded as a promising approach because of its flexibility for incorporating new interactions and behavioral assumptions. Sun et al. developed an agent-based model to simulate and forecast the development of the electric vehicle market based on the U.S. market. Instead of building another "black box" model for a complex real electric vehicle market, we calibrate and validate this model to make it suitable for the Chinese market.

Therefore, the objective of this thesis can be clarified. By comparing effects of diverse subsidy schemes on the diffusion and development of EVs in the Chinese market, an optimal subsidy policy for EV diffusion can be proposed based on the simulation results.

The rationale of this methodology is apparent from the following three aspects.

First, consumer subsidies are the dominant policy implemented in the Chinese EV market. After calibration and validation of the baseline model, the future development trend of the EV market can be predicted. Development of the EV market can be explored under different consumer subsidy withdrawal scenarios.

Second, effects of different subsidy schemes can be compared to assess the benefits and shortcomings of different subsidies. We can explore the optimal coverage of selective R&D subsidies and analyze influential factors for optimal coverage.

Third, a combined subsidy scenario can be designed to combine the benefits of various subsidies based on different distributions of subsidies.

1.5 Outline

The main contents of this thesis are organized as follows: Chapter 2 introduces the structure and results of the baseline model. Chapter 3 forecasts the future development trend of electric vehicles in the Chinese market and different withdrawal scenarios of consumer subsidies. Chapter 4 presents a discussion of the roles of different subsidies for EV market diffusion and explores optimal coverage of selective R&D subsidies. In Chapter 5, different combinations of subsidies are discussed to find the optimal subsidy scenario. Chapter 6 summarizes conclusions and proposes future work.

Chapter 2 Baseline model

This chapter gives a brief introduction to the baseline model. The baseline model of this study is based on the model developed by Sun et al. in 2019 [27]. The baseline model was calibrated using real subsidy data for the Chinese electric vehicle market, validated by sales of EVs during 2013–20 in the Chinese market. In section 2.1, the baseline model framework is discussed based on the ODD protocol. Section 2.2 and 2.3 introduce baseline model agent profiles and mechanisms. In section 2.4, the model validation and verification are discussed. Section 2.5 introduces the model output.

2.1 Description of the model with the ODD protocol

The ODD protocol provides a standard protocol for describing agent-based models. Moreover, the ODD protocol is a framework for thinking about the models as we formulate them [38].

2.1.1 Overview

1). Purpose and pattern: Develop a model that can capture behaviors and interactions among consumers and manufacturers in the EV market. Manufacturers can conduct R&D activity to improve product performance. A consumer can make a purchase according to the performance of every product. Based on actual consumer subsidy data, the model is validated by comparing EVs and CVs sales in the model output with actual sales.

2). Entities, state variables, and scales: Consumers and manufacturers are entities that emerged in the model. The consumer is characterized by annual income and mileage. Willingness to pay for electric vehicles is based on these attributes. Manufacturers are characterized by capital, technology level, and R&D efficiency. Three states of manufacturers are awaiting market entry, participating in the market, and exiting from the market. The temporal scale is 150 steps, which implies a simulation time of 150, where one step stands for one year.

3). Process overview: In this model, the consumer will undertake purchase behavior according to their attributes and vehicle performance. For manufacturers, they can conduct R&D activity to improve the vehicle performance. The R&D investment comes from revenues and capital. When the maximum production capacity is reached, manufacturers will seek investment from banks to expand their production capacity. Manufacturers will switch state from waiting to enter the market to existing in the market when their product level reaches a threshold, switch state from participating in the market to exiting from the market when the exit condition is met.

2.1.2 Design concepts

Emergence: The sale of a vehicle is an emergence. The sale of the vehicle is determined by interaction of R&D activities, consumer purchase behavior, and subsidy policies. Product performance is also an emergence. Product performance is inferred from the interaction of R&D

activities, investment behavior, and consumer purchase behavior. These emergent behaviors are not simply a superposition of behaviors: they are the result of interactions among behaviors. The presence of numerous emergencies also provides a premise for using an agent-based model as a research method.

Adaptation: When the number of orders reaches the maximum production capacity, manufacturers seek investment from banks or financiers. When repaying loans, the share of repayment is judged based on profit. Furthermore, manufacturers adjust their status in the market in consideration of the current level of capital and technology as well as profitability. Consumers make the purchase and select the best choice from different products.

Objectives: Consumers purchase according to the utility provided by products; consumers will rank products according to their utility and choose in the spirit of utility maximization. The manufacturer will compare the price and performance of the products with the maximum budget and minimum mileage demanded by consumers in the market to determine whether firms can enter the market. Finally, manufacturers will choose whether they should exit the market based on current debt leverage, capital levels, and nonprofit time.

Interaction: The model includes vehicle manufacturers of two types: EVs and CVs. Because the number of orders generated by consumers is finite, competition occurs among various manufacturers. An absence of orders might lead to extinction of the firms. The purchase behavior of consumers also determines which firms can get orders and thereby survive in the market. Furthermore, these interactions are based on real market competition mechanisms.

Stochasticity: The initial capital of the firm is distributed uniformly over an interval, whereas the income of consumers and the annual mileage are normally distributed over an interval. The manufacturer's allocation of capital for product performance development and production process development is a stochastic process. It is a random selection process within a range including the time when consumers make purchase choices for vehicles.

Collectives: Each consumer's ranking of product utility is determined by multiple firms' competition and R&D investment. This ranking also dictates the number of orders the company receives and the level of capital and R&D investment subsequently.

Observation: With sales volume statistics, tone can observe the diffusion of vehicles of different types. Cruising mileage data of the vehicles can reflect the vehicle performance. Price data of the vehicles can reflect changes of vehicle prices. The number of firms can be recorded to ascertain the number of firms in different states. Data of firm capital can reveal the firm operating status.

2.1.3 Details

Initialization and input data of the model are discussed in section 2.4.2. Submodels are introduced in section 2.3. Without meaningless repeated expression, the details are omitted.

2.2 Agent profiles

Agents of two types are included: consumers and firms. Firms of two types exist: combustion-powered vehicle (CV) and electric vehicle (EV) firms. The total number of CV firms is Ncv,; the number of EV firms is Nev. The total number of consumers is $Ncon$. Table 1 shows agent profiles in a summary of all variables and parameters involved in the baseline model.

One firm agent produces only one product. The firms interact with others and consumers through order competition. Initially, consumers will be assigned with different annual mileage $Mileage_i$ and annual household income $income_i$. At each iteration time, each consumer i compares the price $price_j$ of each product with their purchase budget $budget_i$, and calculates and sorts the utilities of each product $U_{i,j}$. Then, a consumer chooses one product to purchase from the top 10 list. Before calculating the utility of each product, each consumer calculates the willingness to pay $WTP_{i,j}$ and total cost of each product $TCO_{i,j}$.

The agent profile of firms should be discussed from the R&D process, investment process, entry and exit processes. Initially, firms will be assigned capital k_j. The CV firms can produce products of a certain level: cruising range $range_j$ and cost $cost_j$. However, EV firms must meet minimum conditions before entering the market. Both for CV and EV firms, it is necessary to invest RD_j and conduct R&D to improve product performance eff_j and reduce costs $cost_j$. Firms can get orders from consumers and then produce. However, when orders reach the maximum production capacity Q_{max}, they can obtain investment I_j from the bank. When the firm's capital falls below a certain level, its debt ratio exceeds a certain ratio. When its nonprofit time exceeds a certain limit, the company must leave the market forever.

The function of the bank in the model is rather simplified: it only offers investments to firms and obtains repayment D_j^R from firms. The function of the government in the model is to offer subsidies to consumers $subc_j$ and firms $subf_j$.

Table 1 Agent profile (1)

Type	**Notation**	**Description**
Global	$Ncon$	Consumer number
	Ncv	CV firm number
	Nev	EV firm number
	$Minrange$	Minimum acceptable cruising range
	$year$	Vehicle holding period
	ρ_0	Risk-free interest rate
	m	Firms of different types
	pe_m	Unit price of gasoline or electricity
	d_m	Depreciation rate of EVs and CVs
	λ	Production capacity of one unit of capital
	φ	R&D intensity
	a_0	Rate of process innovation
	b_0	Rate of product innovation
	$Fcost_m$	Technology frontier of vehicle cost
	$Feff_m$	Technology frontier of vehicle efficiency
	ξ	Expansion rate of production capacity
	σ	Percentage of profits of repayment
	ρ_1	Interest rate for bank credit
	ρ_2	Capital depreciation rate
	$size_m$	Tank capacity or battery size
	K	Minimum required level of capital
	T	Maximum nonprofit requirement of time
	Γ	Maximum asset–liability ratio

Table 1 Agent profile (2)

Type	Notation	Description
Consumer i	$U_{i,j}$	Utility of vehicle j
	$WTP_{i,j}$	Willingness to pay for vehicle j
	$TCO_{i,j}$	Total cost of vehicle j
	α_m	Willingness to pay for a mile of added driving range beyond $Minrange$
	ω_m	Willingness to pay for the vehicle with $Minrange$
	$ec_{i,j}$	Annual energy cost of vehicle j
	$Mileage_i$	Annual vehicle miles traveled of consumer
	$budget_i$	Purchase budget of consumer
	$income_i$	Annual income of consumer

Table 1 Agent profile (3)

Type	Notation	Description
Firm j	k_j	Capital of firm j
	$price_j$	Price of vehicles of firm j
	$range_j$	Cruising range of vehicles of firm j
	$resale_j$	Future resale revenue of vehicle j
	$subc_j$	Consumer subsidy of vehicle j
	eff_j	Energy efficiency of vehicle j
	$cost_j$	Cost of vehicle j
	μ_j	Mark-up of price
	Q_{max}	Maximum production capacity
	rev_j	Revenue of firm j
	π_j	Net profit of firm j
	RD_j	Total R&D expenditure of firm j
	RD_j^{pc}	Expenditure of process innovation of firm j
	RD_j^{pd}	Expenditure of product innovation of firm j
	$\Delta cost_j$	Reduction in production cost
	Δeff_j	Reduction in production improvement
	I_j	Scale of capital expansion

	D_j^R	Debt repayment
	D_j	Gross debt of firm j
	$subf_j$	Manufacturer subsidy of vehicle j

2.3 Mechanisms

This section presents an examination of detailed mechanisms used in the simulation model. Figure 2 presents the model framework and demonstrates how the model works on a stepwise yearly basis using programming software such as MATLAB. First, the simulation starts with initial configurations that populate a market with a set of consumer agents and manufacturer agents. We randomize the income of consumers and the capital of manufacturers in the first period so that their characteristics can be heterogeneous and varied in each replication. Then, simulation proceeds with agents interacting according to the rules we specify in the following sub-sections, including how consumers make purchases and how firms make entry and exit decisions, set production and sales, and do R&D activities. After calculation of EV market share, time automatically increases by one-year step. If the pre-fixed number of periods is not reached, agent attributes are updated and the procedures described above are repeated; otherwise, the process terminates. Finally, results in each period are recorded and averaged after many iterations, as reported and discussed hereinafter.

The simulation model process is divisible into four modules: R&D activity, purchasing activity, investment, and market entry and bankruptcy. Hereinafter, we present the respective modules.

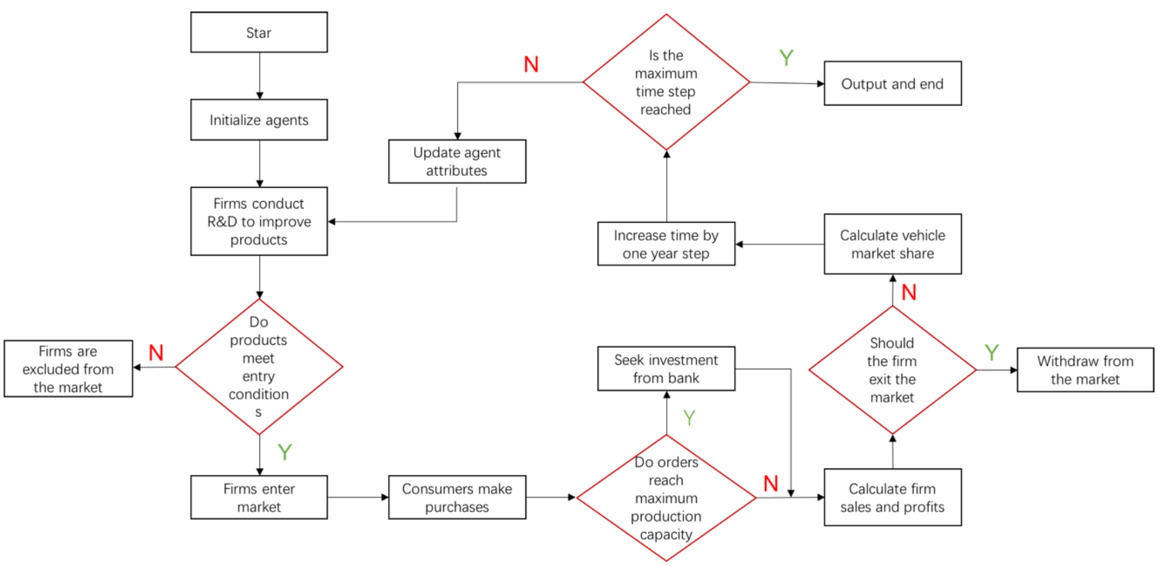


Fig. 2. Flow chart of the simulation model.

2.3.1 R&D activity

For firms to improve their competitiveness and profitability, R&D activity is the fundamentally important factor. Extensive empirical studies have revealed evidence of a marked decrease in firms'

R&D investments before and after they enter a market. Consequently, we adopt the following assumptions given the R&D intensity, denoted as ϕ, for unprofitable potential entrants and incumbents, R&D expenditures are predicted to be derived from the firm's original capital, whereas profitable incumbents foster R&D funds from their sales revenue to ensure that the production capacity remains unaffected. Consequently, the R&D expenditure of firm j is shown below.

$$RD_j = \phi * k_j$$
$$RD_j = \phi * rev_j \tag{1}$$

Because technology innovation consists of process innovation and product innovation, the R&D expenditures of firms also include process innovation expenditure RD_j^{pc} and product innovation expenditure RD_j^{pd}, of which the former is aimed at decreasing the product's cost, whereas the latter is intended to improve the efficiency of the vehicle. Coefficient q controls the distribution of R&D expenditure, which is randomly assigned a value from [0, 1]. The value of q is fixable in the following two situations: first, the cruising range meets the threshold of market entry, although the attribute of price fails. In this situation, firms will specifically examine process innovation to lower the cost. Coefficient $q = 1$. Conversely, the attribute of price meets the minimum requirement of customers, although the range performance fails. Firms will put all their efforts into product innovation. Consequently, coefficient $q = 0$.

$$RD_j^{pc} = q * RD_j$$
$$RD_j^{pd} = (1 - q) * RD_j \tag{2}$$

In each period, referring to Malerba et al. [39], reduction of the production cost and improvement of energy consumption efficiency are presented below.

$$\Delta cost_j = a_0 * RD_j^{pc} * (1 - Fcost_m / cost_j) \tag{3}$$
$$\Delta eff_j = b_0 * RD_j^{pd} * (1 - eff_j / Feff_m) \tag{4}$$

According to the law of diminishing marginal returns, $(1 - Fcost_m / cost_j)$ and $(1 - eff_j / Feff_m)$ are added, which means that when an attribute approaches the technology frontier, the rate of technical progress decreases gradually. Based on the variation of $cost$ and eff, one can calculate their new values in the next period.

2.3.2 Purchasing activity

In this model, consumers are designed with two characteristics: heterogeneous preferences and bounded rationality. To describe heterogeneous preferences of consumers, the purchase budget and driving mileage are assumed to differ among consumers. Regarding bounded rationality, because of the existence of search costs and information asymmetry, consumers are assumed to choose a vehicle randomly from a top ten satisfactory list, rather than in line with the principle of maximum utility.

The utility of purchasing a product $U_{i,j}$ is defined as the remainder that consumer's willingness to pay for a vehicle (WTP) minus the product's total cost of ownership (TCO). Where i stands for consumer and j denotes the vehicle as

$$U_{i,j} = WTP_{i,j} - TCO_{i,j}. \tag{5}$$

The value for WTP is correlated positively with the part that the vehicle range surpasses the market's minimum requirement $Minrange$, where α_m and ω_m respectively represent consumers'

WTP for a mile of added driving range beyond $Minrange$ and vehicles with $Minrange$.

$$WTP_{i,j} = \alpha_m * (range_j - Minrange_m) + \omega_m \tag{6}$$

The total cost of ownership for a vehicle in a given holding period includes three terms: the purchase cost, annual discounted energy expenditure, and the negative present value of vehicle resale revenue. Also, ec and $subc$ respectively denote the vehicle's annual energy cost and consumer purchase subsidy; $resale$ represents the vehicle's future resale revenue. $A(\rho_0,\ year)$ is the annuity factor, where ρ_0 represents the risk-free interest rate, and $year$ signifies the vehicle holding period.

$$TCO_{i,j} = price_j - subc_j + ec_{i,j} * A(\rho_0, year) - \frac{resale_j}{(1+\rho_0)^{year}} \tag{7}$$

Annual energy cost represents the annual expenditure for vehicle refueling (CVs) or charging (EVs). Regarding other variables, $Mileage$ represents the annual vehicle miles traveled of consumers, eff represents the energy consumption efficiency of vehicles, and pe_m stands for the unit price of gasoline or electricity, respectively. The future resale revenue of a vehicle ($resale$) is related to holding period $year$ and depreciation rate d_m.

$$ec_{i,j} = Mileage_i * pe_m / eff_j \tag{8}$$

$$resale_j = (1 - d_m * year) * price_j \tag{9}$$

2.3.3 Investment

If the total number of consumer orders in the current period reaches the maximum production capacity, then the firm will seek a capital infusion to expand its scale of production, such as purchasing new equipment and installing another production line. The scale of capital expansion is assumed to be at a given percentage ξ of the current capital. The production investment is calculated as presented below.

$$I_j = \begin{cases} 0 & (Q_{max} > Q_j) \\ \xi * k_j & (Q_{max} = Q_j) \end{cases} \tag{10}$$

Provided that a firm makes a profit in t period, a certain percentage σ of the net profits is assumed to be the repayment of debt D. The remainder is added to the firm's current capital. If $\sigma\pi$ exceeds the current debt D, then it is expected that all debt will be paid off. Otherwise, debt will remain. Therefore, the debt payment for each period D_j^R is related to the current total debt and profits earned.

$$D_j^R = \begin{cases} \sigma * \pi_j & (D_j > \sigma * \pi_j) \\ D_j & (D_j < \sigma * \pi_j) \end{cases} \tag{11}$$

The capital depreciation rate is ρ_2. After adding the remaining profit to the gross capital, the new value for capital is expressed as shown below.

$$k_{j,t} = (1 - \rho_2) * k_{j,t-1} + I_{j,t} + \pi_{j,t} - RD_{j,t} - D_{j,t}^R \tag{12}$$

Then, the total debt in time $t+1$ is renewed.

$$D_{j,t+1} = D_{j,t} - D_{j,t}^{R} + I_{j,t+1} \quad (13)$$

2.3.4 Market entry and bankruptcy

For all start-up EV firms, the driving range and price competitiveness of vehicles are assumed to be zero in the first phase. They can be improved continuously through R&D activity. When a product meets the following two entry requirements at the same time, it can enter the market. First, the vehicle driving range exceeds the minimum requirement of consumers. Second, the product price is lower than the maximum purchasing budget of potential purchasers.

Related to market incumbents, each firm offers prices based on the mark-up rule. The mark-up is measured as μ_j. The relation between a vehicle's sale price $price$ and production cost $cost$ can be expressed as shown below.

$$price_j = cost_j * (1 + \mu_j) \quad (14)$$

The mark-up is determined as 0.5 multiplied by the ratio of the vehicle's driving range to the current maximum level within the similar products, as Eq. (15) shows.

$$\mu_j = \frac{range_j}{Max(range_j)} * 0.5 \quad (15)$$

Furthermore, the sales volume of each firm Q is assumed to be the sum of all consumers' orders. However, because of the limitation of production capacity Q_{max}, which is proportional to the capital of firms, it is worth noting that the actual sales volume might fall short of the order quantity.

$$Q_{max} = \lambda * k_j \quad (16)$$

Given that the interest cost is incorporated exclusively in the administrative expense, the net profit π can be forecast as shown below.

$$\pi_j = rev_j - \rho_1 * D_j \quad (17)$$

In the process of market selection, competitive firms survive and develop, whereas the uncompetitive ones are eliminated. Additionally, if a firm with any of the following three characteristics is likely to exit the market and be incapable of reentrance: (a) capital below the minimum required level K, (b) time for the firm operating at a loss surpasses the maximum requirement T, (c) asset–liability ratio exceeds Γ. The firm will go bankrupt under such a condition.

2.4 Model validation and verification

The vast majority of simulation modelers in general and the system dynamics modeling community particularly agree that validation is a process of building confidence in a model’s usefulness [40]. In general, validation frameworks rely on verification (software test) and output validation [41].

2.4.1 Verification

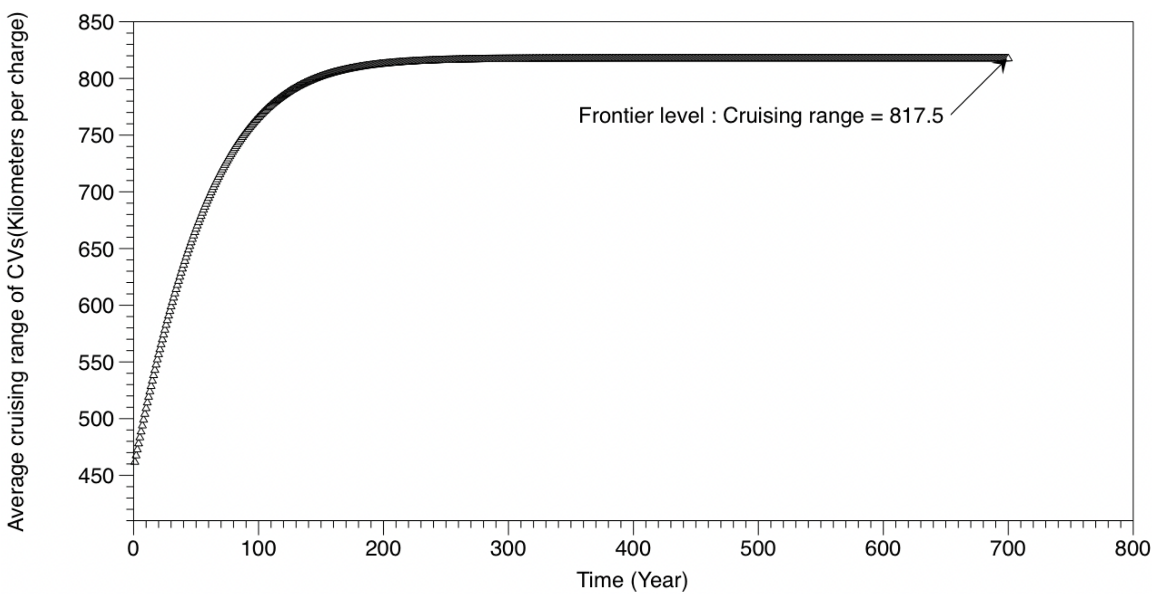
The purpose of verification is to ascertain that a system dynamics model generates the right output behaviors for the right reasons. This process verifies the reasonableness of the model, determining whether the model output is correct and whether it is consistent with common sense. In this section, we discuss the rationality of the four main modules.

2.4.1.1 R&D module

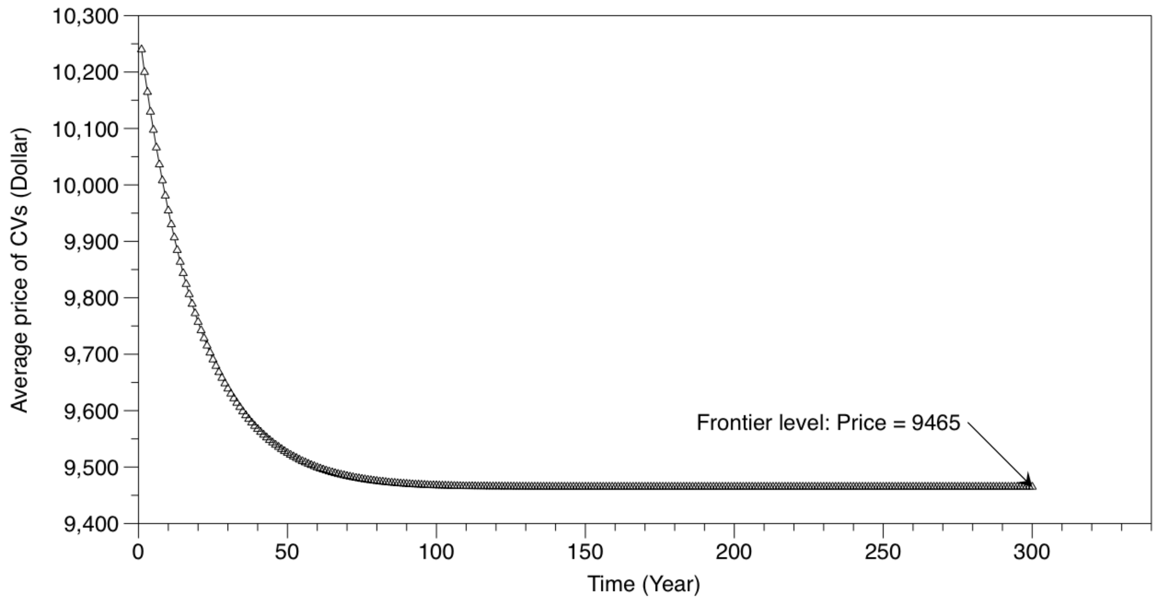
We consider only the R&D module in the baseline model. Only EV or CV firms exist in the market. Therefore, no competition arises from other types of products in the market and the firm has the most ideal environment for growth. The firm can improve product performance and reduce product prices by conducting R&D activity. According to Eqs. (3) and (4), the product price and the performance of the product can eventually reach the frontier technology level and should fit the logistic curve.

Figure 3 shows that only CV firms exist in the market. No competition arises from EV firms. Finally, the average cruising range of CV firms can reach the frontier level (817.5 km from one tank of fuel). Furthermore, the average price of CV firms can reach the frontier level (9465 dollars). These results demonstrate that the structure of the R&D module of CVs is reasonable.

Figure 4 shows that only EV firms exist in the market: no competition arises from CV firms. The average cruising range of EV firms can reach the frontier level (600 km from one charge). Furthermore, the average price of EV firms can reach the frontier level (13193 dollars). These results demonstrate that the R&D module structure of EVs is reasonable.

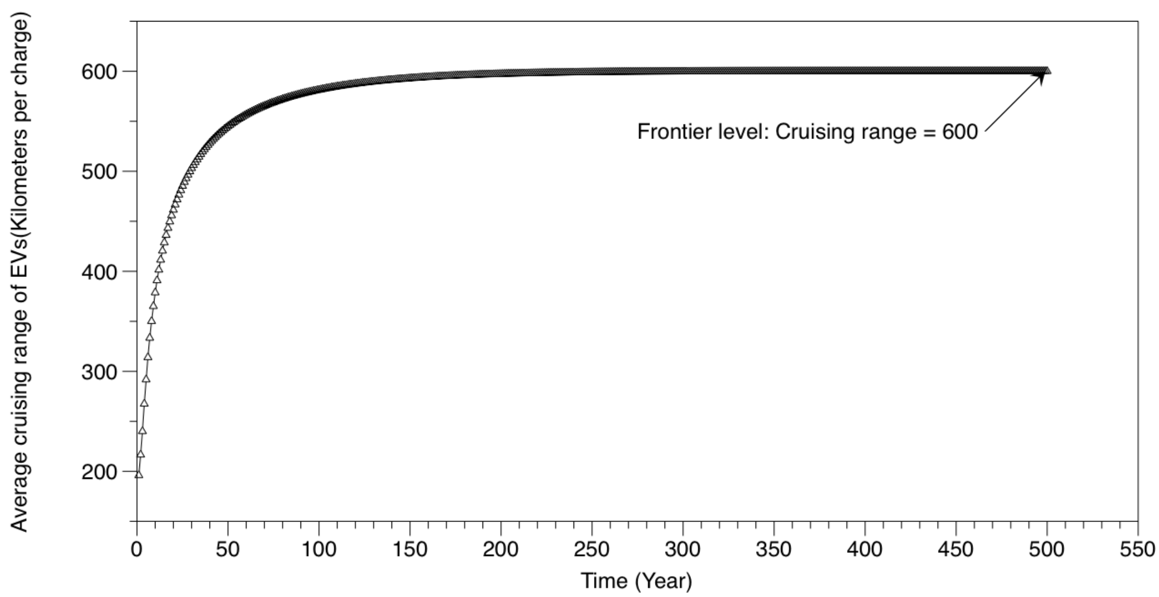


(a)

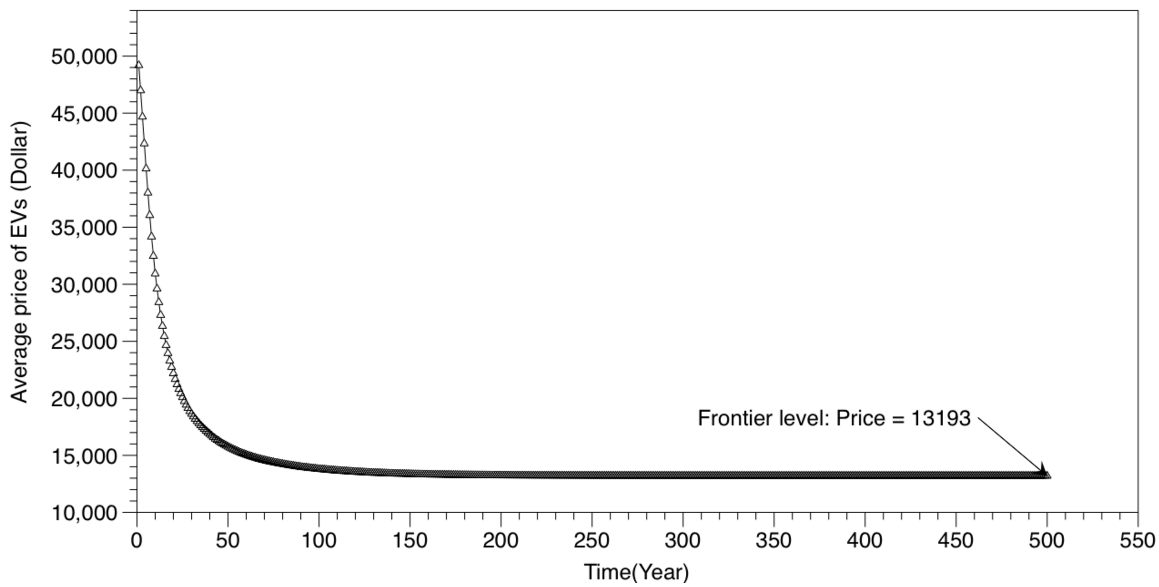


(b)

Fig. 3 Cruising range and price of CVs under ideal conditions.



(a)



(b)

Fig. 4 Cruising range and price of EVs under ideal conditions.

2.4.1.2 Purchase activity

As described above for the purchase activity module, consumers can calculate the utility of each product and then purchase the product based on the utility maximization principle. If the consumer's utility for a product in the market is positive infinity, then this firm should attract all orders from the consumer (we assume that there are 10 million consumers in the model).

Figure 5 presents an illustration showing that the orders of the 137th firm are 10 million at each step of the simulation time. Therefore, all consumers chose the firm's products based on the principle of utility maximization and prove the effectiveness of the module on purchasing activity.

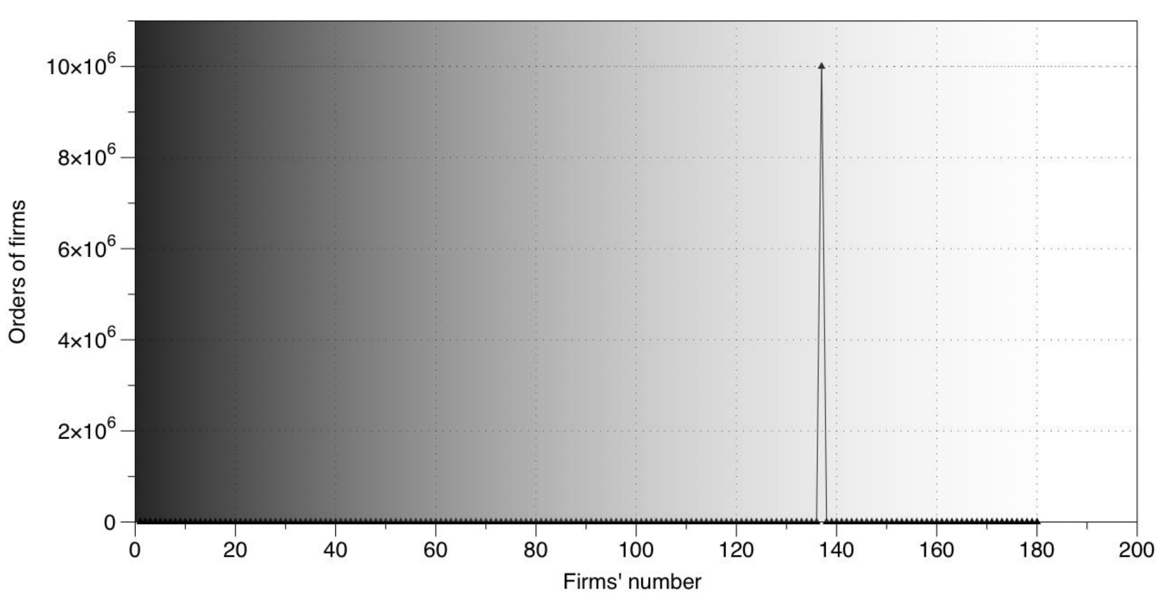


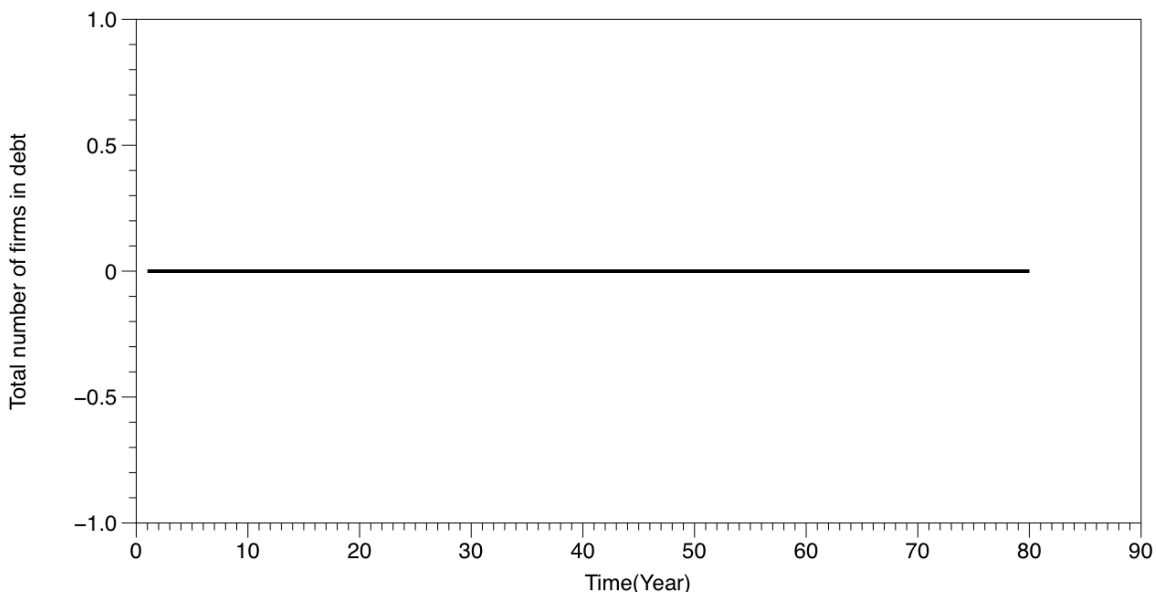
Fig. 5 Firm orders at every time step (randomly select a firm from 180 firms for which utility is positive infinity for all consumers).

2.4.1.3 Investment

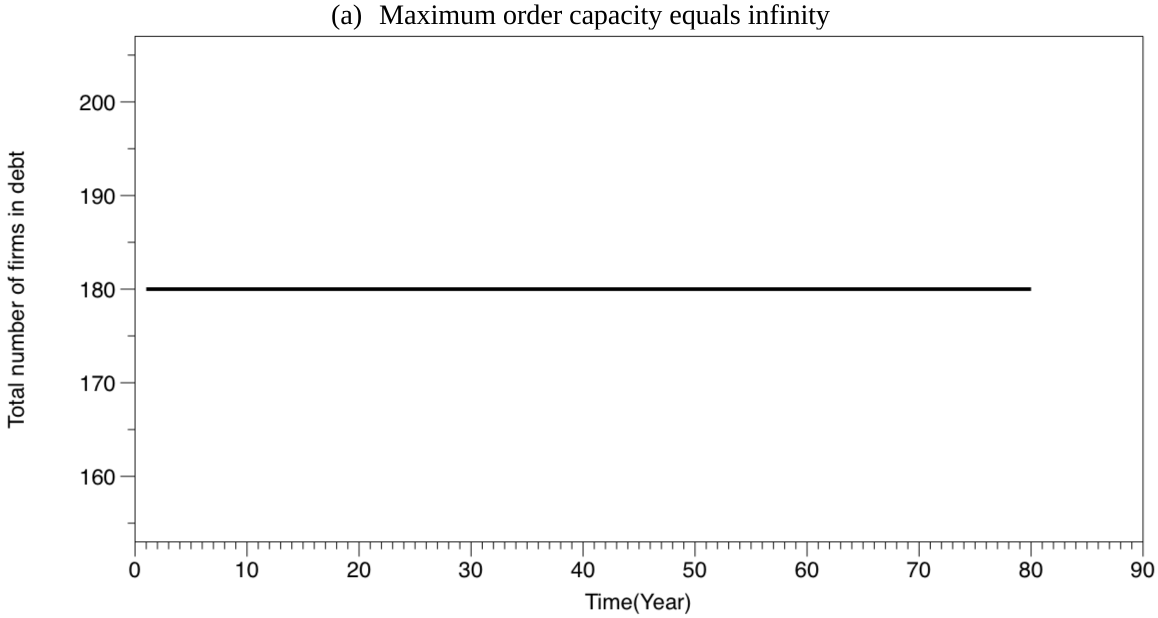
As described above, when orders meet the maximum production capacity, firms will seek investment from banks. By controlling the maximum order capacity, the number of firms in debt is presumed to be different. Therefore, we adjust the maximum order capacity to infinity and negative infinity to verify the validity of this module.

If the maximum order capacity equals infinity, the firm does not need outside investment. Therefore, the number of firms in debt should always be zero. Figure 6(a) shows that the total amount of firms in debt equals zero.

When the maximum order capacity is negative infinity, all firms must seek outside investment to expand production capacity. Therefore, the number of indebted firms should be constantly equal to 180, assuming that there are 180 firms in all. As Fig. 6(b) shows, the indebted firms are 180.



(a) Maximum order capacity equals infinity



(b) Maximum order capacity equals negative infinity

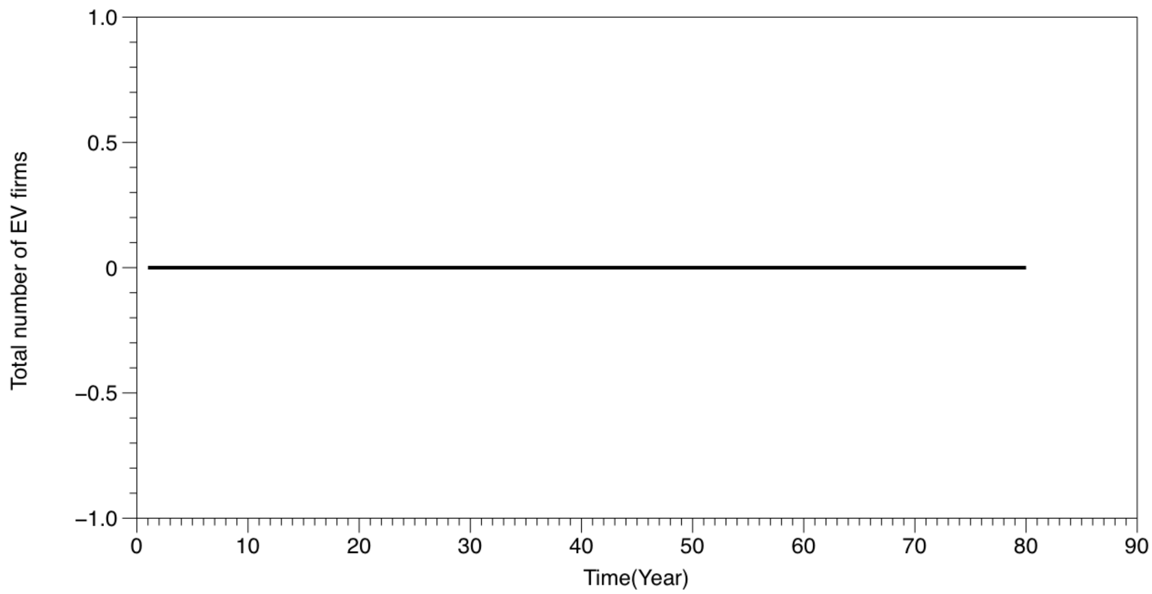
Fig. 6 Total number of indebted firms under different scenarios.

2.4.1.4 Market entry and bankruptcy

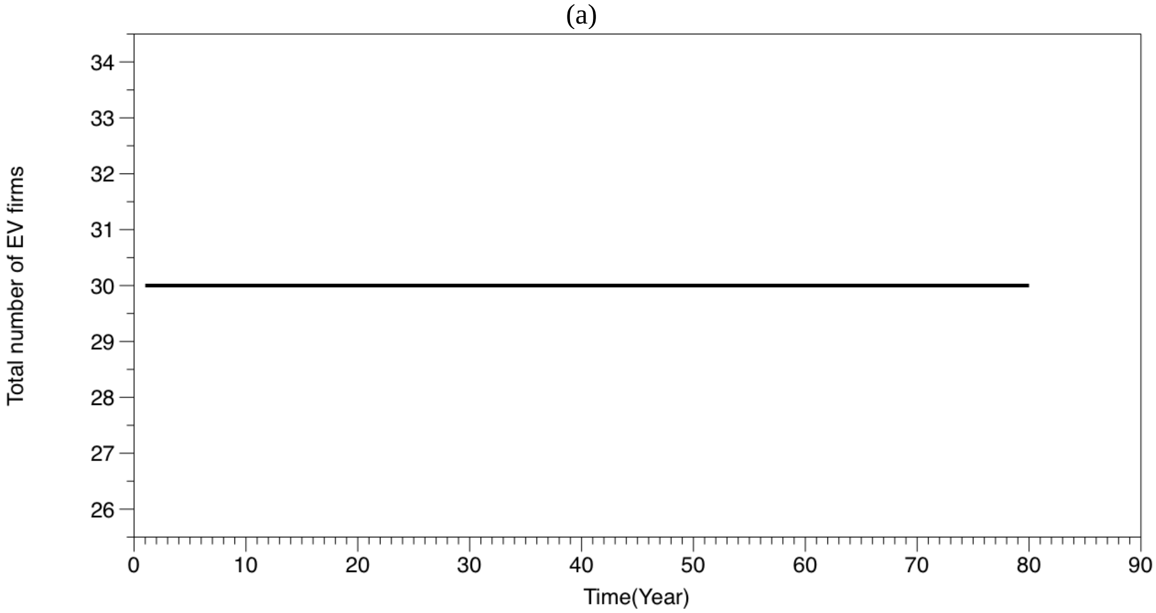
As described above, EV firms should meet the entry conditions before entering the market. Consequently, by controlling the threshold of entry conditions, the number of EV firms entering the market can be expected to be different.

If the requirement of range and price is infinity, no EV firm can enter the market. Figure 7(a) shows that no EV firm can enter the market.

If the requirement of range and price is negative infinity, all EV firms can easily enter the market. Figure 7(b) shows that all EV firms can enter the market, assuming that there are 30 EV firms in all.



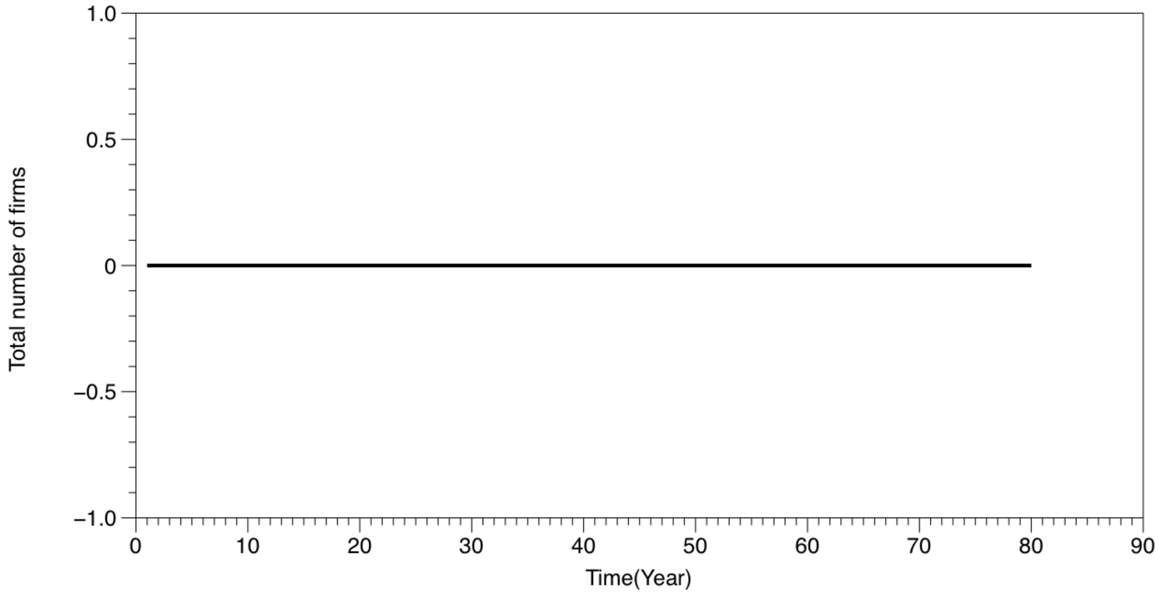
(a)



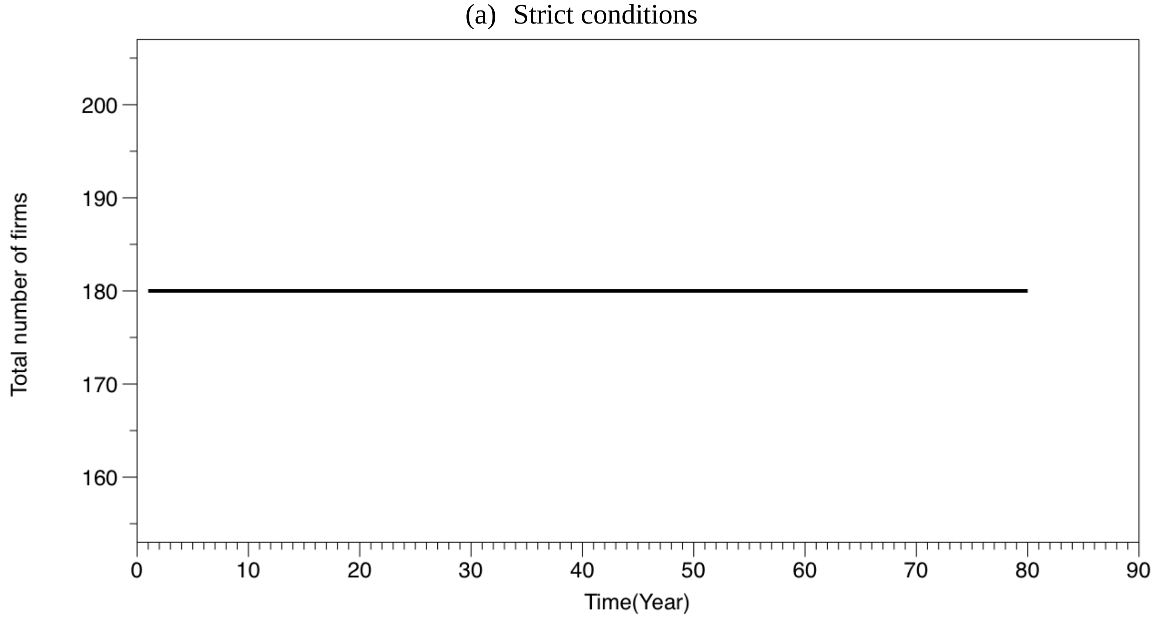
(b)

Fig. 7 Total number of EV firms under different entry conditions.

By controlling the threshold of bankruptcy conditions, the number of firms exiting the market differs. The conditions are divisible into strict conditions and lenient conditions. For strict conditions, consider a minimum capital requirement of positive infinity, a maximum loss-making operating time of negative infinity, and a maximum debt ratio of negative infinity. The firm will not survive under these conditions. For relaxed conditions, consider a minimum capital requirement of negative infinity, a maximum loss-making period of positive infinity, and a maximum debt ratio of positive infinity. Under these conditions, the firm can survive forever. Figure 8 presents results for the total number of firms in strict and loose bankruptcy conditions.



(a) Strict conditions



(b) Loose conditions

Fig. 8 Total number of firms under strict and loose exit conditions.

Through verification of the four modules, the model rationality can be fully verified. Model validation will be discussed next, with comparison of the model output and the actual condition.

2.4.2 Model validation

The main purpose of validation is to compare the model-generated behavior to the observed behavior of the real system. Several statistical tests have been suggested in the validation literature for comparing output data from a system dynamics-based simulation model with corresponding data from a real-world system. Before comparing the model output with reality, one must assign parameters for the model. As shown in Table 2, we initialize and assign the parameters presented in Table 1. The original author used data from the United States to define the model parameters based on related papers. Based on the original authors' definition of the parameters, we use actual data of consumers in the Chinese market and calibrate the baseline model using consumer subsidy policies enacted by the Chinese government.

Table 2 Initialization (1)

Type	**Notation**	**Value**
Global	$Ncon$	10 million
	Ncv	150
	Nev	30
	$Minrange$	75
	$year$	6
	ρ_0	0.32%
	m	0 or 1
	pe_m	2.7424 or 0.1154
	d_m	6.7% or 12.5%
	λ	0.0001
	φ	5%
	a_0	36 or 15
	b_0	0.0545 or 0.01005
	$Fcost_m$	13193 or 9465
	$Feff_m$	54.5 or 15
	ξ	0.1
	σ	15%
	ρ_1	3.43%
	ρ_2	1%
	$size_m$	15 or 40
	K	5×10^6
	T	5
	Γ	2

Table 2 Initialization (2)

Type	**Notation**	**Value**
Consumer i	a_m	35 or 63
	ω_m	22006
	$Mileage_i$	Normally distributed $N(10609{,}5995)$
	$budget_i$	Normally distributed $N(9396{,}6336)$
	$income_i$	Normally distributed $N(15660{,}10560)$

Table 2 Initialization (3)

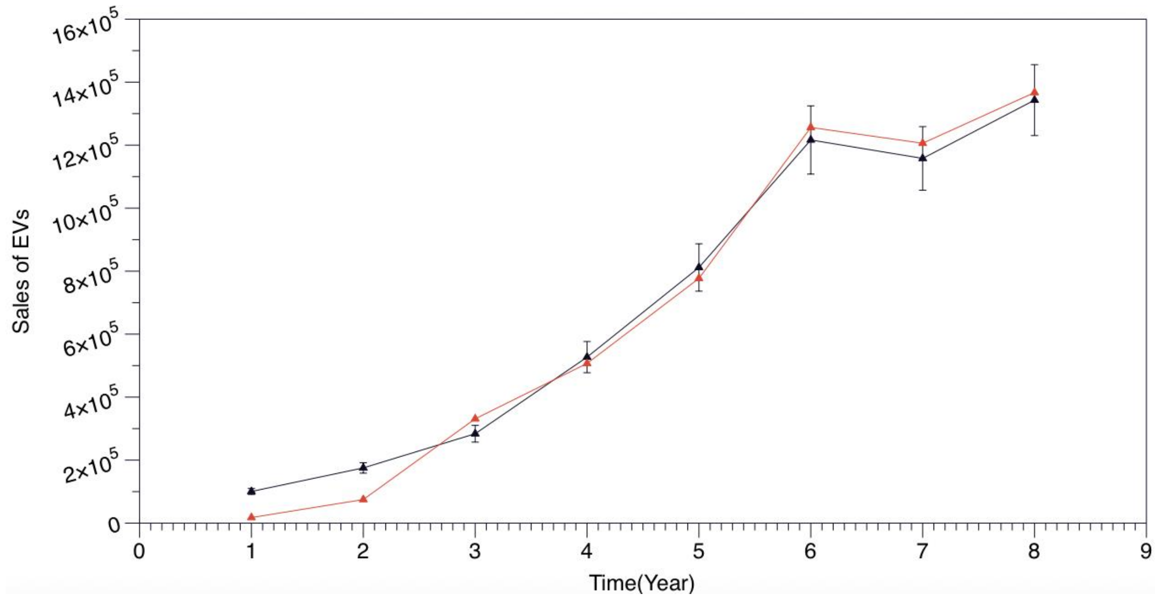
Type	**Notation**	**Description**
Firm j	k_j	Evenly distributed $U(1\ billion, 10\ billion)$
	$range_j$	405 or 0
	eff_j	27 or 0
	$cost_j$	10822 or 49193

The consumer subsidy policy in China was implemented during 2013–2022. The criteria for obtaining subsidies have become stricter each year. The number of subsidies has decreased each year. Table 3 demonstrates the subsidy amount and criteria.

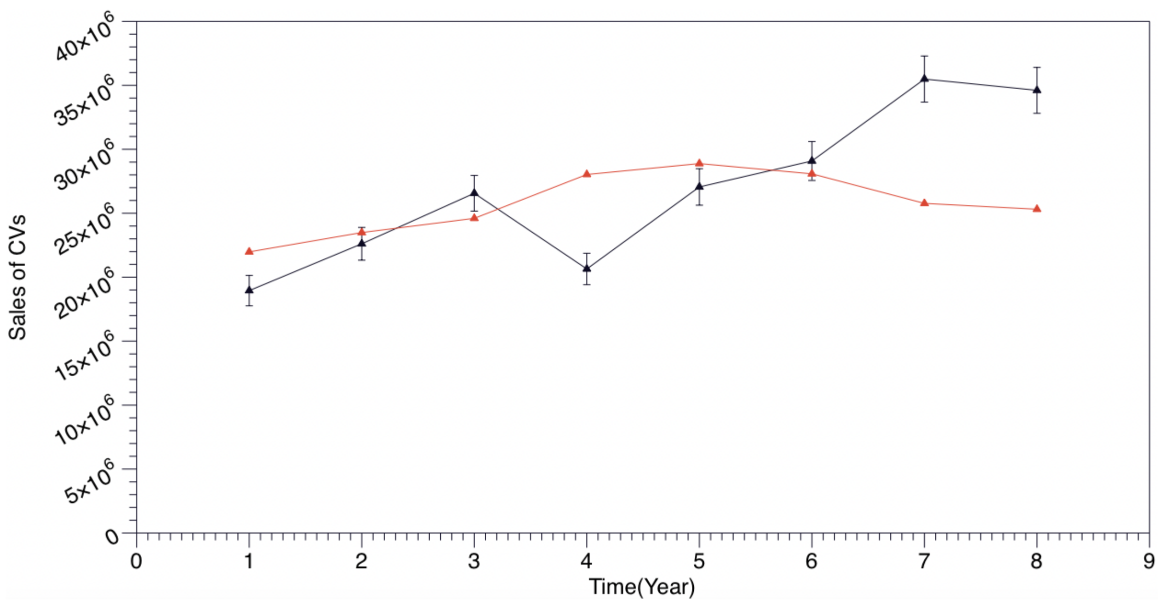
Table 3 Financial subsidies to private EV (pure electric) in China (unit: 10,000 CNY per vehicle)

Year	**Subsidy amount for different cruising range** R (KM)		
	$80 \le R < 150$	$150 \le R < 250$	$R \ge 250$
2013	3.5	5	6
2014	3.15	4.5	5.4
2015	2.8	4	4.8
	$100 \le R < 150$	$150 \le R < 250$	$R \ge 250$
2016	2.5	4.5	5.5
2017	2	3.6	4.4
2018	1.75	3.15	3.85
	$250 \le R < 400$	$R \ge 400$	
2019	1.8	2.5	
	$300 \le R < 400$	$R \ge 400$	
2020	1.62	2.25	
2021	1.3	1.8	
2022	0.91	1.26	

After defining parameters of the baseline model and real data for consumer subsidies from China, we compare results of the simulation model with real conditions. Generally, the total sales of EVs and CVs will be compared to actual sales in the market during 2013–2020. Figure 9 shows EV and CV sales during 2013–2020 in terms of simulation model output and actual data.



(a) Simulated and actual EVs sales during 2013–2020 (red line, real condition; black line, simulated condition; error rate = 0.77).

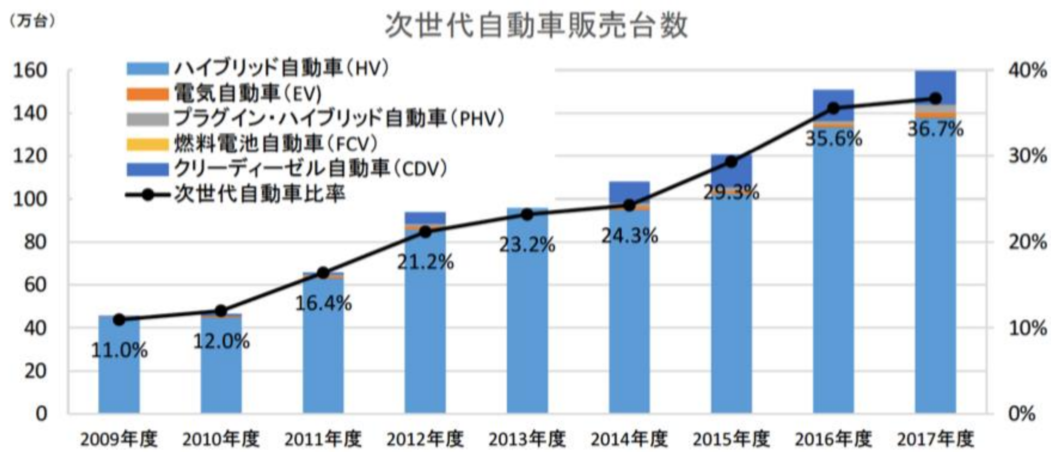


(b) Comparison of simulated and actual CVs sales during 2013–2020 (red line, real condition; black line, simulated condition; error rate = 0.17).

Fig. 9 Plots of trends of model-generated and reference data.

Generally, the simulated results are slightly larger than actual results in the early stage. Here one must consider the negative consumer perception of EVs in the early stage. Although the subsidy amount is large, the penetration rate of EVs in the market is very low, which is expected to have a negative effect on consumer perception of EVs, and then engender simulated results that are slightly larger than the actual results. Following the same notion, during 2018–2020, the actual sales are expected to be slightly larger than the simulated results. Rapid penetration of EVs has made consumers more receptive to EVs, which drives the actual numbers to be slightly higher than the simulated results.

However, the actual data might not match the simulation results very closely in terms of CV sales, but always by an order of magnitude. This model does not incorporate consideration of hybrid vehicle effects, which are used widely in today's society as a means of transition. For example, hybrid vehicles in Japan account for most new energy vehicle sales. Deliberation about hybrid vehicles will be undertaken in future work. This study specifically examines EV diffusion and subsidy policies for EVs. Hybrid vehicles are neglected here.



	2004年度	2005年度	2006年度	2007年度	2008年度	2009年度	2010年度	2011年度	2012年度	2013年度	2014年度	2015年度	2016年度	2017年度 (万台)	2017年度 新車販売にしめるシェア
HV	6.5	6.1	8.9	8.9	11.0	45.2	44.8	63.1	85.7	101.5	95.1	102.4	133.5	138.0	31.7%
EV	0	0	0	0	0	0.2	0.7	1.1	1.4	1.6	1.5	1.3	1.3	2.4	0.5%
PHV	0	0	0	0	0	0	0	0.4	1.3	1.3	1.5	1.5	1.4	3.4	0.8%
FCV	0	0	0	0	0	0	0	0	0	0	0.01	0.05	0.12	0.07	0.02%
CDV	-	-	-	-	0.2	0.4	1.1	1.2	5.6	7.8	10.0	15.4	14.7	15.8	3.6%

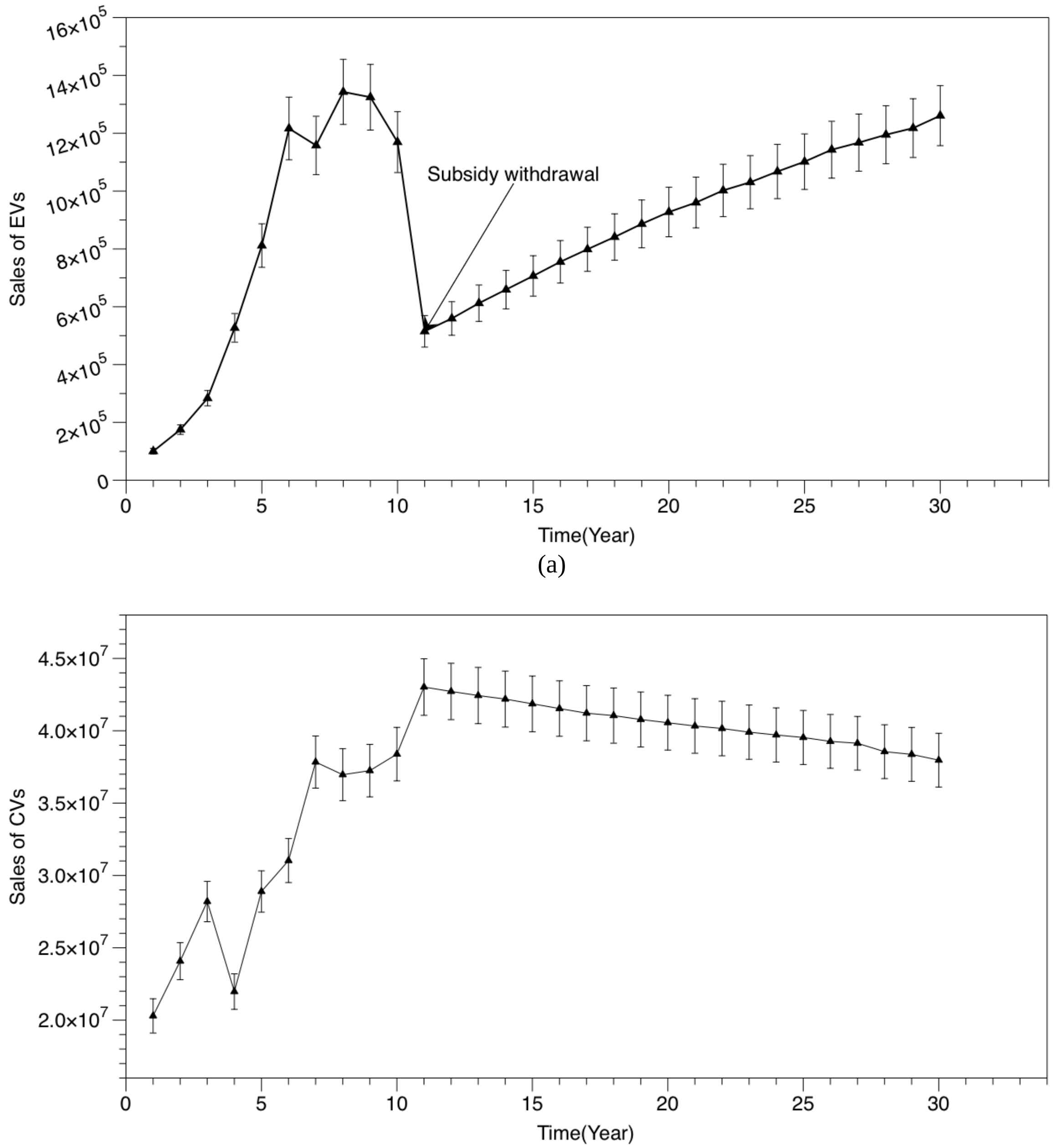
Fig. 10 New energy vehicle sales in Japan [42].

This section presents a discussion of the validation and verification of the model. The results demonstrate the model validity. The model output is discussed in the next section.

2.5 Output

Here we present a short introduction of simulation results. We discuss results obtained using the model in three respects: diffusion of EVs and CVs, performance of EVs and CVs, and operation of firms. Therefore, we must analyze the phase diagrams of different vehicle sales, prices, cruising ranges, and capital of each firm.

Figure 11 presents the variation of EVs and CVs sales during 2013–42. EV sales increased rapidly because of early consumer subsidies. However, because consumer subsidies will be abolished in 2022, sales are expected to fall by almost 40%. Wang et al. [5] used the S.D. model to predict and conclude that EV sales will drop by 40% after the consumer subsidy repeal. After the big shock, EV sales will grow slowly, but it will take 20 years to get back to the highest level of sales. For CV sales, it will be a short-lived decrease with the sharp increase in EV sales. However, with the decline in consumer subsidies, CV sales will increase gradually and will eventually stabilize at a certain level.

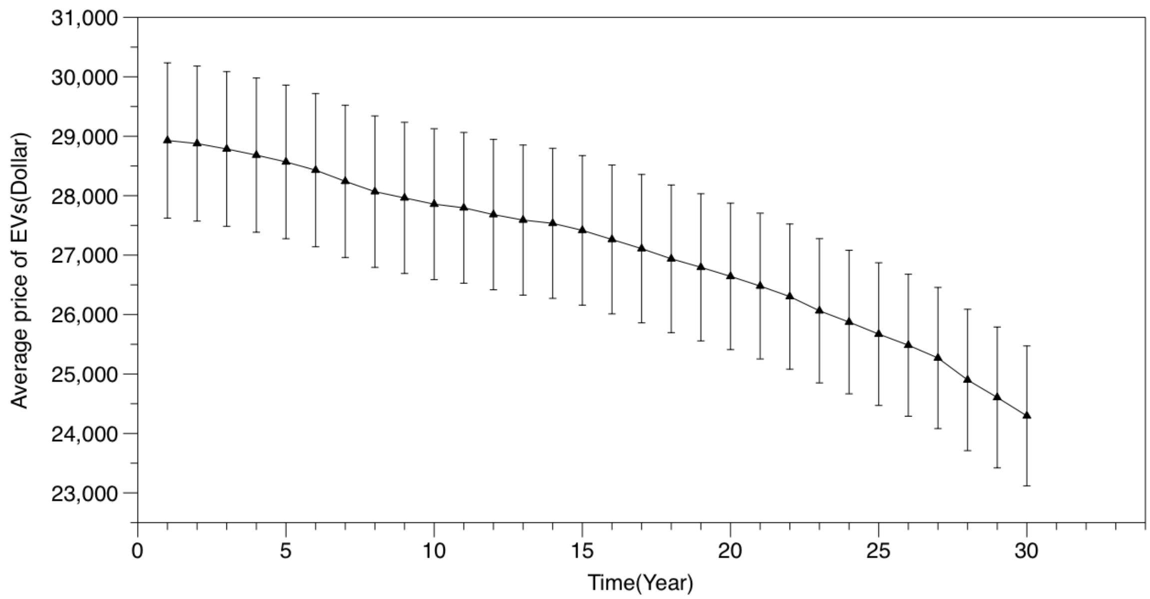


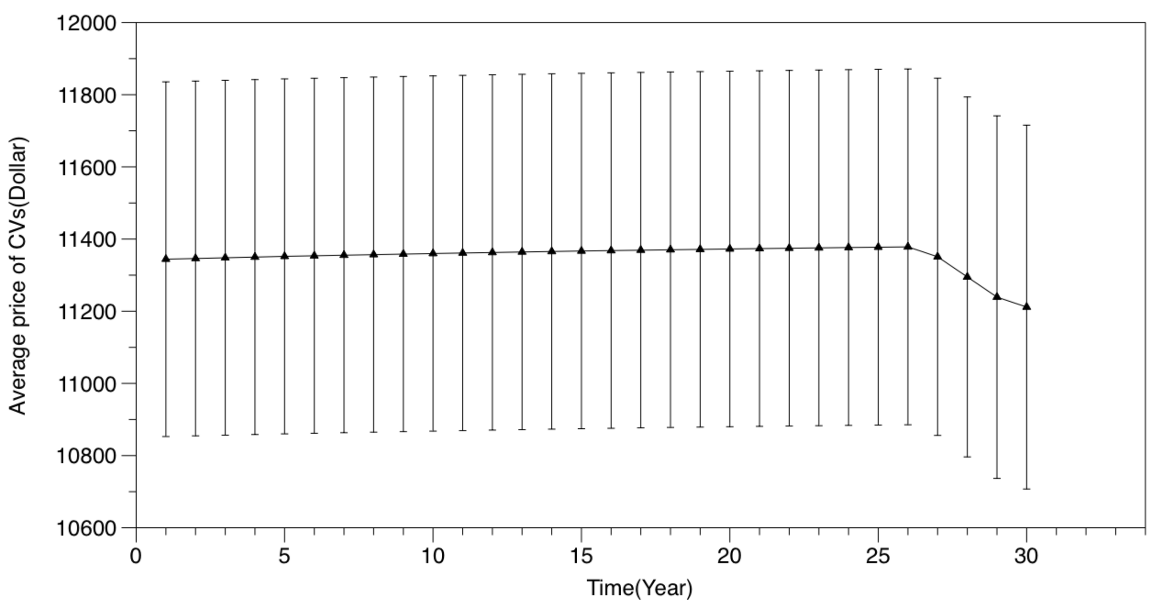
(a)

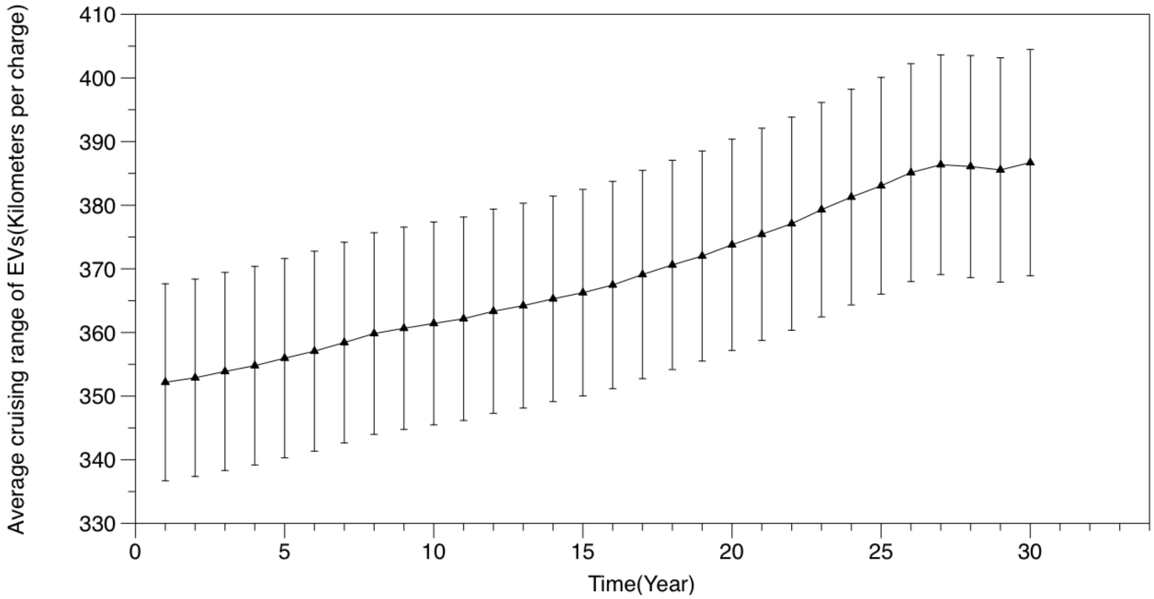
(b)

Fig. 11 Total sales of EVs and CVs during 2013–42.

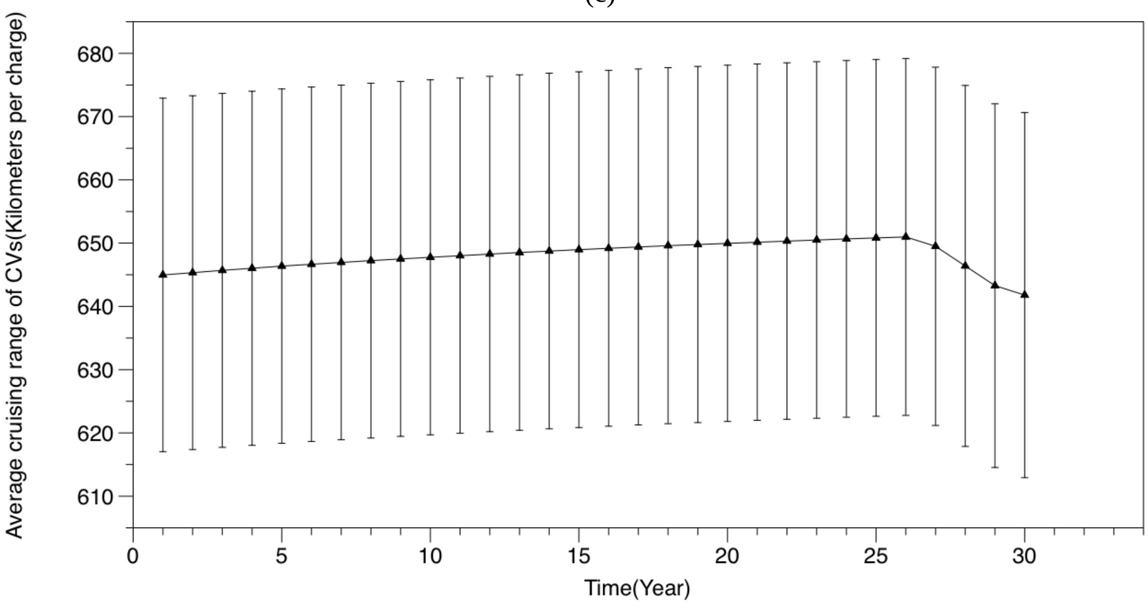
Figure 12 presents variations of EV and CV product performance over time. The firms conduct R&D activities that gradually increase the product performance. For CV firms, the increase is smaller as the product performance gets closer to the frontier level. However, for EV firms, the product performance has improved considerably. It is approaching the frontier level.


Average price of EVs(Dollar)
Time(Year)
(a)


Average price of CVs(Dollar)
Time(Year)
(b)



(c)

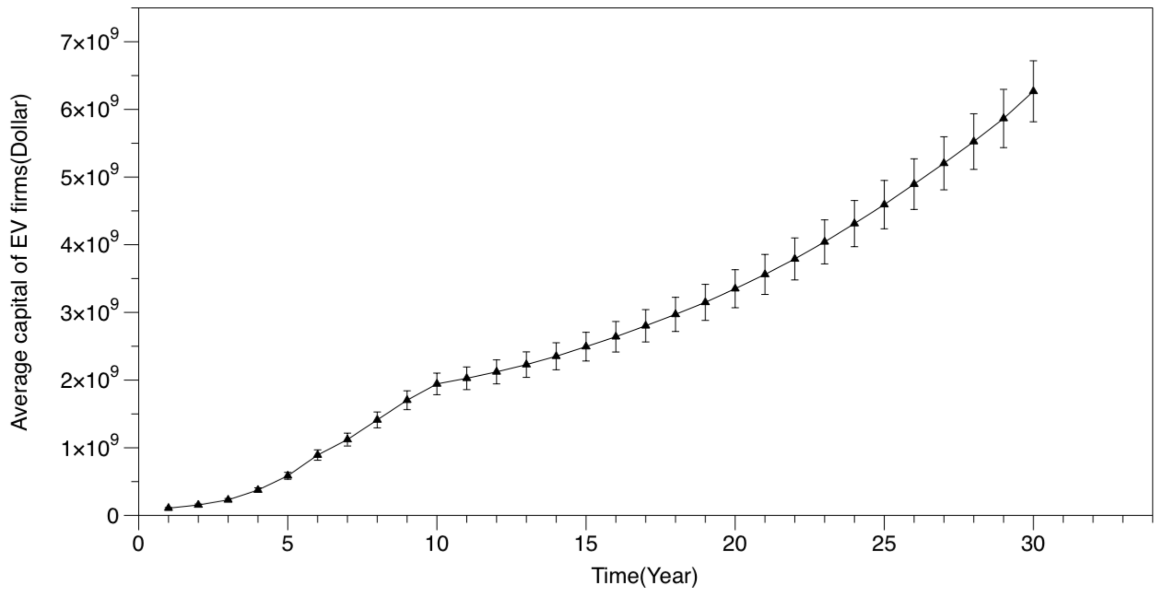


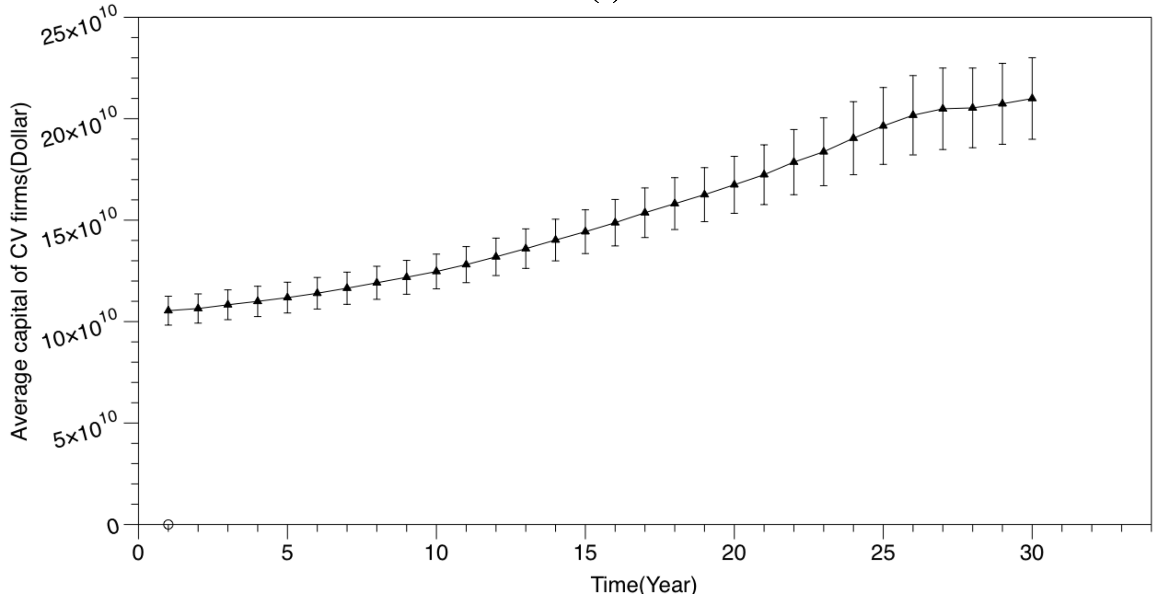
(d)

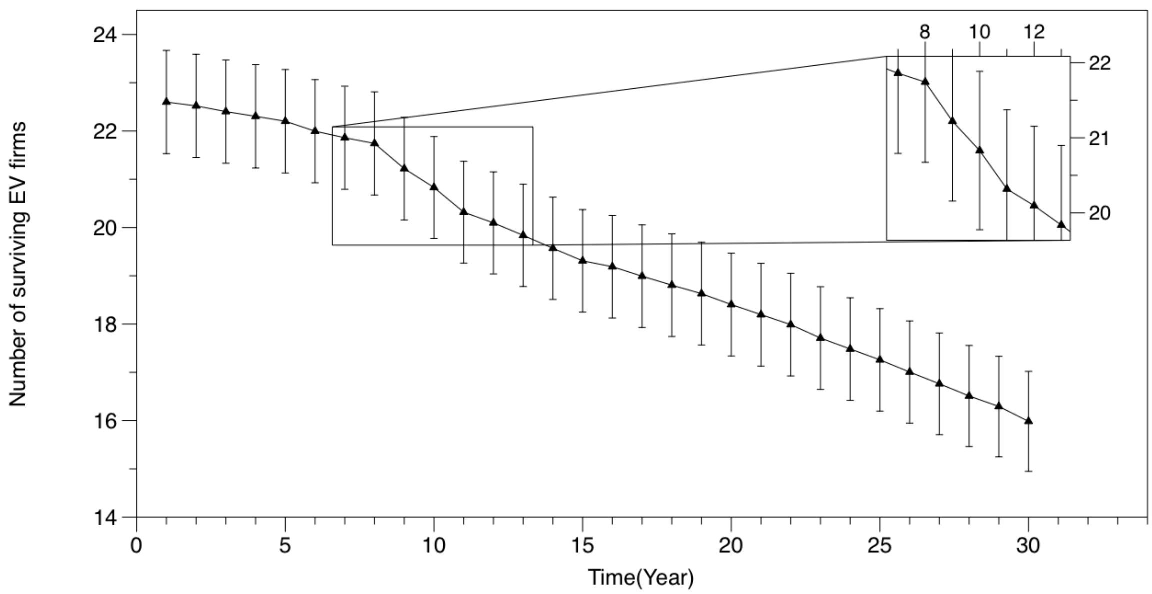
Fig. 12 EV and CV product performance variation during 2013–2042.

Figure 13 presents the surviving number of firms and the capital lapse. For the average capital of EV firms, a rapid increase in capital occurred during the early period when consumer subsidies existed. However, when subsidies were abolished, capital growth tends to be slow. CV firms' average capital rises slowly in the early years because of EV firm competition and rises faster in later years.

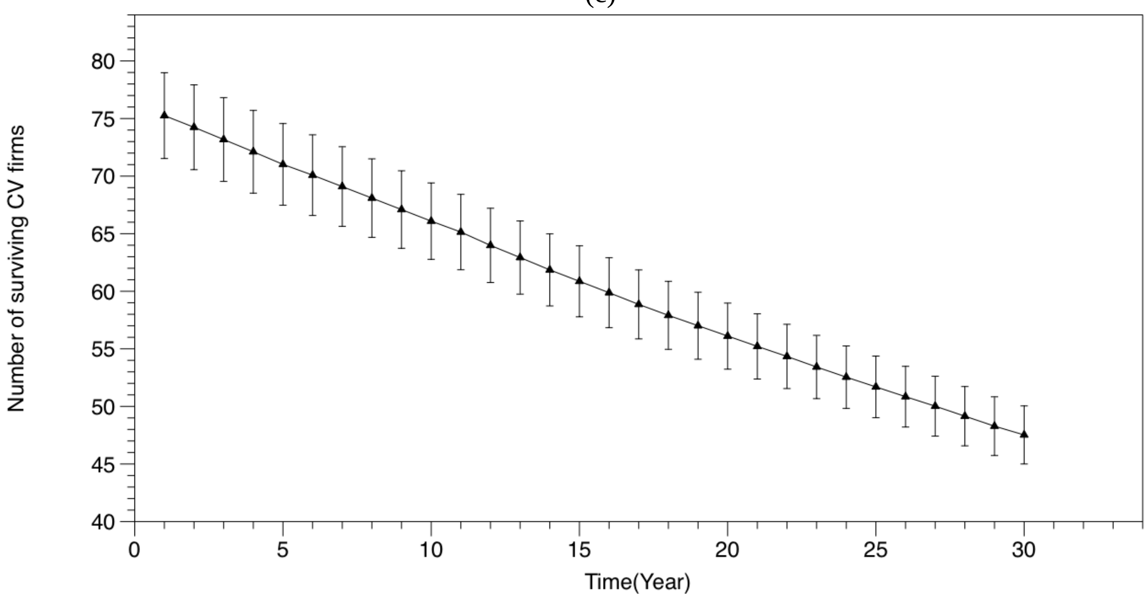
A few firms have greater initial capital, which engenders more R&D input and engenders better product performance than other firms, which creates a tendency to monopolize. Because of monopoly, some firms with smaller capital will leave the market gradually. From Fig. 13(c), one can see the accelerating rate of firm insolvency under the trend of gradual abolition of subsidies. This rate is attributable to the greater difficulty for firms to obtain orders to gain revenue. CV firms exited the market at a steady and flat rate because of product advantages created by the market dominance of gasoline-fueled cars.


Average capital of EV firms(Dollar)
Time(Year)
7×10^9
6×10^9
5×10^9
4×10^9
3×10^9
2×10^9
1×10^9
0
0
5
10
15
20
25
30
(a)


Average capital of CV firms(Dollar)
Time(Year)
25×10^10
20×10^10
15×10^10
10×10^10
5×10^10
0
0
5
10
15
20
25
30
(b)



(c)



(d)

Fig. 13 Number of surviving firms and the status of the firms' capital lapse.

In describing the model output above, one finds that EVs are not competitive to CVs. Although consumer subsidies can allow EVs to reach a large degree of diffusion in a short period, the abolishment of consumer subsidies will bring great shock and turbulence to the EV market and EV firms. Currently, the EV market is dependent on consumer subsidies. It is reliant only on the price advantage brought by subsidies to drive EV diffusion, which is of minor assistance to the long-term development of EVs.

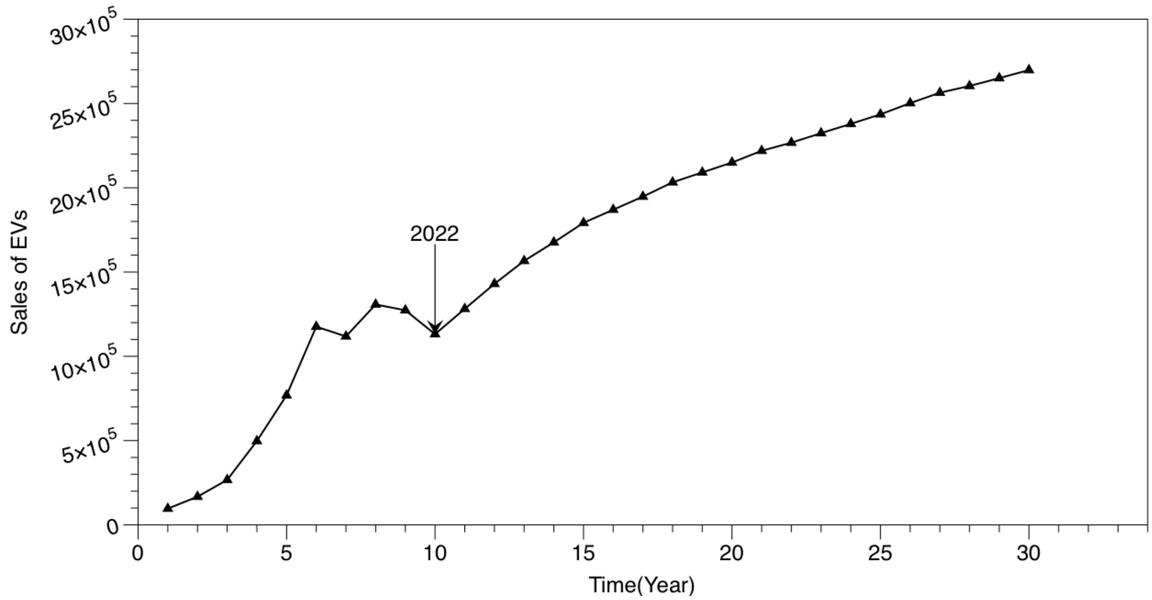
Chapter 3
Prediction with different consumer subsidy withdrawal scenarios

This part presents a study of EV diffusion under different consumer subsidy withdrawal scenarios in the baseline model. The preceding chapter showed that EV diffusion goes through huge shock and turbulence when the consumer subsidy is abolished. A sudden cessation of subsidies will lead to EV inability to compete with CVs. How will the diffusion of EVs be affected if consumer subsidies continue after 2022? Three scenarios are discussed here: (1) maintain the subsidy amount and standards of 2022; (2) follow the trend of subsidy reductions of 2020–2022, with annual reductions of 30% from the prior year until the subsidy amount is less than $100; and (3) implement more stringent subsidy standards than in 2022 and reduce the subsidy amount by 30% from the prior year until the subsidy amount is less than $100.

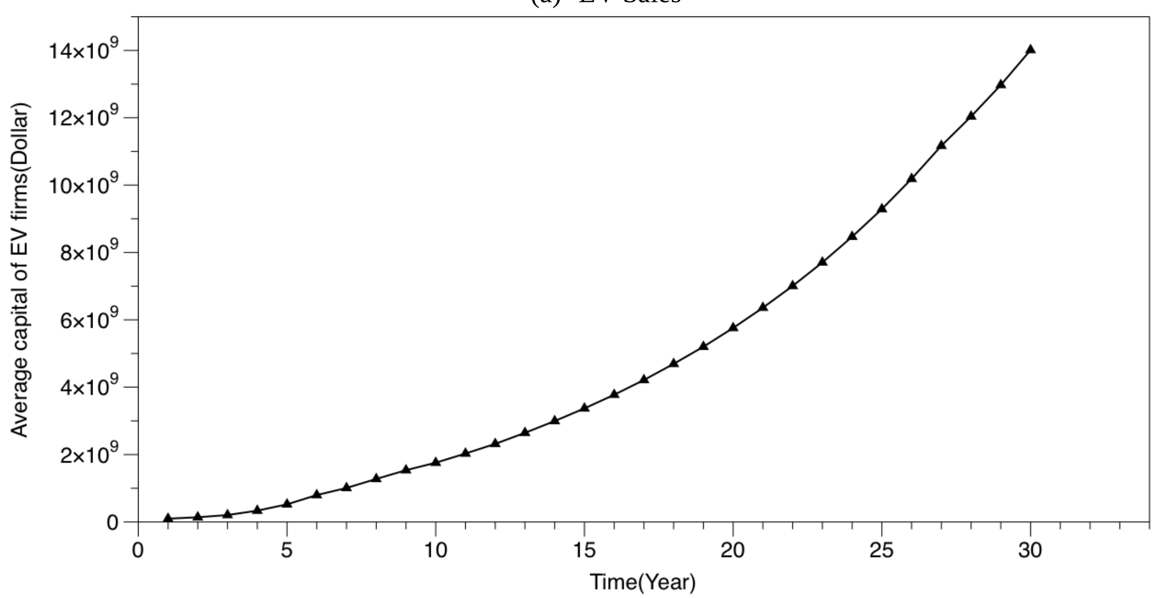
3.1 Withdrawal with loose consumer subsidy policy

Effects of a loose subsidy policy are discussed next: when consumer subsidies are maintained from 2022 at the same standards and amount as in 2022.

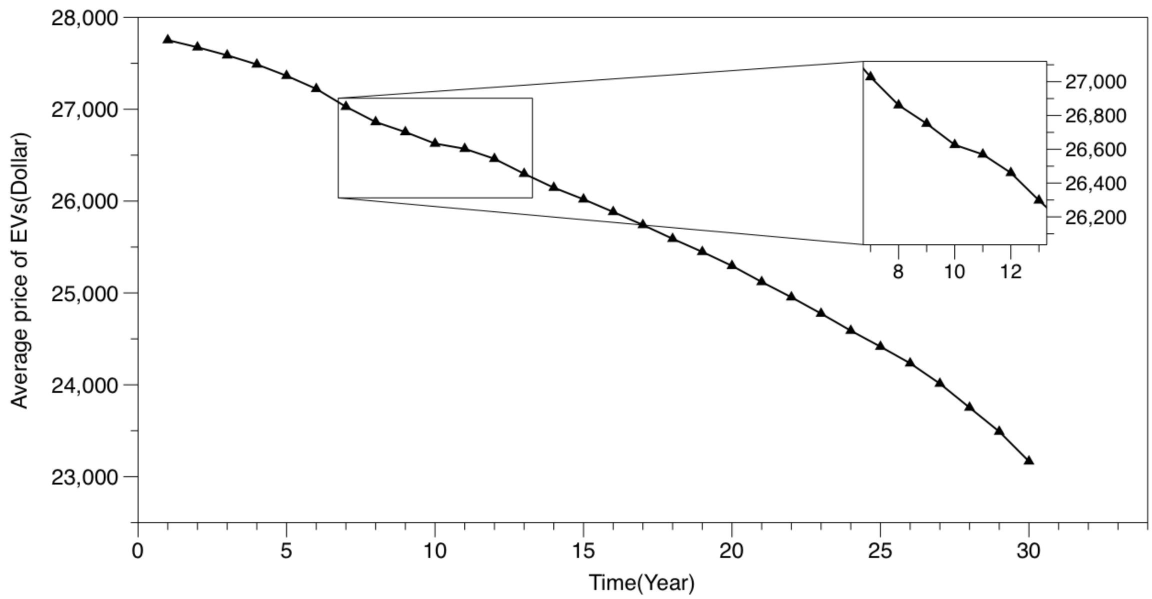
As shown in Fig. 14(a), when consumer subsidies persist, EV sales continue to rise and reach an unprecedented level of sales. Furthermore, the increment of sales is attributable to improved product performance, which attracts more EV purchasers. The increment of sales will logically increase the firm's capital, as shown in Fig. 14(b). The increment of sales also engenders an increase in R&D investment. A faster increase in sales is associated with faster improvement in product performance, which in turn attracts more consumers to buy the product, thereby creating a virtuous circle.



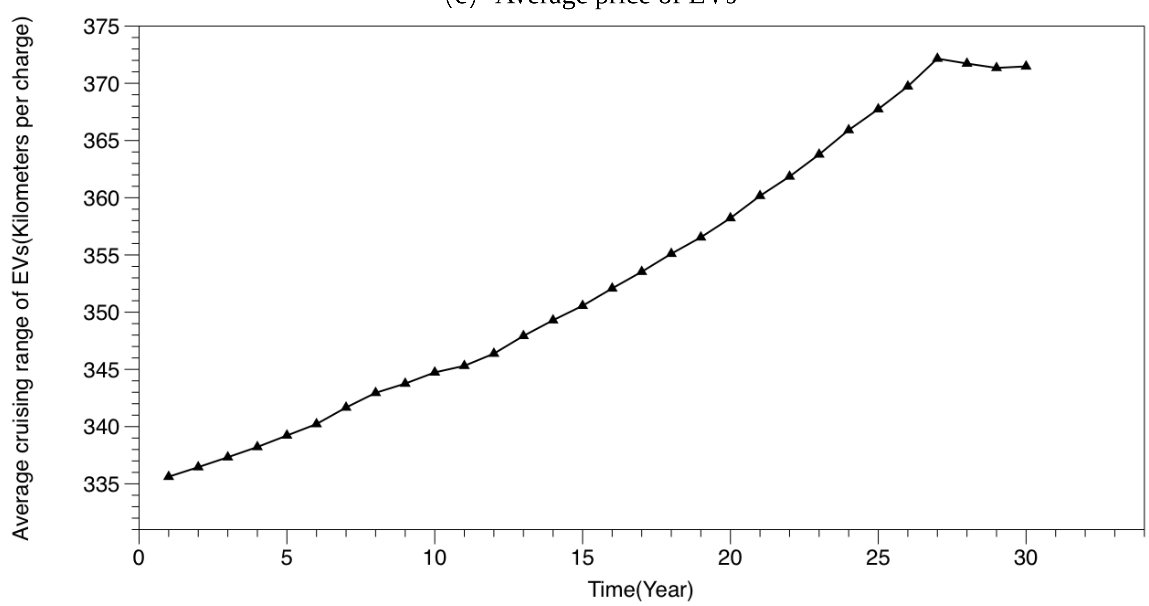
(a) EV Sales



(b) Average capital of EV firms



(c) Average price of EVs



(d) Average cruising range of EVs

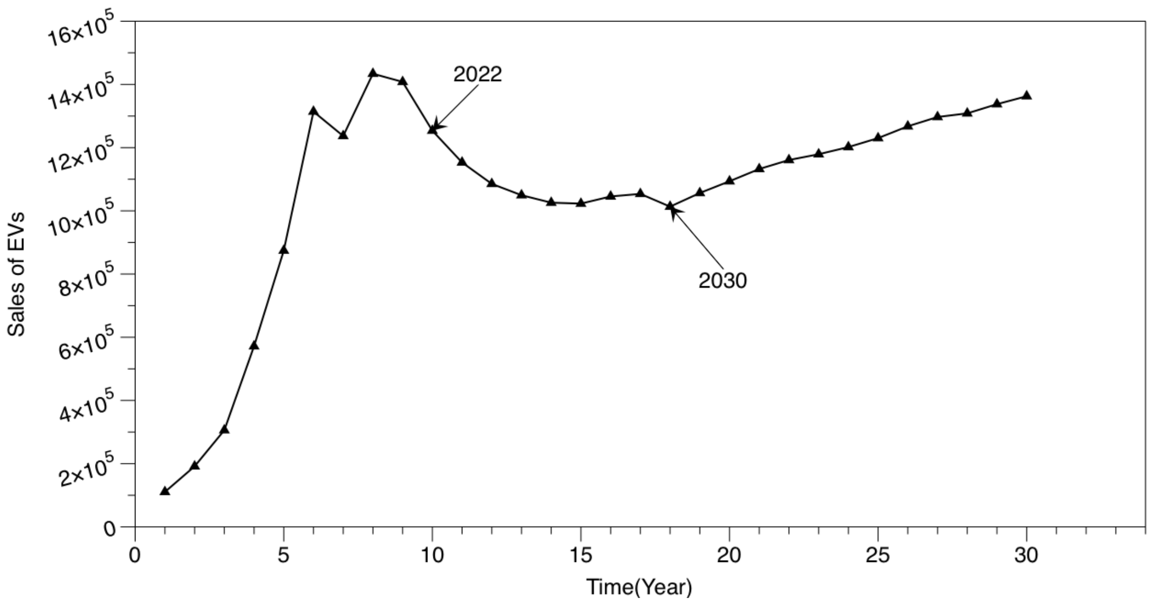
Fig. 14 Diffusion and performance of EVs with the loose consumer subsidy policy.

3.2 Withdrawal with moderately strict consumer subsidy policy

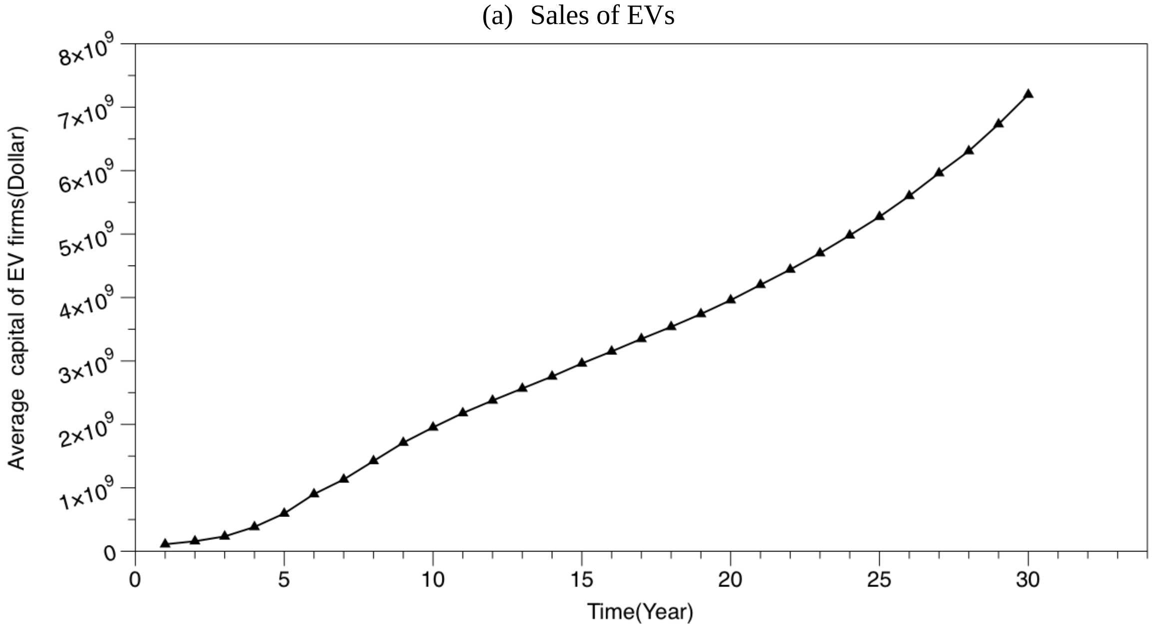
Next, we discuss effects of a moderately strict subsidy policy. We follow the trend of subsidy reductions during 2020–2022, with annual reductions of 30% from the prior year until the subsidy amount is less than $100.

Figure 15(a) shows that, under a moderately strict consumer subsidy policy, EV sales remain on a downward trend during 2022–2030, although consumer subsidy remains. Eventually, the sales in 2042 can only reach the sales level of 2021. During 2022–2030, sales are on a downward trend because the sales described above depend on the product performance. The decline in sales reflects a mismatch between current product performance and sales. The utility of the product increases rapidly with consumer subsidies, but the utility of the product cannot reach the level of the subsidized period when subsidies are decreased or even eliminated.

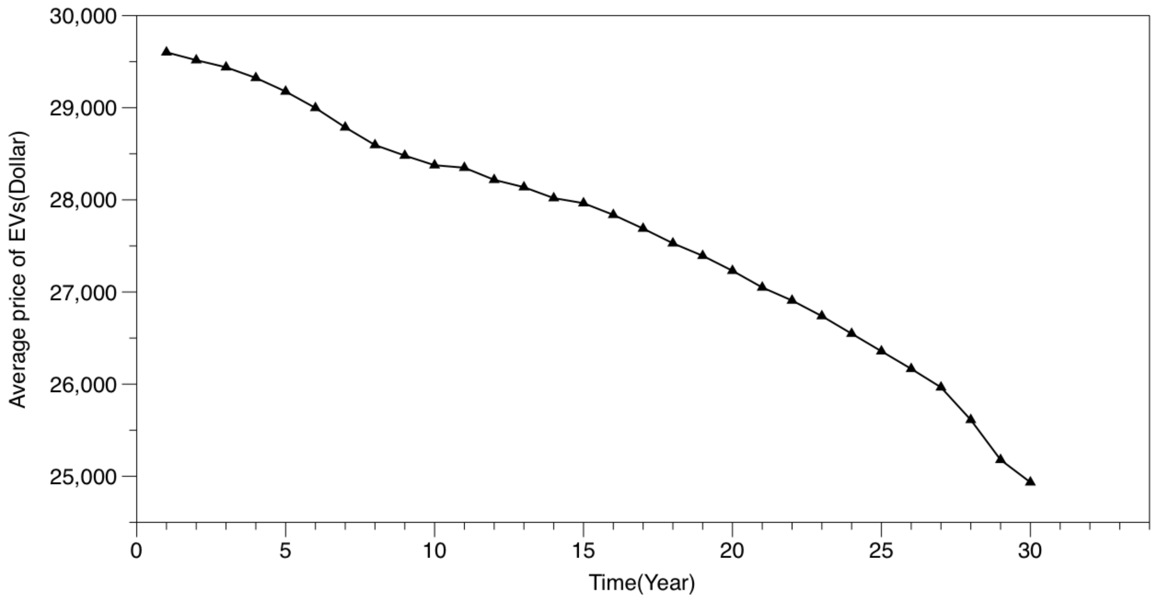
As described in the earlier section, the growth in sales shows positive feedback with the company's capital and product performance. Changes in sales volume also have a direct effect on the rate of change in the company's capital and product performance.



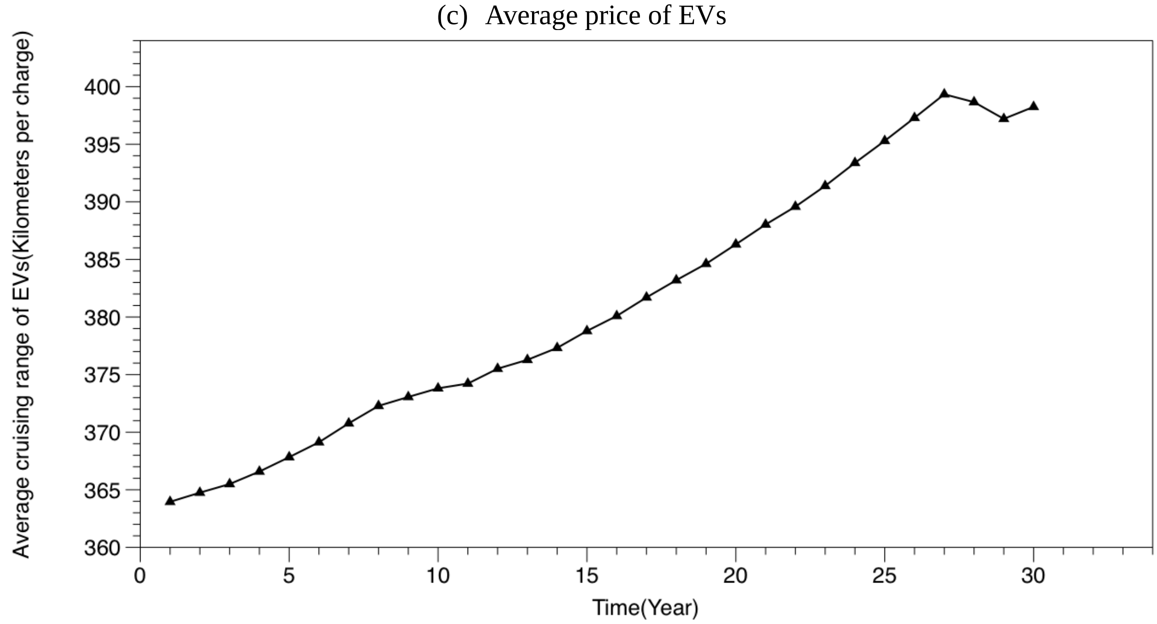
(a) Sales of EVs



(b) Average capital of EV firms



(c) Average price of EVs



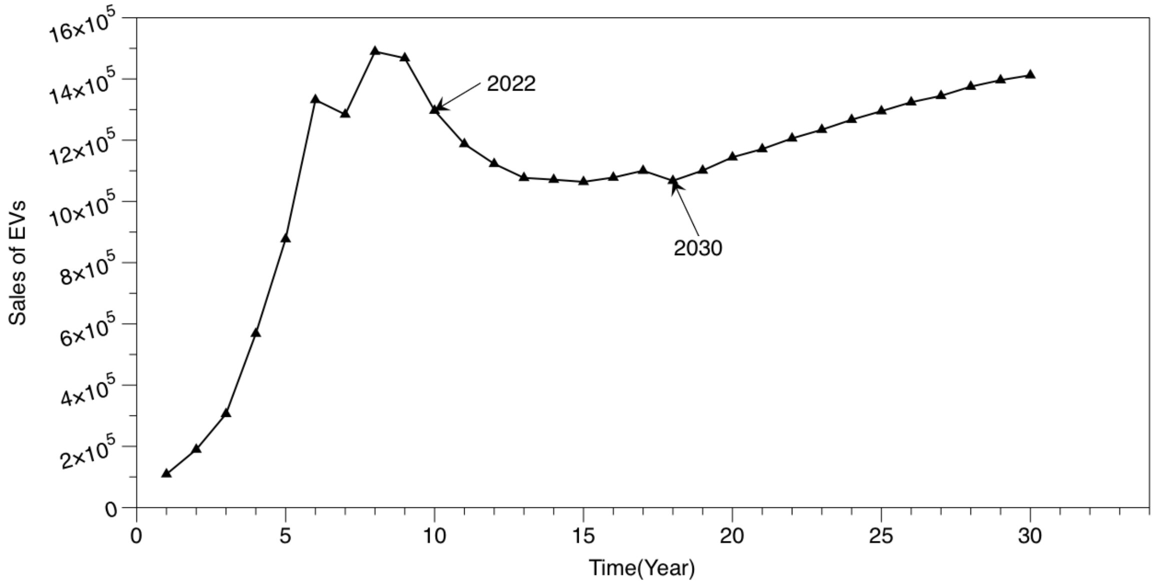
(d) Average range of EVs

Fig. 15 Diffusion and performance of EVs with the moderately strict consumer subsidy policy.

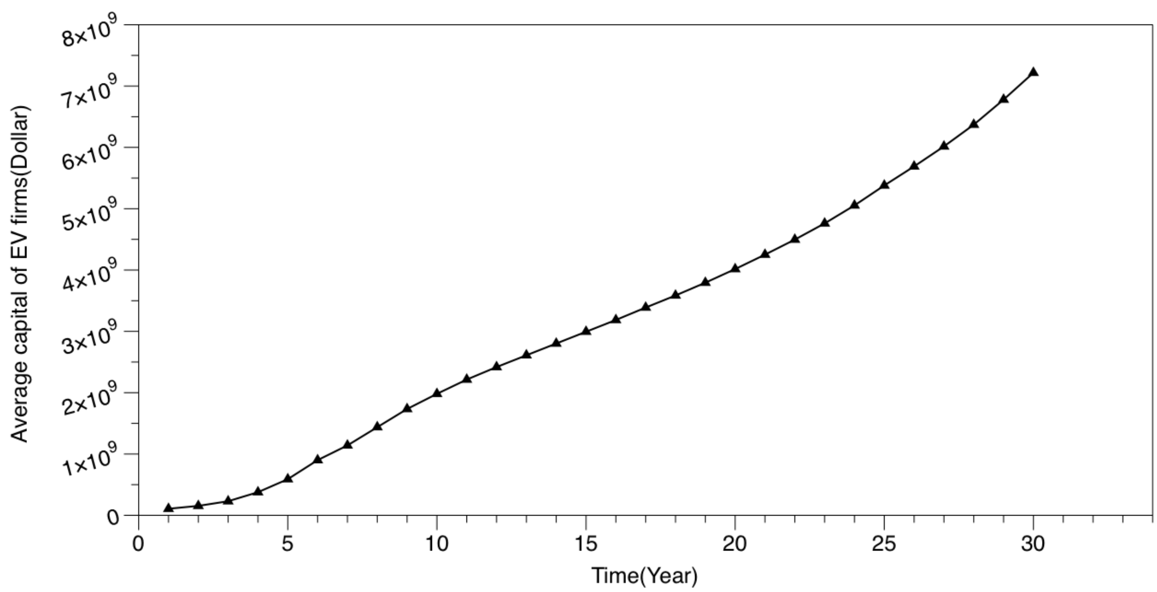
3.3 Withdrawal with a strict consumer subsidy policy

Next, we discuss the effects of a strict subsidy policy: implement more stringent subsidy standards than in 2022 and reduce the subsidy amount by 30% from the prior year until the subsidy amount is less than $100. As shown in Table 3, the subsidy standard for 2020–2022 is that of the cruising distance range of [300, 400] and more than 400. Following the trend of increasing standards, the standard for 2023 increases by 150 km based on the 2020 standard.

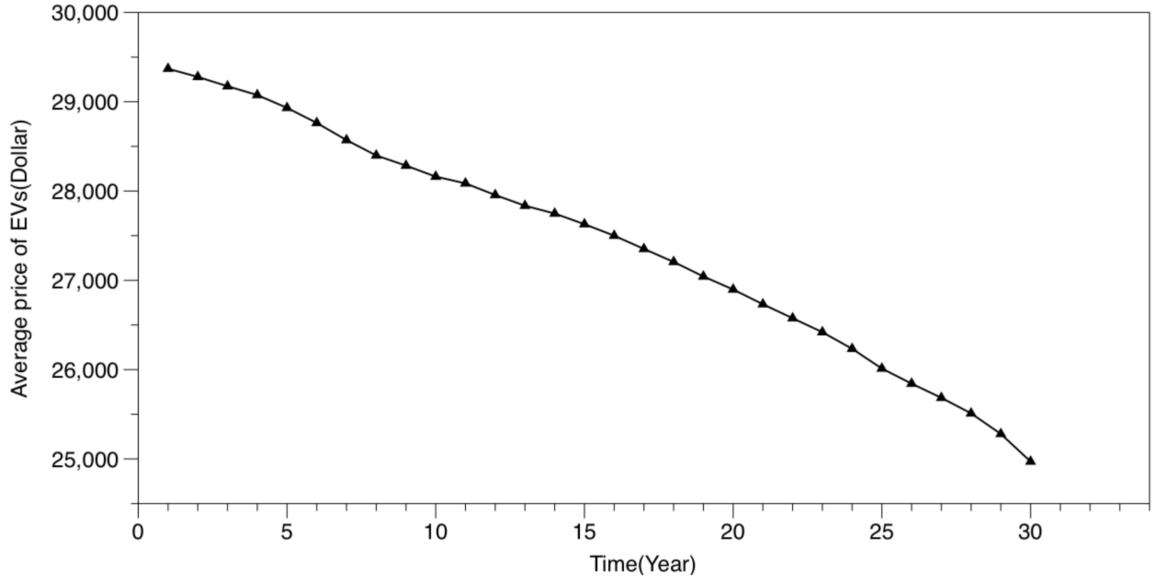
Similar to the moderate strict subsidy policy, the strict subsidy policy shows the same pattern of growth, with a constant downward trend in sales during 2022–2030, even though consumer subsidies continue to exist. The reason for the decline is the mismatch between product performance and the volume of sales, as stated in the preceding section.



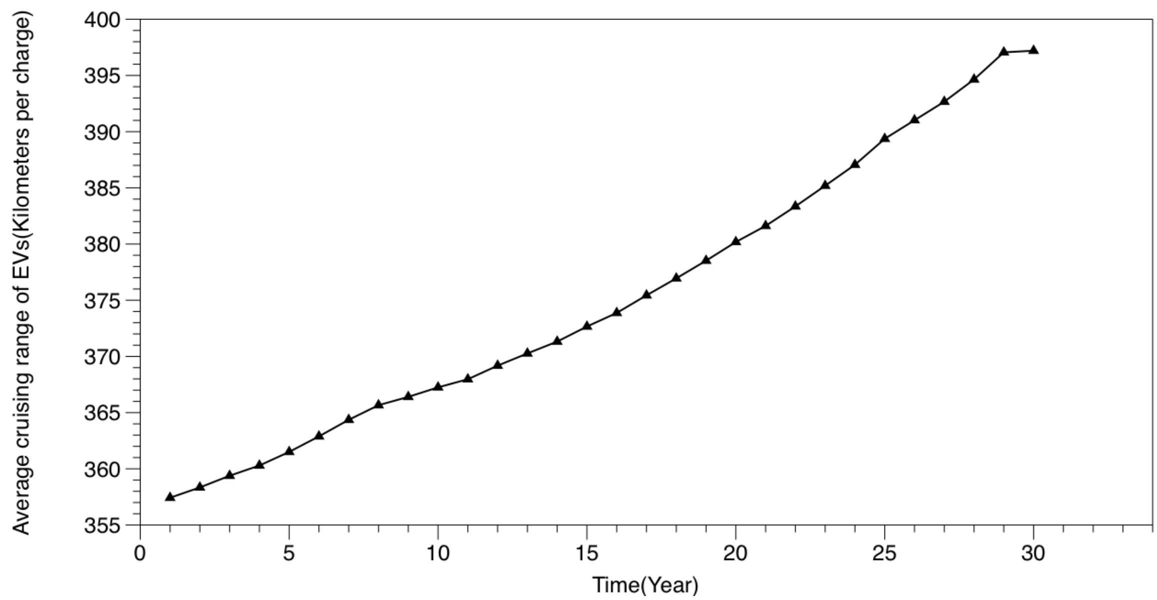
(a) EV Sales



(b) Average capital of EV firms



(c) Average price of EVs



(d) Average range of EVs

Fig. 16 Diffusion and performance of EVs with the strict consumer subsidy policy.

3.4 Reflection

After discussing the three withdrawal scenarios above, it is apparent that a loose subsidy policy can be more conducive to the diffusion and development of EVs, but it would place a heavy financial burden on the government. A strict subsidy policy can only maintain the current level of sales, it cannot bring a further expansion of sales. Such a result might be readily predicted: more money invested by the government to increase the utility of EVs will certainly increase EV sales. However, this increase in sales is 'illusory'. Warren Buffett once said 'You never know who is swimming naked until the tide goes out." When the subsidies have been abolished, the performance of EVs will not be able to support sales, thereby leading to turbulence and shock in the EV market. Figure 17 shows the turbulence in EV sales when the loose subsidy policy is abolished from 2042. Whatever consumer subsidy policy is implemented, it will create dependence on subsidies. When the subsidy is abolished, there will be a shock in the market.

These results lead to a critical view of whether consumer subsidies are the best subsidy policy? From the discussion above, we pointed out that the reason for the turbulence in sales is a mismatch between product performance and sales. In other words, product performance is the ultimate factor affecting EV diffusion. Without performance support, EVs will not be able to gain long-term growth.

Consumer subsidies can increase R&D investment only indirectly by raising revenue. Targeting subsidies to a firm's R&D process is apparently a good option, R&D subsidies can directly help firms to improve the performance of their products. Furthermore, selective R&D subsidies have been proved to be more effective than automatic R&D subsidies for new technology-based firms. Is this also true in the EV field? These issues are discussed in the next chapter.

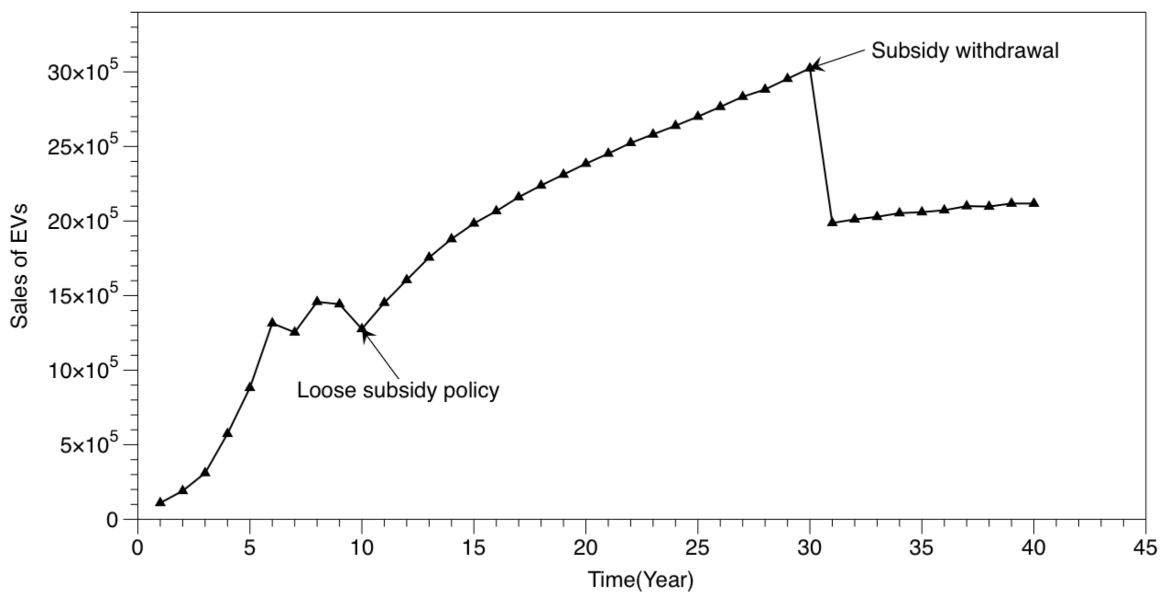


Fig. 17 Sales of EVs with a loose subsidy policy during 2013–52 (subsidy ceased in 2042).

Chapter 4
Effects of R&D subsidy and selective R&D subsidy on EV diffusion

In the preceding chapter, we analyzed effects of different consumer subsidy withdrawal scenarios and explored some doubts about the effectiveness of a consumer subsidy. This chapter presents studies of R&D subsidy and selected R&D subsidy effects on electric vehicle (EV) market diffusion. Furthermore, we discuss factors influencing the optimal coverage of a selective R&D subsidy.

4.1 Background

The original model of subsidies was used to compare consumer and manufacturer subsidy effects. Results demonstrate that consumer subsidies are far more effective than manufacturer subsidies. Unlike consumer subsidies, which increase the utility of the product directly, manufacturer subsidies can only improve product performance indirectly through subsidies as a small proportion of capital. Revenues are used to support R&D activities.

In fact, R&D subsidies are used as a policy instrument to reduce market failure. They have positive effects on both R&D expenditure and value-added productivity. A selective R&D subsidy, as a special type of R&D subsidy, supports firms when they meet certain screening criteria. Selective R&D subsidies first proposed by Colombo in 2012 are effective at increasing the total factor productivity (TFP) of firms. They generate a certification effect, which helps firms to reduce external information uncertainty and to obtain more investment. However, no report describes a study of effects of a selective R&D subsidy in the EV industry. Does it have a better promotional effect on EV market diffusion?

To compare the effects of different subsidies on an equal basis, the manufacturer subsidy and R&D subsidy are inferred from total government expenditures on consumer subsidies, although the subsidy duration remains the same. In the R&D subsidy scheme, the total amount of the consumer subsidy is calculated for each year. Then subsidies are added to the firm’s R&D activities. The selective scheme means that only selected firms can obtain a subsidy. The criteria for selection are based on product performance. The coverage of selection reflects the number of firms which can be subsidized.

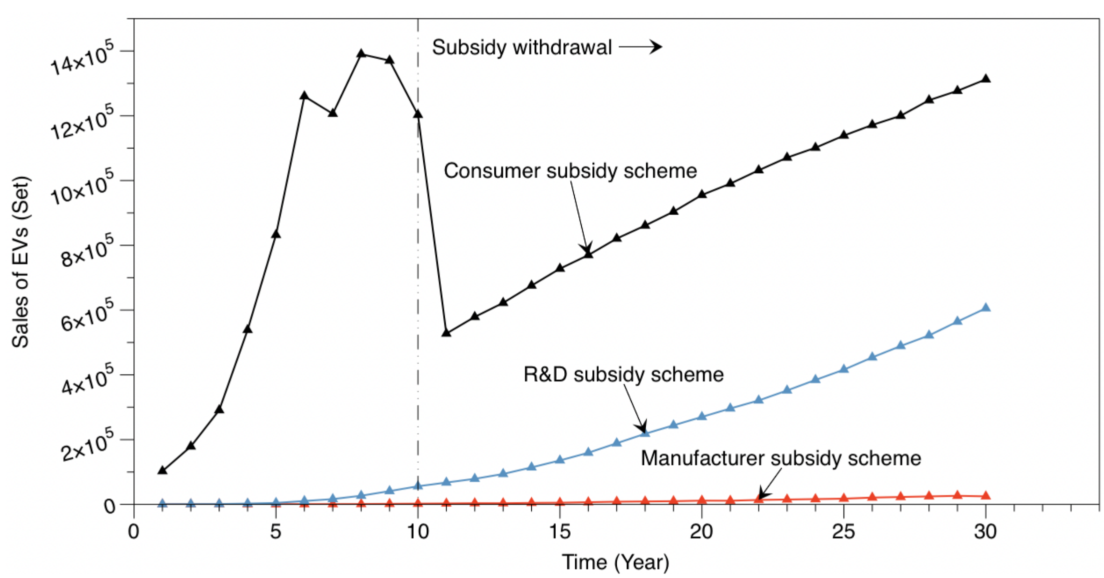
4.2 Comparison of subsidy effects on EV diffusion

First, we compare the respective effects of the consumer subsidy, manufacturer subsidies, and R&D subsidy on EV diffusion and development. The total amount of subsidies in each year is kept equal to the consumer subsidy scheme. Figure 18 presents effects of different subsidy schemes on the diffusion and development of EVs during 2013–2042. The subsidy is expected to end in 2022. The consumer subsidy policy is expected to cease in 2022.

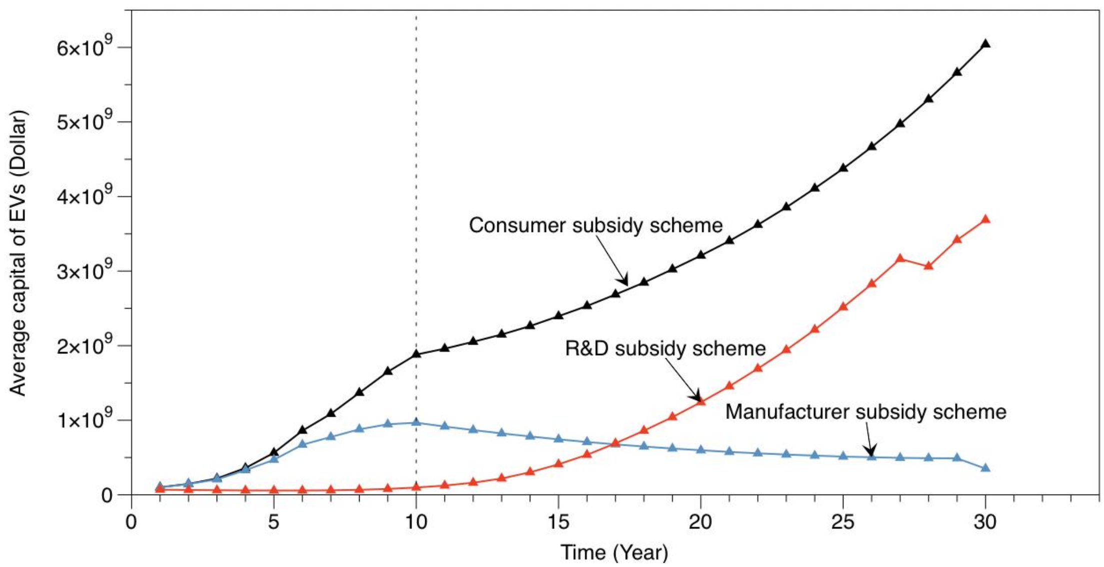
Figure 18(a) presents effects of subsidies of different types on EV diffusion. Results show that a consumer subsidy is more effective for EV diffusion than a manufacturer subsidy or R&D subsidy. Sun et al. [27] proved that consumer subsidies are more effective than manufacturer subsidies. Figure 18(b) shows that, under the manufacturer subsidy scheme, EV firms' capital temporarily exceeds that under the R&D subsidy scheme. However, after 2029, the capital decreases gradually as a result of poor sales caused by the exit of firms. The manufacturer subsidy also has a limited effect on the performance improvement of the product, lagging far behind the other two subsidy schemes. Therefore, manufacturer subsidy policies should be rejected by policymakers because of their ineffectiveness.

Figures 18(c) and (d) demonstrate that an R&D subsidy can markedly improve product performance compared to a consumer subsidy. However, under the R&D subsidy scheme, EV sales did not exceed sales achieved under the consumer subsidy scheme. Huge orders generated by firms under the consumer subsidy can increase the firm's capital considerably and can support a large production capacity. In contrast, sales under the R&D subsidy scheme show a slow-growth trend, which engenders the slower accumulation process in the firm's capital, which then limits the firm's ability to obtain more orders. Furthermore, when the R&D subsidy is abolished, product performance improves at rates that are lower than that under the consumer subsidy scheme.

In summary, a consumer subsidy has a good initial effect, which allows EVs to diffuse quickly and which helps the EV firms to accumulate large amounts of capital. When consumer subsidies are withdrawn, EV sales can be maintained at a higher level than under the R&D subsidy scheme, which eliminates concerns related to the transitory effects of a consumer subsidy. Huge sales of EVs in early stages will bring confidence to the market, thereby facilitating greater capital flows into the EV market to promote EV development. An R&D subsidy can improve EV performance considerably, but when the subsidies cease, the rate of product performance improvement is expected to be lower than that achieved under the consumer subsidy scheme. In the long term, a consumer subsidy will be more effective at improving product performance.

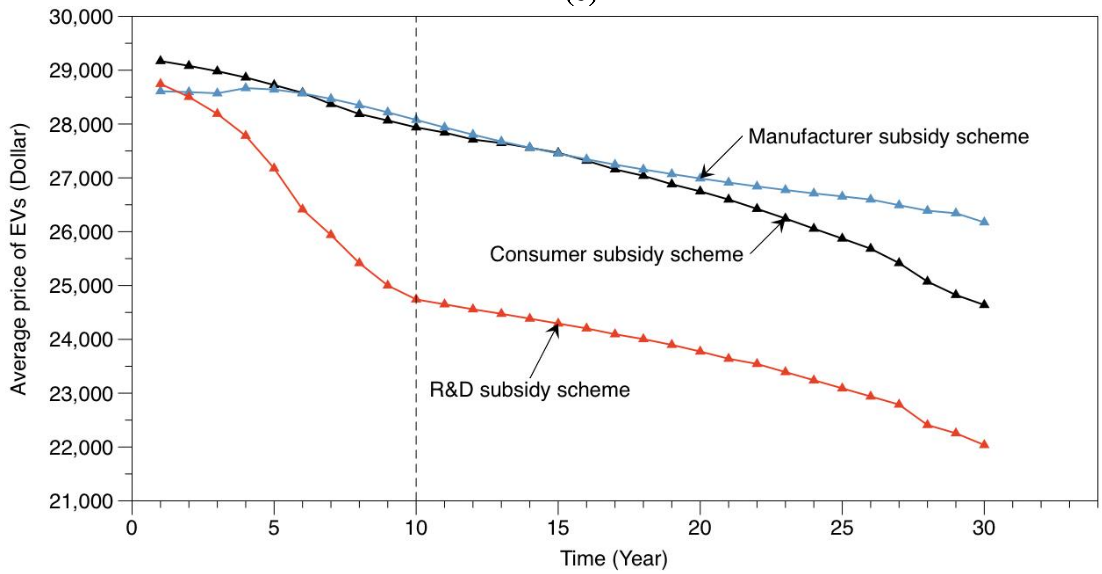


(a)



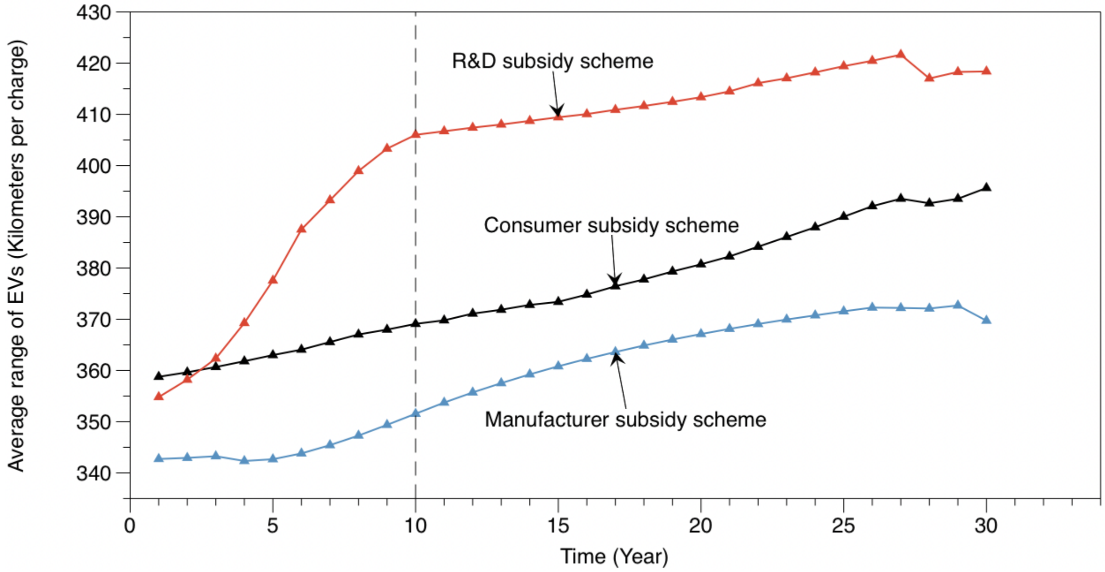
Average capital of EVs (Dollar)
Time (Year)
Consumer subsidy scheme
R&D subsidy scheme
Manufacturer subsidy scheme

(b)



Average price of EVs (Dollar)
Time (Year)
Manufacturer subsidy scheme
Consumer subsidy scheme
R&D subsidy scheme

(c)



(d)

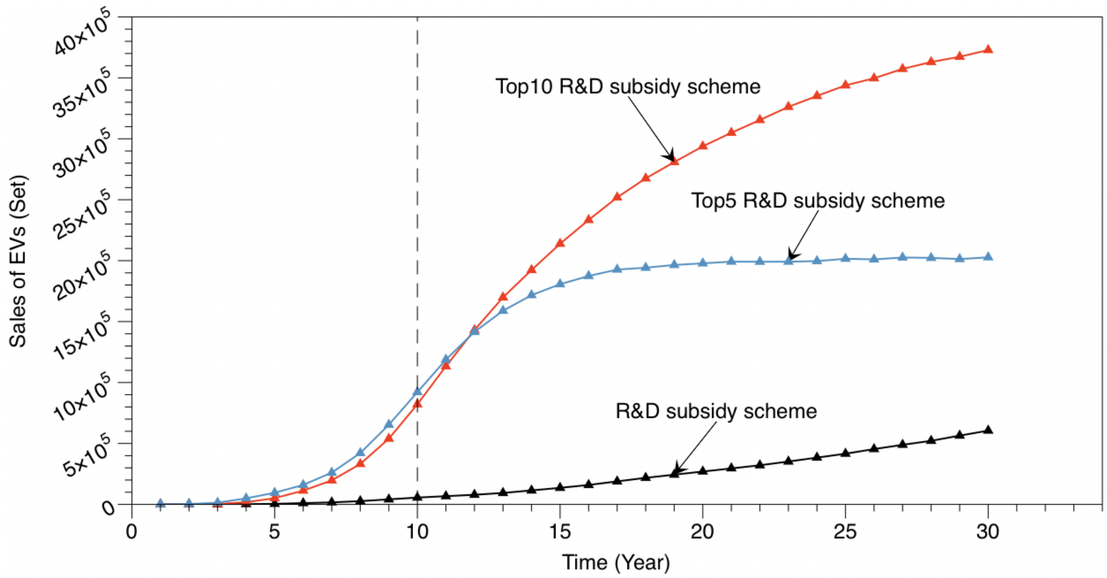
Fig. 18 Subsidy scheme effects on EV diffusion and development during 2013–2042.

After comparing effects of a consumer subsidy, manufacturer subsidies, and an R&D subsidy on the diffusion and development of EVs, we discuss effects of the selective R&D subsidy scheme. The criteria for the selective subsidy in this study are based on the EV cruising range: a firm producing a vehicle with a greater EV cruising range is more likely to obtain an R&D subsidy. We will also control for the coverage of a selective subsidy, where we use $Top\ n$ to denote the top n firms producing EVs in terms of a cruising range sufficient to receive subsidies.

Figure 19 shows effects of different R&D subsidy schemes on EV diffusion and development during 2013–2042. The subsidy intensity and duration time of each subsidy remain the same. Subsidies were abolished in 2022. Figure 19(a) shows that Top 10 and Top 5 R&D subsidy schemes are more effective than an automatic R&D subsidy for encouraging EV diffusion. Particularly, the Top 10 R&D subsidies have shown excellent effects for EV market diffusion.

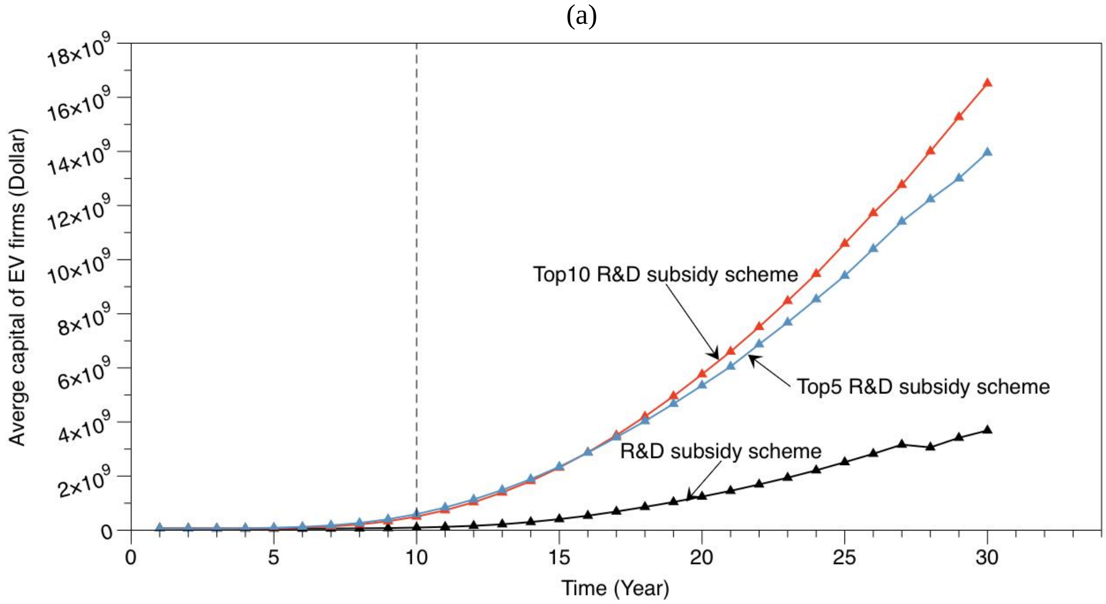
Nevertheless, a salient concern is that selective a R&D subsidy can engender market monopolization by a few firms. Results demonstrated that a selective R&D subsidy showed no better results than an automatic R&D subsidy in terms of the average EV performance. These results suggest that the selective R&D subsidy scheme will foster more oligarchs in the market who can produce better-performing EVs and who have more capital, so that small and medium enterprises (SMEs) will develop slowly and be phased out of the market gradually.

Figure 19(b) presents an interesting phenomenon by which, although the Top 10 R&D subsidy scheme had greater sales than the Top 5 scheme, the average capital values of EV firms in the respective schemes seem to be very similar. To explain this phenomenon, we must explore the firm distributions of capital and product cruising ranges under these two schemes.



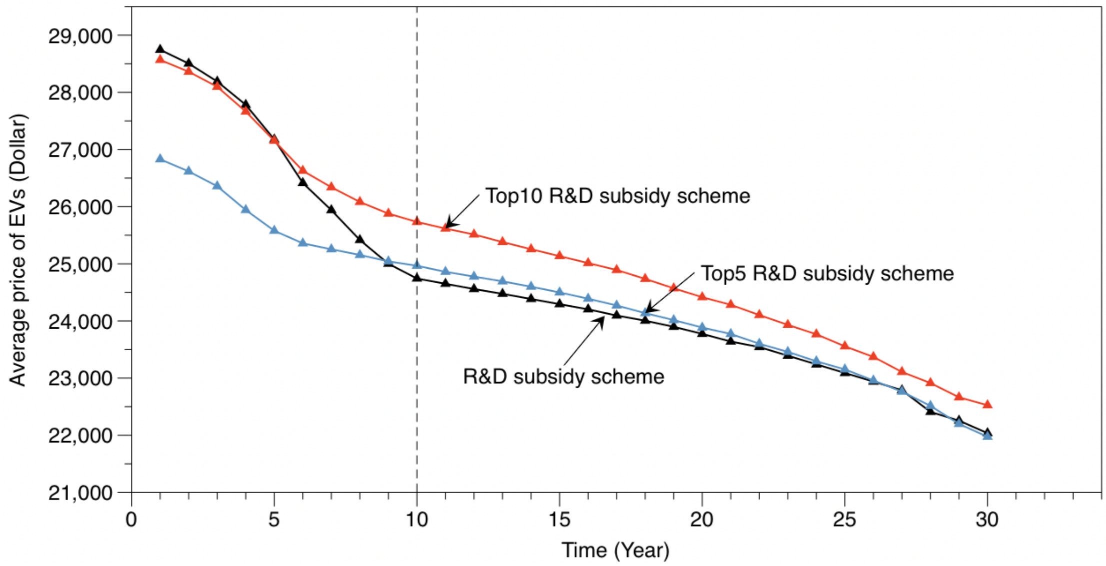
Sales of EVs (Set)
Time (Year)
Top10 R&D subsidy scheme
Top5 R&D subsidy scheme
R&D subsidy scheme

(a)

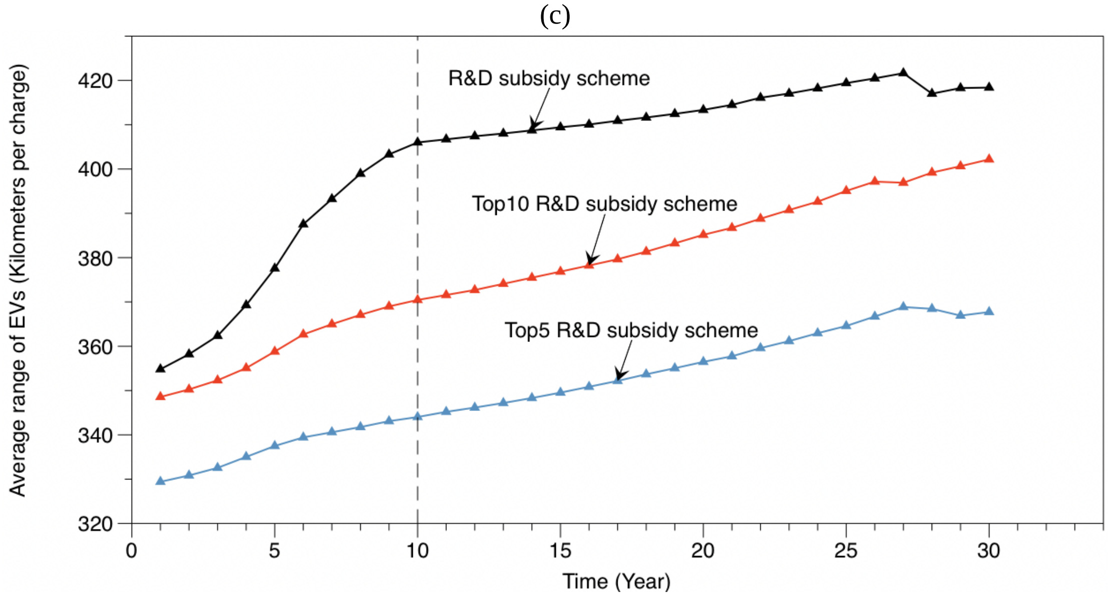


Averge capital of EV firms (Dollar)
Time (Year)
Top10 R&D subsidy scheme
Top5 R&D subsidy scheme
R&D subsidy scheme

(b)



(c)



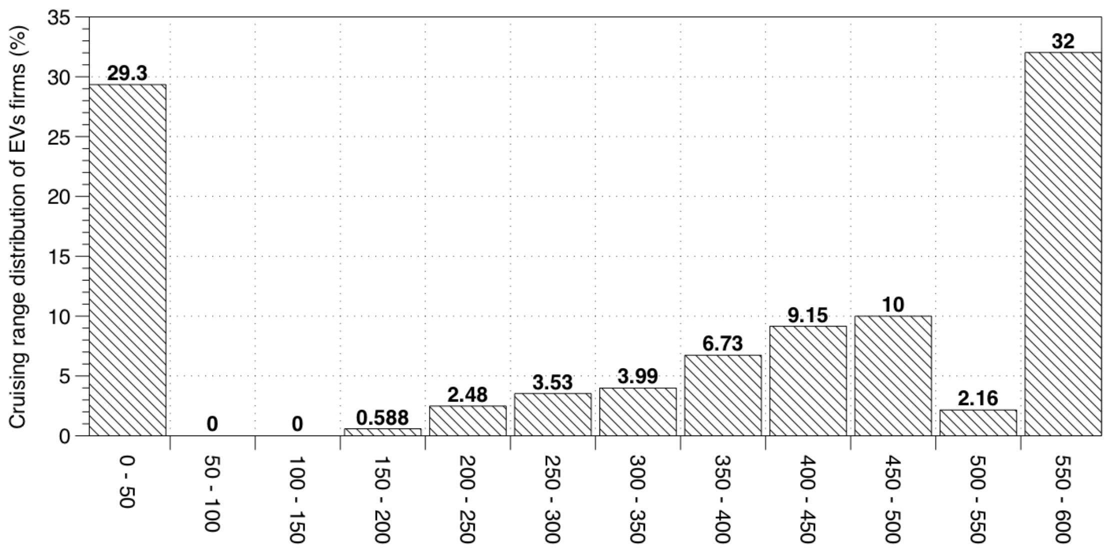
(d)

Fig. 19 R&D subsidy scheme effects on EV diffusion and development during 2013–2042.

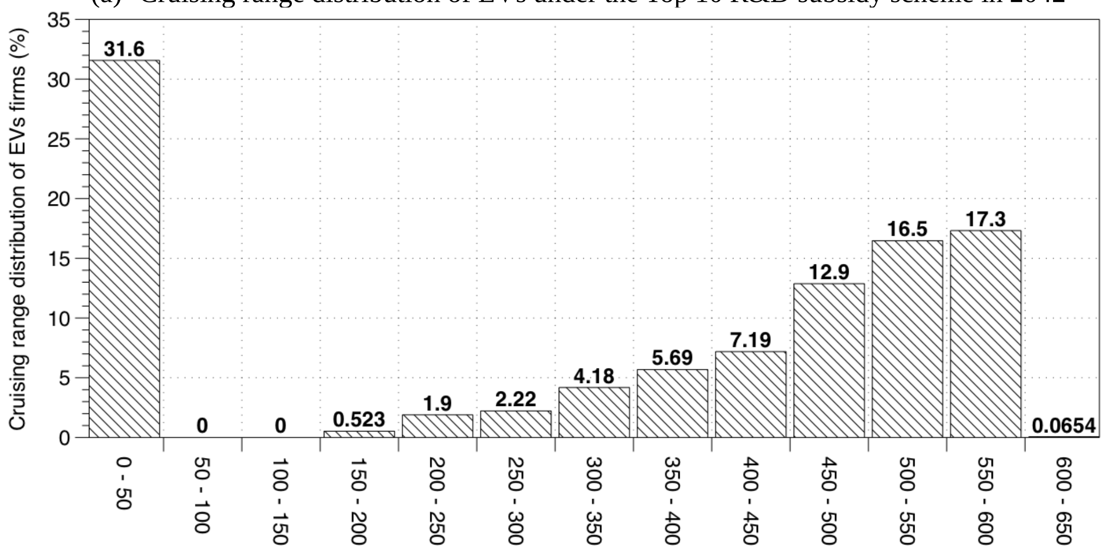
For clarification of the different effects on EV diffusion and development under the Top 10 R&D subsidy schemes and Top 5 R&D subsidy schemes, the simulation results in the capital distribution of firms and cruising range distribution of EVs are presented in Fig. 20. Under the Top 10 R&D subsidy scheme, 32% of the firms' products have a long cruising range of [550, 600]. In contrast, under the Top 5 R&D subsidy scheme, only about 17.4% of the firms' products have a long cruising range of [550, 600]. According to Eq. 6, when calculating the utility of each EV, the cruising range plays a crucially important role: a larger number of firms with high-performance vehicles is associated with higher EV sales, which also explains that there are more sales of EVs under the Top 10 R&D subsidy scheme in Fig. 19(a).

Figure 20(c) shows that the capital of most EV firms under the Top 10 R&D subsidy scheme is distributed evenly: [3e+10, 5.5e+10]. In contrast, under the Top 5 R&D subsidy scheme the capital of EV firms is more concentrated: [4.5e+10, 6.5e+10]. Therefore, under the Top 10 R&D subsidy scheme, a proportion of EV firm capital is distributed evenly at medium to high levels, whereas, under the Top 5 R&D subsidy scheme a small proportion of EV firms' capital is distributed at high levels, while most firms remain at low or even dangerous capital levels. The medians of firm capital are close under both schemes, which leads to a similar amount of average capital of firms despite much larger sales under the Top 10 R&D subsidy scheme than under the Top 5 R&D subsidy scheme.

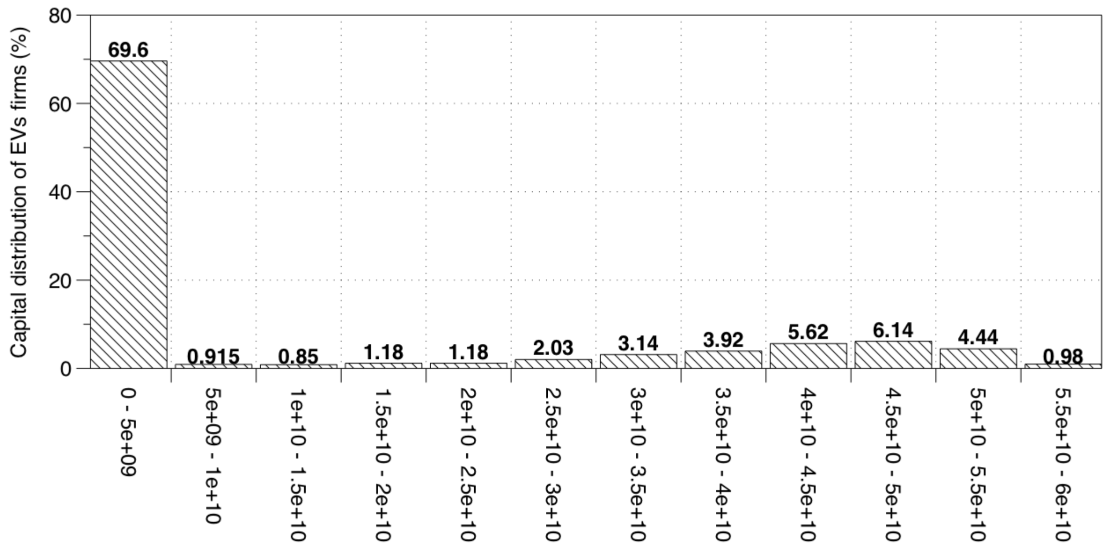
Under the Top 5 R&D subsidy scheme, more oligarchs emerged in the market with better-performing products and greater amounts of capital, which makes it more difficult for small to medium-sized enterprises (SMEs) to survive and obtain orders because of the overly narrow coverage of the subsidy. The Top 10 subsidy scheme produces apparently very good coverage of selective R&D subsidy able to generate larger sales: it will not create more oligarchs. Next, we discuss whether optimal coverage of selective R&D subsidy can best promote EV diffusion and development.



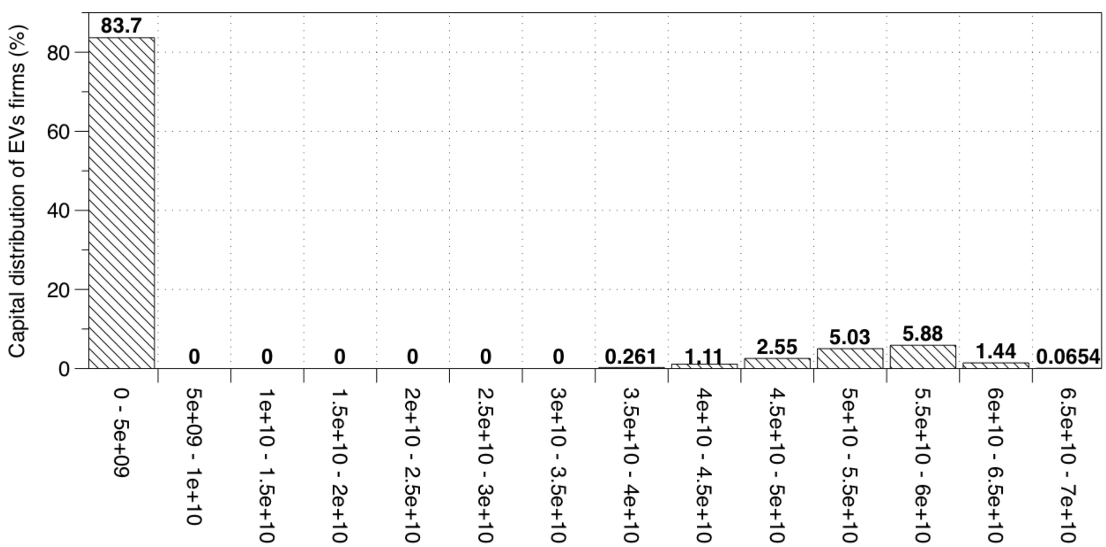
(a) Cruising range distribution of EVs under the Top 10 R&D subsidy scheme in 2042



(b) Cruising range distribution of EVs under the Top 5 R&D subsidy scheme in 2042



(c) Capital distribution of EV firms under the Top 10 R&D subsidy scheme in 2042



(d) Capital distribution of EV firms under the Top 5 R&D subsidy scheme in 2042

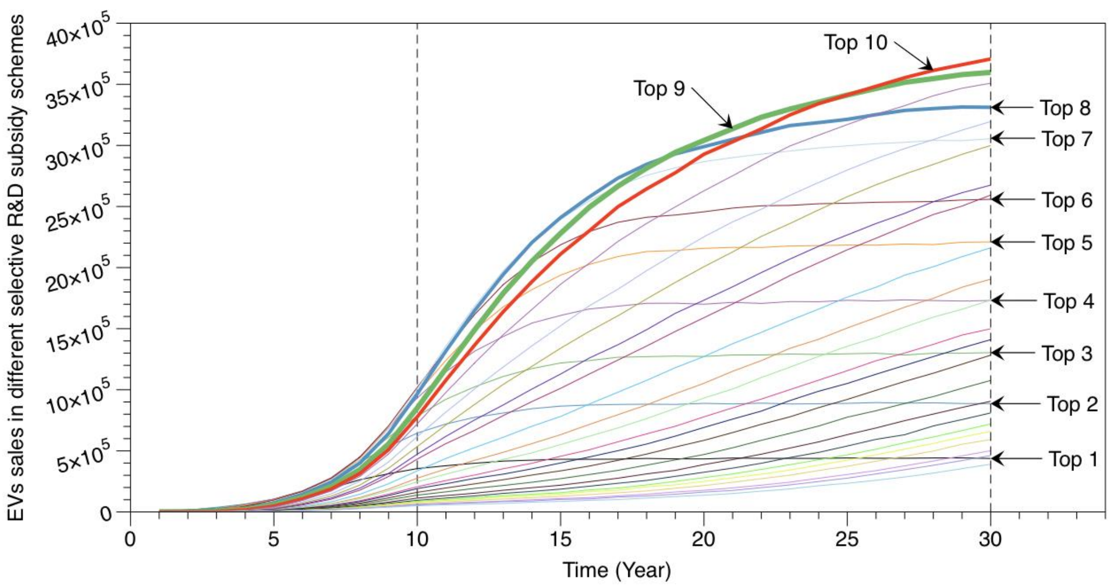
Fig. 20 Distributions of EV firm capital and EV cruising range under different subsidy schemes in 2042.

4.3 Optimal selective R&D subsidy coverage

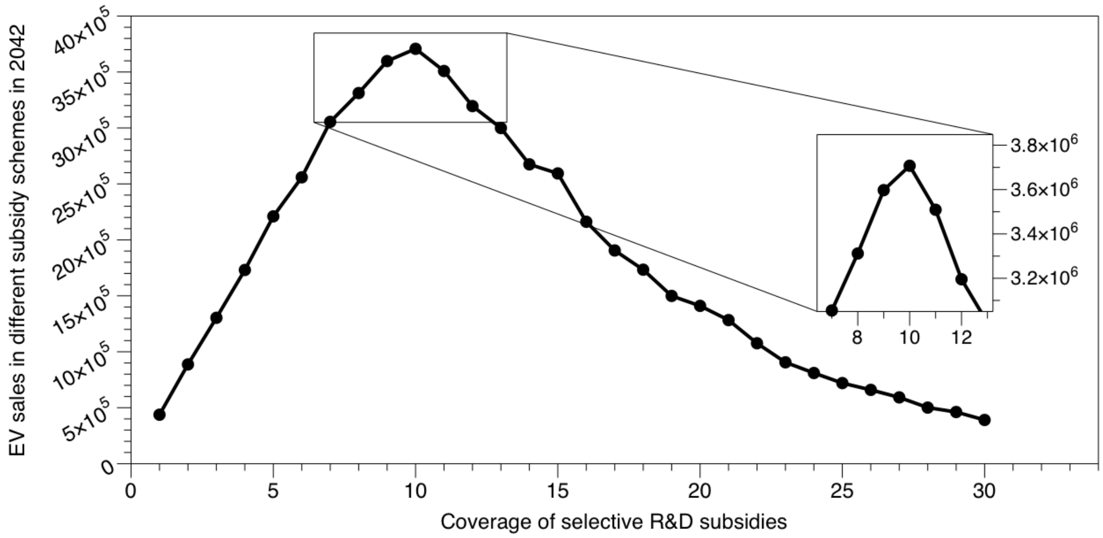
The discussion presented above demonstrates that each firm will obtain a smaller subsidy when the R&D subsidy coverage is more extensive. More firms with high-performance products are not likely to emerge. In contrast, if the coverage is small, then a few firms can obtain more subsidies. Only a few firms will have high-performance products. Therefore, one can expect some degree of optimal coverage of an R&D subsidy that can produce the greatest number of firms with high-performance products in the market, thereby achieving maximum EV sales.

To compare effects of R&D subsidies with different coverage set on the same basis, the intensity and duration time are kept equal to the consumer subsidy scheme. For different degrees of R&D subsidy coverage, the effects of R&D subsidy schemes are presented in Fig. 21. Apparently, when the subsidy coverage is ten, EVs reach their highest sales in 2042. However, in the middle time of the simulation, the Top 8 and Top 9 R&D subsidy are apparently more effective in support of EV diffusion. This finding can be explained by the fact that narrower subsidy coverage is more effective for the emergence of firms with high-performance products so that firms can get more orders in the early stage. However, a narrower coverage of subsidies will result in a monopolistic market with only a few firms able to survive in the long term.

Furthermore, one can observe two increasing trends of EV sales in Fig. 21(a). The first is that when the R&D subsidy coverage is less than nine, EV sales will eventually stabilize at a certain level. They will not continue to increase. The other is that when the subsidy coverage is greater than or equal to nine, the sales trend continued to increase. As described above, an overly limited R&D subsidy coverage will allow a few subsidized firms to increase and improve their products quickly, thereby leading to market monopolies. The remaining firms, which cannot receive R&D subsidies, are unable to obtain orders. Therefore, they must follow a slow process of improving the vehicle performance. The total sales volume will be maintained at a certain level eventually. It might be questioned whether, if faster-improving firms with high-performance products emerged, greater sales will be gained if consumers only select the best-performing products to buy and if the growing capital of firms does not limit production capacity. Consumers do not always purchase the best-performing vehicles. Their rationality is limited because of brand effects of vehicles or policy restrictions, etc. In this model, consumers will choose a vehicle to purchase from the top ten listed in terms of utility. Therefore, if more EVs with high performance exist in the market, then they are more likely to be chosen.



(a) EV sales for different coverages of R&D subsidy schemes during 2013–2042 (Top 1 – Top 30)



(b) Sales of EVs for different coverages of selective R&D subsidy in 2042
Fig. 21 Effects of different coverages of selective R&D subsidies on EV diffusion.

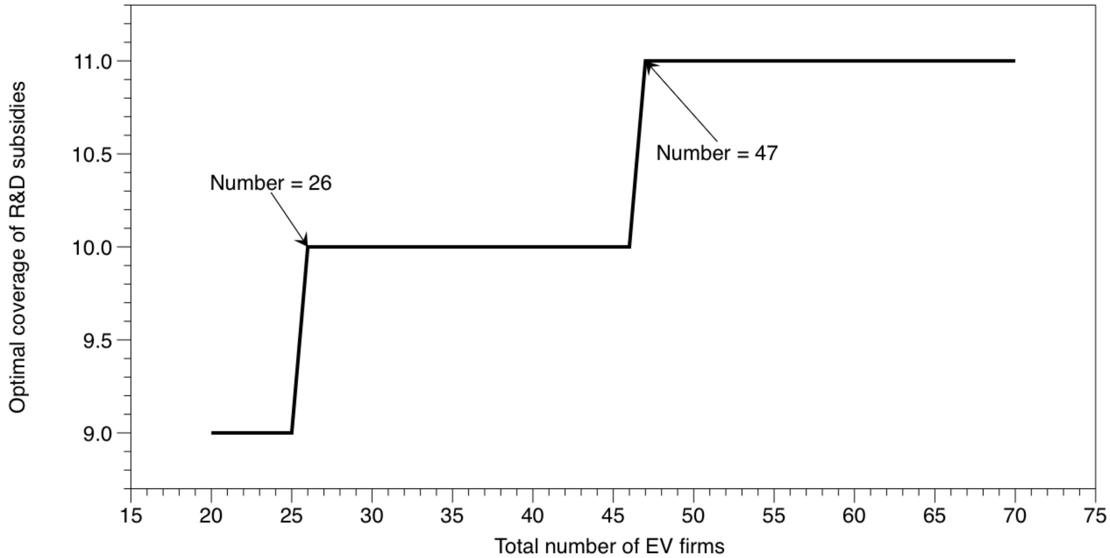
Results of simulations show that the Top 10 R&D subsidies have the strongest effect on EV diffusion. The optimal R&D subsidy coverage at ten firms is based on the calibrated parameter setting of the model and actual data. However, for practical purposes, sometimes parameters are not set as they are in the current model. In such a case, would the optimal R&D subsidy coverage 10 change or not?

Next, we discuss effects of changes in the total number of EV firms, the efficiency of firms' R&D processes, and the number of subsidies on the optimal coverage of the R&D subsidy.

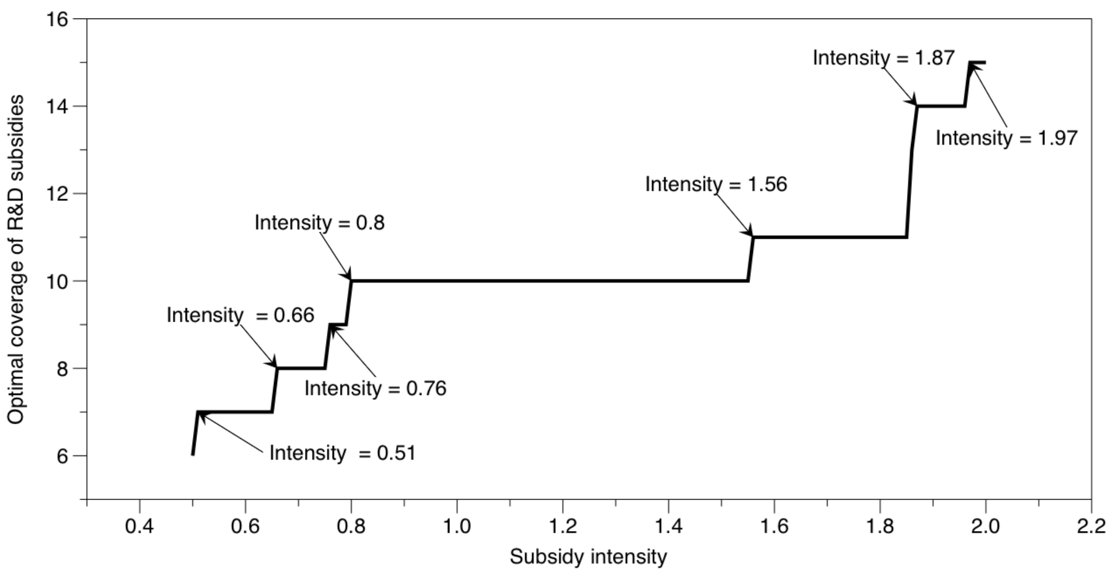
Effects of changes in different parameters on the optimal coverage of R&D subsidy are presented in Fig. 22. The optimal coverage of R&D subsidies is tested with different numbers of EV firms. Results show that the optimal coverage at ten is robust when the total number of EV firms changes. When the total number of EV firms in the market decreases, fewer firms have large amounts of capital. Therefore, fewer firms need an R&D subsidy to improve products to yield high performance. In contrast, when the number of EV firms increases, more firms have high amounts of capital. Then more firms need R&D subsidies to improve products and achieve high performance.

However, the optimal R&D subsidy coverage changes greatly when the R&D subsidy intensity changes. When the subsidy amount decreases, the original distribution will be dispersed. Only by tightening the R&D subsidy coverage will more firms with high performance emerge, and vice versa. The turning points are marked in Fig. 22(b).

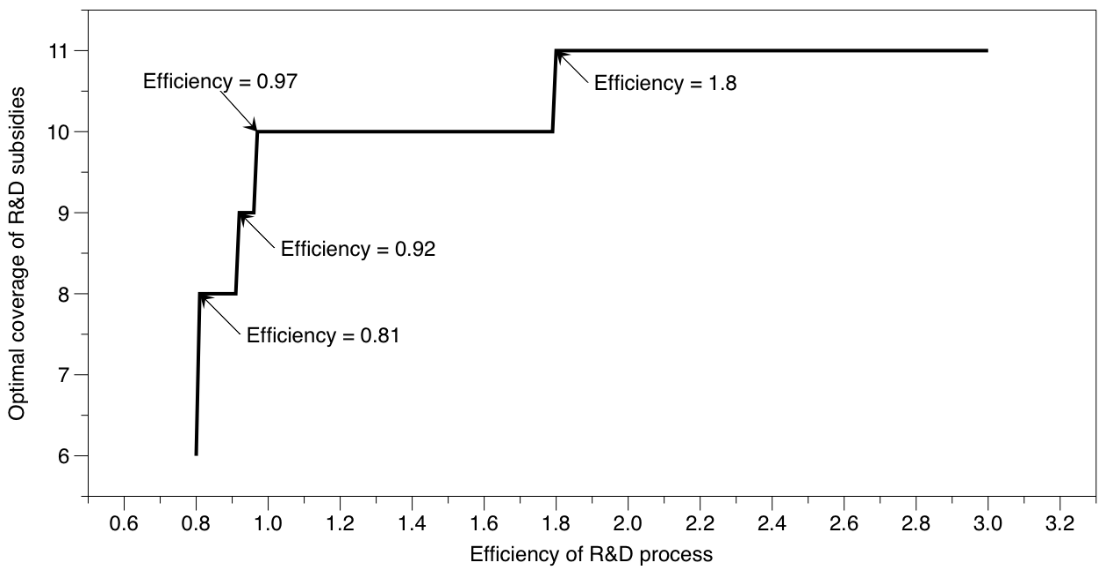
Then, the firm can improve the performance of its products faster or slower when the R&D process efficiency changes. If R&D efficiency decreases, then the company needs more subsidies to bring the product up to high performance. Therefore, the optimal R&D subsidy coverage is reduced. As R&D efficiency increases, we find little change in the optimal R&D subsidy coverage. Generally, higher R&D efficiency allows firms with high capital and high-performance products to monopolize the market faster, making the gap separating EV firms larger. Consequently, SMEs find it harder to obtain orders, which slows product performance, making it difficult for SMEs to produce high-performance products even when subsidized. However, every firm can produce high-performance products quickly if R&D efficiency is very high. In such a case, the optimal R&D subsidy coverage is 30. Consequently, we only explore R&D efficiency within a specific practical range.



(a) Optimal coverage of R&D subsidies for different numbers of EV firms



(b) Optimal coverage of R&D subsidies for different subsidy intensities (e.g., intensity = 0.66 means that the subsidy amount is 66% of that in the original model)



(c) Optimal coverage of R&D subsidy on different R&D efficiencies of EV firms (e.g., efficiency = 0.81 means that the R&D efficiency is 81% of that in the original model)

Fig. 22 Effects of changes in different parameters on the optimal coverage of R&D subsidy.

In summary, we explore the effects of changes in three parameters on the optimal coverage of an R&D subsidy. Optimal coverage achieved for ten is robust when the number of EV firms changes. The number will change more when the subsidy intensity and R&D efficiency change. These results can help policymakers ascertain the optimal coverage of an R&D subsidy to promote EV diffusion based on actual conditions.

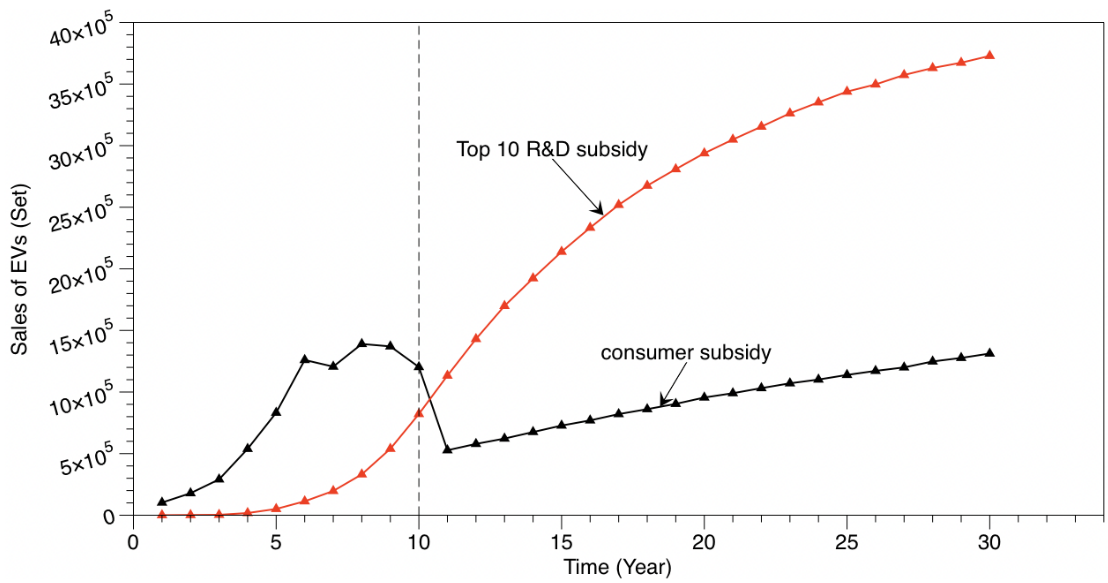
4.4 Discussion

Public subsidies play a crucially important role in supporting the cultivation of the EV industry. However, subsidies of different types exert different effects on EV diffusion. This chapter explores R&D subsidy and selective R&D subsidy effects on EV diffusion and development. Furthermore, results show that the Top 10 R&D subsidy scheme is more effective than other selective R&D subsidy schemes and automatic R&D subsidy schemes. Consumer subsidy exerts a better effect on EV diffusion than manufacturer subsidy or R&D subsidy. Which of the consumer subsidy and Top 10 R&D subsidy can better promote EV diffusion and development?

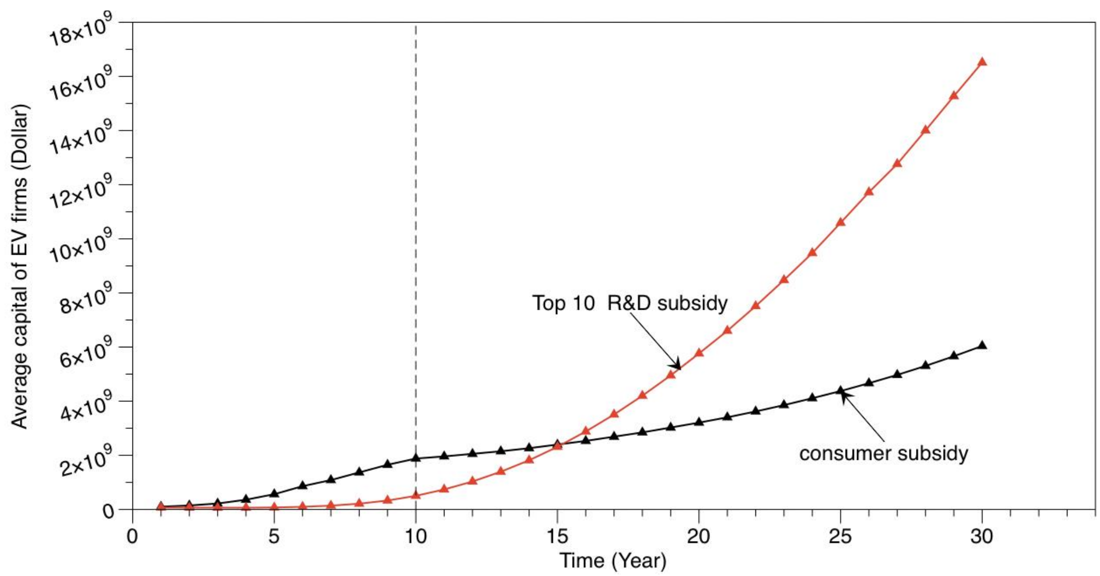
Comparisons of a consumer subsidy and a Top 10 R&D subsidy on EV diffusion and performance are presented in Fig. 23. The first finding is related to consumer subsidy effects in the short term: a consumer subsidy has a better initial effect on EV diffusion and development for EV firms than the Top 10 R&D subsidy. A consumer subsidy brings a considerable increase in product utility initially, which allows EVs to diffuse rapidly and which allows EV firms to accumulate large amounts of capital to expand production capacity. With the upfront benefit of the consumer subsidy, EV firms can quickly improve product performance and reduce costs. However, the market will face shock and turbulence when a consumer subsidy is withdrawn, which can slow product performance improvement and send many firms out of business.

The second finding is related to the Top 10 R&D subsidy effect in the long term: although the subsidy ends in 2022, EV sales continue to grow at a higher rate than the consumer subsidy. Because of the gradual increment in sales, EV firms accumulate huge amounts of capital. Furthermore, because of the accumulation of capital and sales, the Top 10 R&D subsidy scheme entails a higher product performance improvement rate and higher product performance. At the same time, better product performance will engender more sales. However, the performance improvement follows a logistic trend. In fact, the rate of improvement is slow in the initial stage, which engenders a low rate of EV sales.

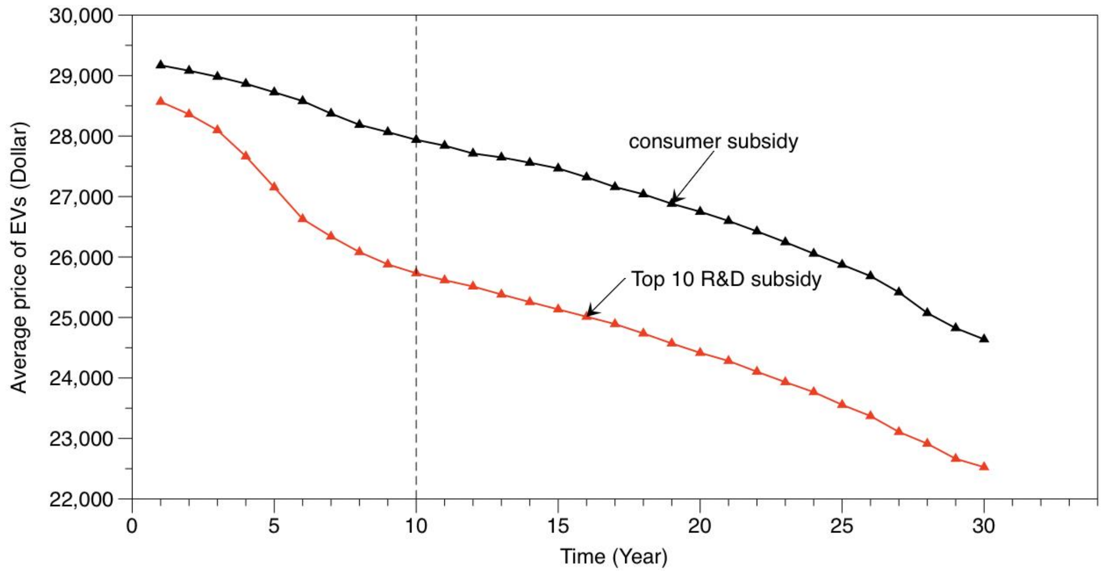
Overall, a consumer subsidy has a good upfront effect on EV diffusion, but it will engender market shock once it is withdrawn, whereas a Top 10 R&D subsidy has an excellent long-term effect, but the sales are subdued in the early stage. Can some combined subsidy policy bestow benefits of a consumer subsidy and of a Top 10 R&D subsidy?



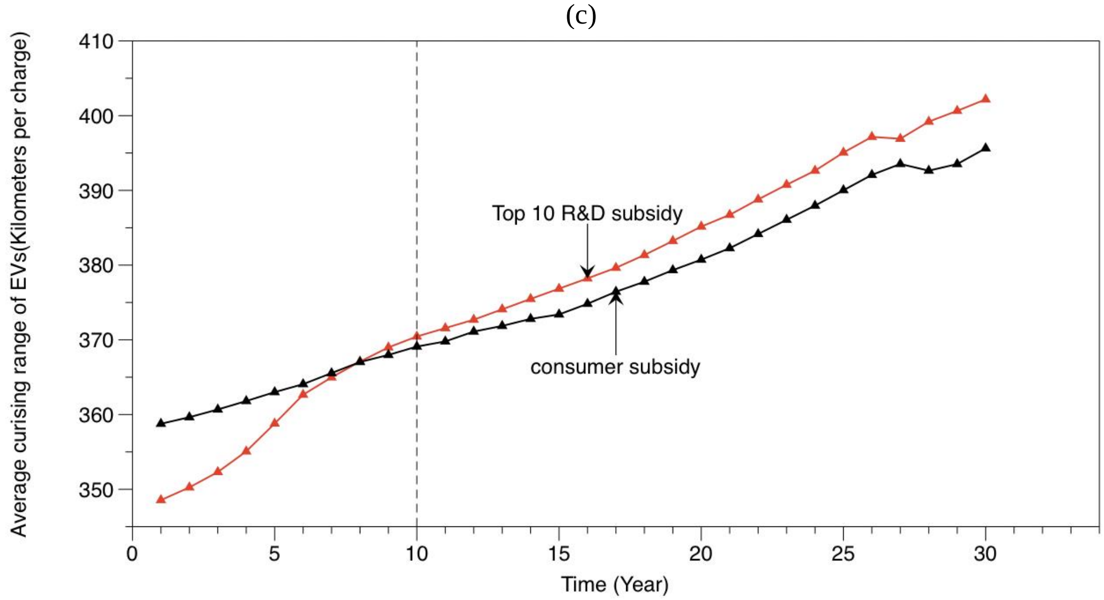
(a)



(b)



(c)



(d)

Fig. 23 Comparison of consumer subsidy and Top 10 R&D subsidies during 2013–2042.

Chapter 5
Optimal Subsidy Policy for EV Diffusion

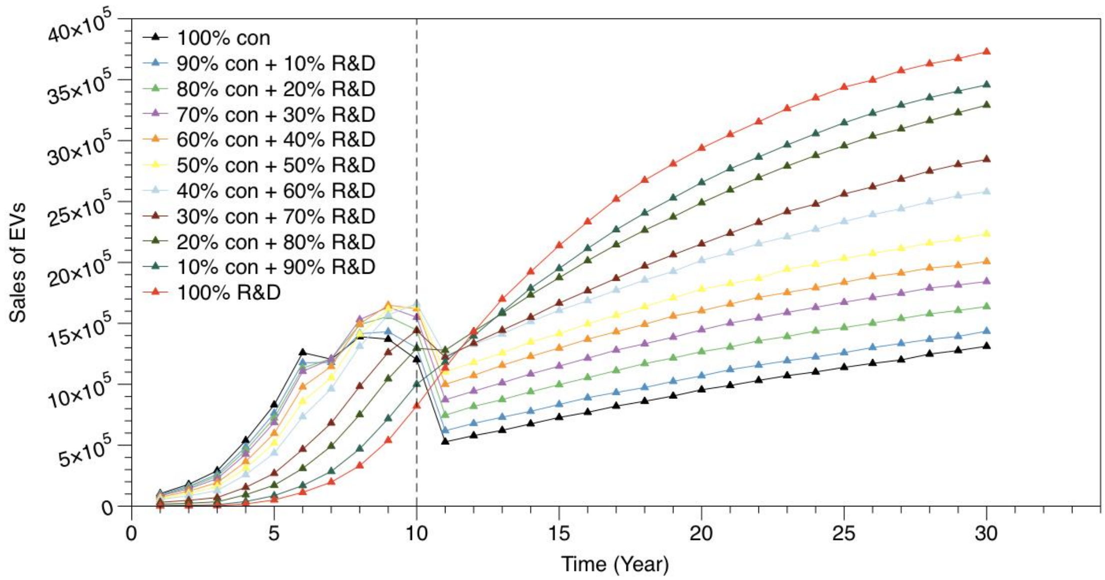
This chapter explores the optimal subsidy policy for EV diffusion. Consumer subsidies are pushed as the dominant policy in the Chinese EV market to promote EV diffusion and development. However, a consumer subsidy is apparently a double-edged sword, which can quickly increase the utility of products and thereby generate huge sales. Nevertheless, once they are abolished, they will bring huge shocks and turbulence to the market. We discussed the benefits and shortcomings of a selective R&D subsidy in chapter 4 and inferred the optimal coverage of a selective R&D subsidy based on the actual subsidy intensity and duration time. We expect to obtain an optimal subsidy policy by combining a consumer subsidy and a selective R&D subsidy. Here, we use two combinations: 1. allocate the subsidy to both the consumer subsidy and the Top 10 R&D subsidy; 2. apply the consumer subsidy and the Top 10 R&D subsidy at a specified time.

5.1 Subsidy policy combined with different subsidy distribution schemes

This section presents exploration of the effects on EV diffusion exerted by a subsidy policy combined with different subsidy distributions. The total amount of subsidy is inferred from total expenditures in consumer subsidies during 2013–2022, as described above. The subsidy distribution scheme stipulates that a portion of the subsidy be used to implement a consumer subsidy; the remaining portion is used to implement a Top 10 R&D subsidy.

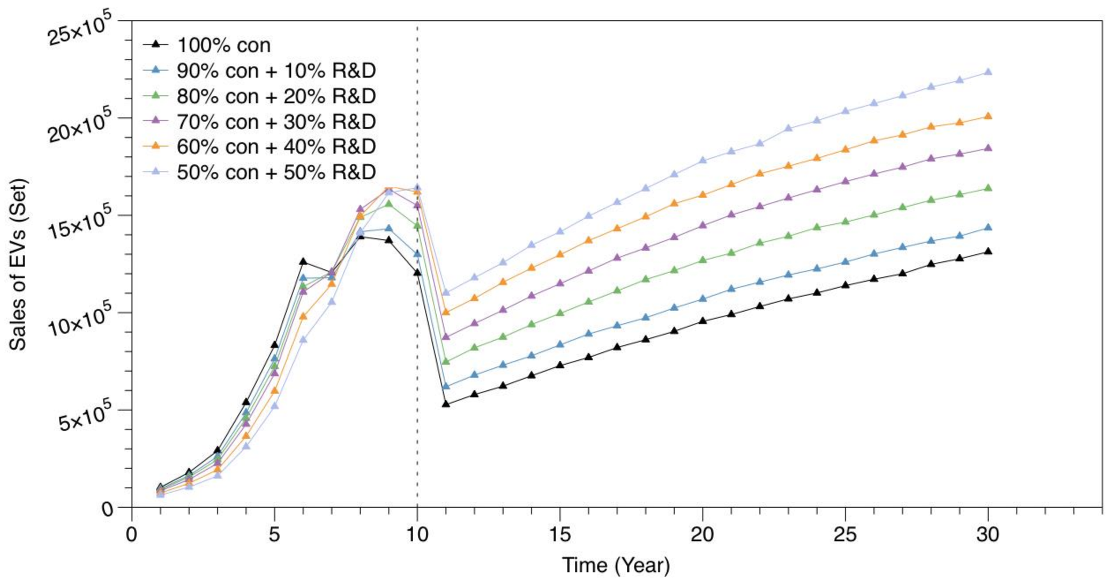
Effects of different subsidy distribution schemes on EV diffusion are presented in Fig. 24(a). Schemes with more subsidies allocated to a consumer subsidy are shown in Fig. 24(b). The schemes with more subsidy allocated to Top 10 R&D subsidy are presented in Fig. 24(c). For those schemes that allocate more subsidies to a consumer subsidy, the trend of EV sales is similar to the trend under a consumer subsidy. In the early stage, results show that a larger proportion of subsidy allocated to a consumer subsidy is associated with greater sales of EVs. However, because a subsidy granted for R&D activity can enhance product performance directly, increasing the granting of an R&D subsidy can lead to greater sales of EVs in a later stage.

The market shock caused by offending of a subsidy is evident from the results until the consumer subsidy accounts for only 20% of the total subsidy amount. Furthermore, the market turbulence progressively lessens as the distribution of a Top 10 R&D subsidy increases. That lessening is attributable to improved performance deriving from the R&D subsidy and narrowing of the gap separating the product performance and inflated utility by the huge price discount from the consumer subsidy. When considering the effects of combined policies on EV diffusion under this combination, one finds that the final generated EV sales are higher when the distribution ratio to consumer subsidies is smaller. This effect is apparently better when the Top 10 R&D subsidy accounts for 100% of the total amount of the subsidy.



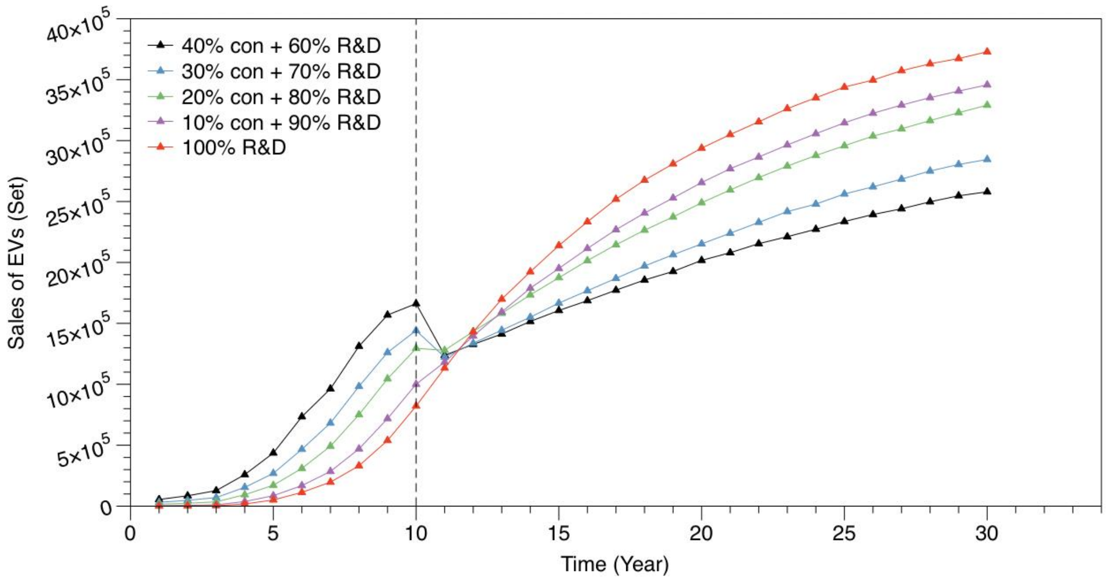
100% con
90% con + 10% R&D
80% con + 20% R&D
70% con + 30% R&D
60% con + 40% R&D
50% con + 50% R&D
40% con + 60% R&D
30% con + 70% R&D
20% con + 80% R&D
10% con + 90% R&D
100% R&D
Sales of EVs
Time (Year)

(a)



100% con
90% con + 10% R&D
80% con + 20% R&D
70% con + 30% R&D
60% con + 40% R&D
50% con + 50% R&D
Sales of EVs (Set)
Time (Year)

(b)



(c)

Fig. 24 Effects of different subsidy distribution schemes on EV diffusion.

In summary, the scheme of distributing subsidies to a consumer subsidy and a Top 10 R&D subsidy in different proportions is not very successful. Although the combined subsidy policy has a greater effect on EV diffusion in early stages than under the Top 10 R&D subsidy scheme, as the subsidy is removed, EV sales under the combined subsidy scheme still have a big gap with sales under a Top 10 R&D subsidy scheme.

5.2 Subsidy policy combined with different implementation timing

As described in this section, effects of a subsidy policy combined with different implementation timing on EV diffusion are explored. The subsidy duration time is inferred from the total implementation time of a consumer subsidy in China. We explore two implementation schemes: 1. apply a Top 10 R&D subsidy before a consumer subsidy; 2. apply a consumer subsidy before a Top 10 R&D subsidy.

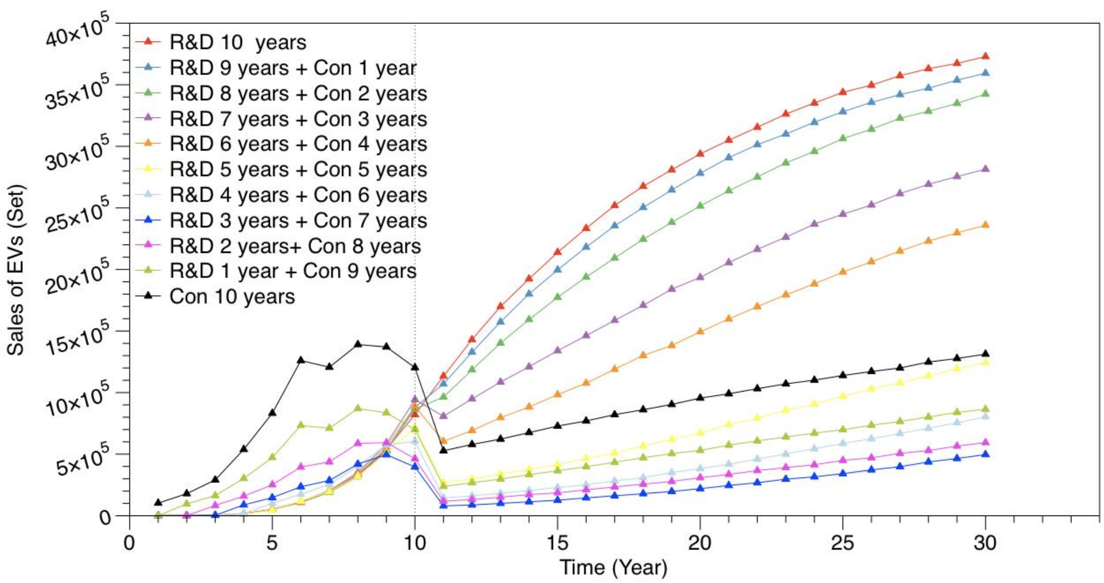
5.2.1 Top 10 R&D subsidy first

From a scheme for which a Top 10 R&D subsidy is applied first, the effects of applying the different duration times of Top 10 R&D subsidy on EV diffusion might be diverse. The total subsidy period is ten years. Effects of various combined subsidy schemes on EV diffusion are presented in Fig. 25.

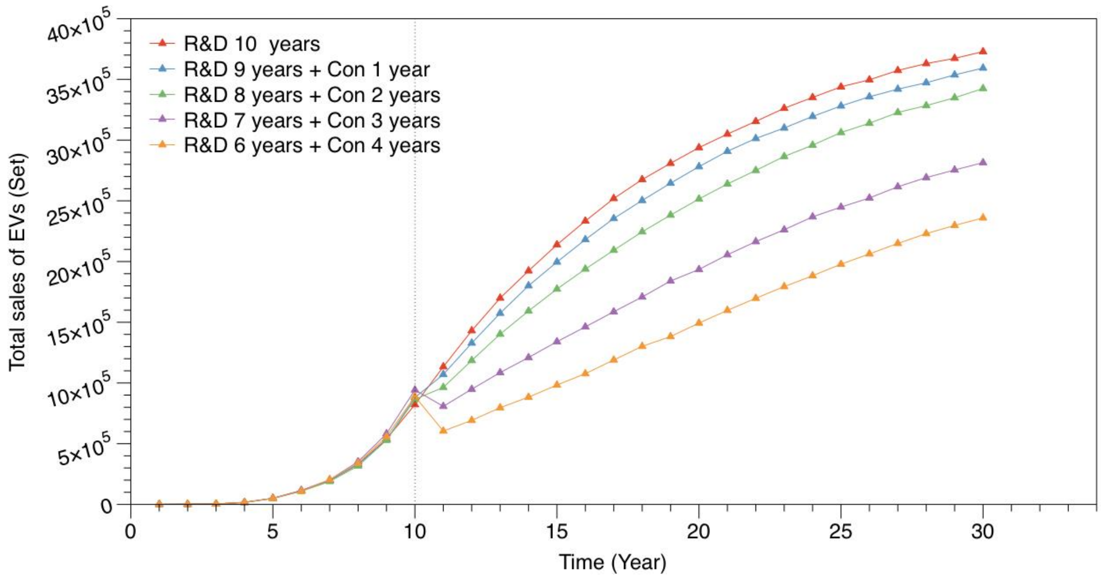
From Fig. 25(b), one finds that when the consumer subsidy duration becomes longer in the later stage, a reduction in EV sales will occur because a shorter R&D subsidy duration does not generate more firms with high-performance products. However, with participation of a consumer subsidy, the huge increase in EV sales does not occur in the early diffusion stage of EVs brought by consumer subsidy. Therefore, allowing the consumer subsidy to be granted in the later stage is unsuccessful. It does not take advantage of the rapid growth in sales of EVs that a consumer subsidy can bring in the short term because the amount of subsidy in the late stages is reduced gradually, decreasing the consumer purchase subsidy. However, with the R&D subsidy serving to increase the performance improvement, some EV firms can lead the way in the vehicle market with no need for utility improvement brought by the price discount.

A combined subsidy scheme with a longer duration of a consumer subsidy and a shorter R&D subsidy duration is presented in Fig. 25(c). Generally, the effect of the implementation of the Top 10 R&D subsidy with a shorter duration in the early stage does not produce better results for EV diffusion than a consumer subsidy. This result is obtained because the performance improvement follows a logistic trend: the rate of improvement is prolonged in the initial stage. The shorter duration of R&D subsidy investment will lengthen the initial technology accumulation time. Another finding is that a big gap separates the consumer subsidy scheme and the combined subsidy scheme of nine years of consumer subsidy. Furthermore, a big gap separates the combined subsidy scheme with nine years of consumer subsidy and the combined subsidy scheme with eight years of consumer subsidy. These huge gaps illustrate the importance of a consumer subsidy during the first two years of EV diffusion.

Overall, it is not wise to implement a consumer subsidy in the late stage, which will not take advantage of consumer subsidy and make the initial technology accumulation time much longer because the duration of the Top 10 R&D subsidy shortens in the later stage. Results also show that a consumer subsidy plays a more important role than the Top 10 R&D subsidy during the first two years of EV diffusion.



(a)



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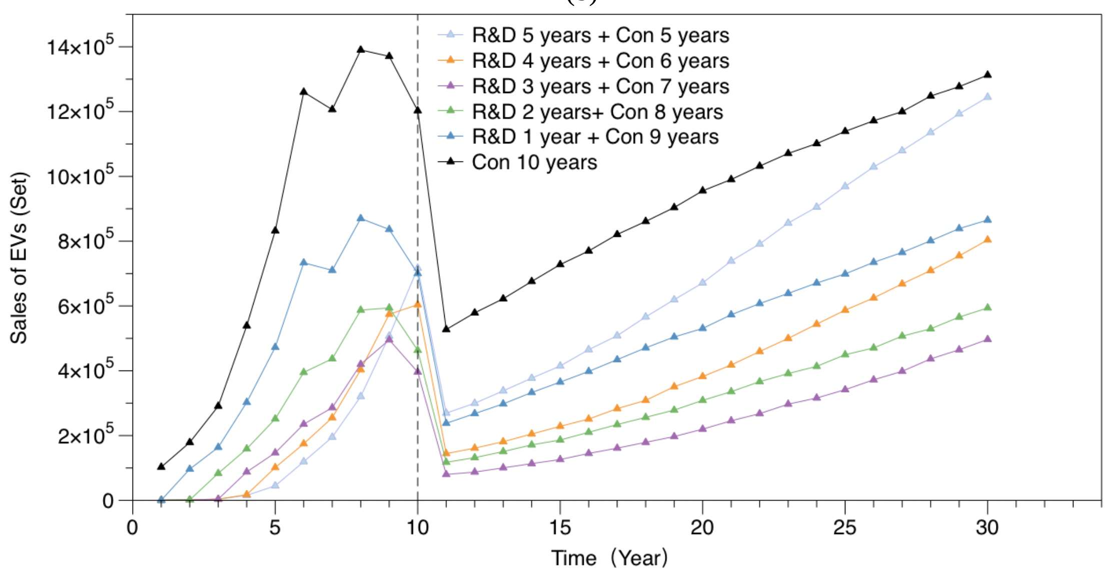


(c)

Fig. 25 Effects on EV diffusion of different combined subsidy schemes for the Top 10 R&D subsidy and consumer subsidy.

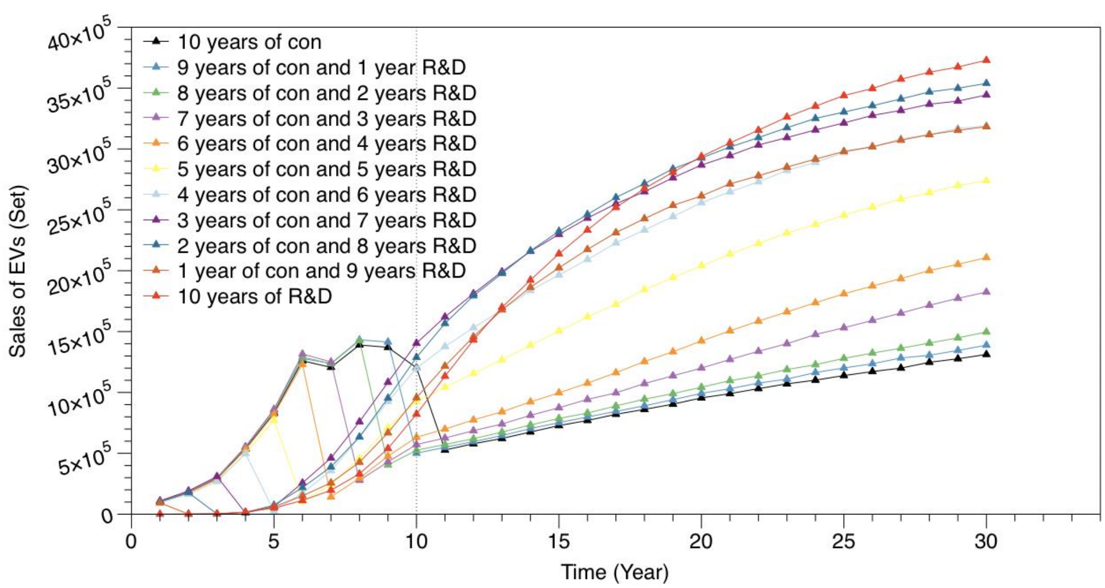
5.2.2 Consumer subsidy first

This section presents an exploration of the effects on EV diffusion of instituting a subsidy policy combined with a consumer subsidy first scheme. As described above, consumer subsidies exert strong effects during the first two years of EV diffusion. A Top 10 R&D subsidy requires a longer duration to help EV firms get through the technology accumulation period faster. Therefore, we expect to achieve an optimal combination of subsidy policies based on these experiences.

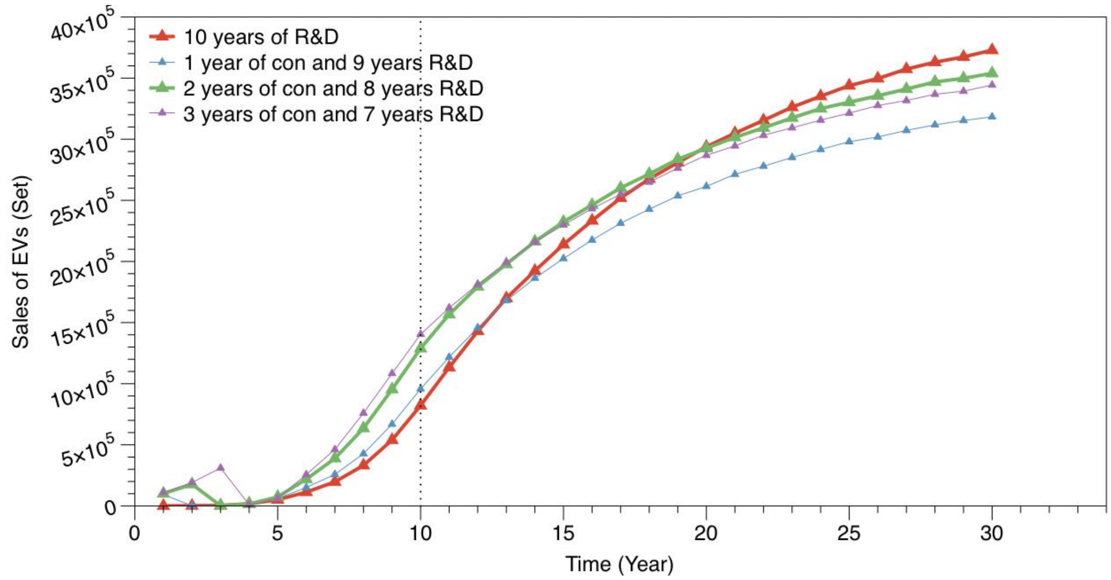
From Fig. 26(a), it is apparent that, because of the consumer subsidy implementation, EV sales grew rapidly during the early stage of EV diffusion. Subsequently, implementation of the Top 10 R&D subsidy led to greater EV sales than those achieved under the consumer subsidy scheme. Furthermore, with increasing duration of the consumer subsidy, the sales trend will closely resemble that of the consumer subsidy scheme. With increasing duration of the Top 10 R&D subsidy, the sales curve trend will closely resemble that of the Top 10 R&D subsidy scheme.

From Fig. 26(b), one finds that a two-year consumer subsidy and an eight-year Top 10 R&D subsidy scheme ('2+8' scheme) achieves greater sales than under the Top 10 R&D subsidy scheme by 2032. Subsequently, the policy can also achieve the level of sales under the Top 10 R&D subsidy scheme. When the consumer subsidy lasts for only one year, it is apparent that the sales of EVs under the '1+9' scheme are much lower than those under the '2+8' scheme, which indicates that the consumer subsidy will be more effective than the Top 10 R&D subsidy scheme in 2014. Furthermore, when the consumer subsidy continues for three years, although it will be slightly ahead of the sales under the '2+8' scheme at the early stage of EV diffusion, the final sales will be lower than those achieved under the '2+8' scheme, which indicates that in 2015, the Top 10 R&D subsidy scheme is more effective than the consumer subsidy scheme. Overall, the '2+8' scheme shows a good promotional effect on EV diffusion, echoing the conclusion presented in the preceding section that the consumer subsidy yields better results in the first two years.

Generally, based on simulation results, we inferred two years as the optimal duration for a consumer subsidy. The '2+8' scheme presents both the benefits of a consumer subsidy to promote EV sales initially and the benefits of the Top 10 R&D subsidy scheme to increase later EV sales. Factors that determine EV sales are product performance and the capital level of the firm. The distribution of capital and cruising range under the '2+8' scheme and Top 10 R&D subsidy scheme are discussed next.



(a)



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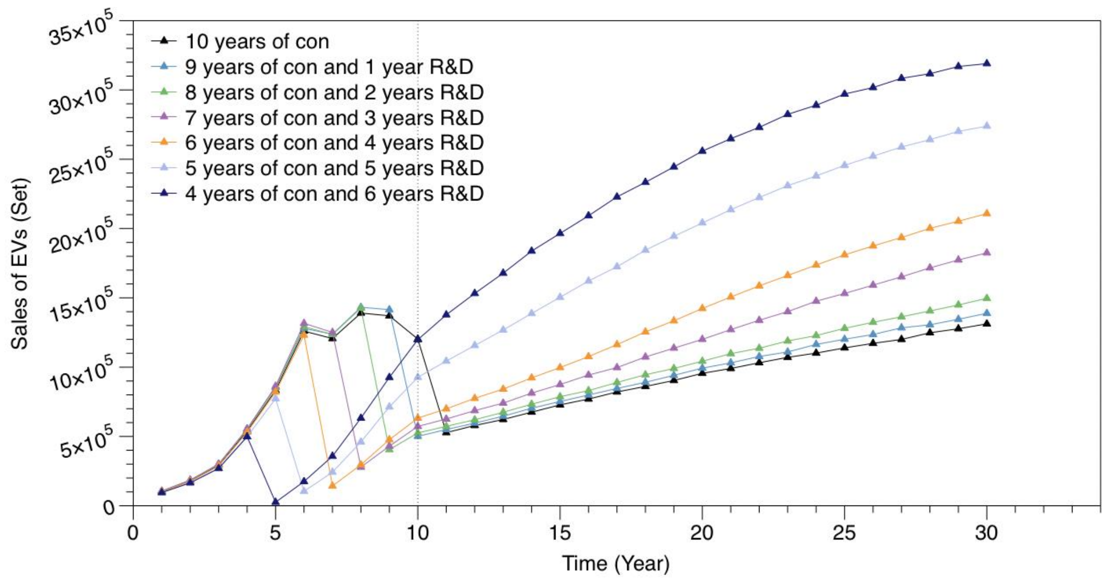
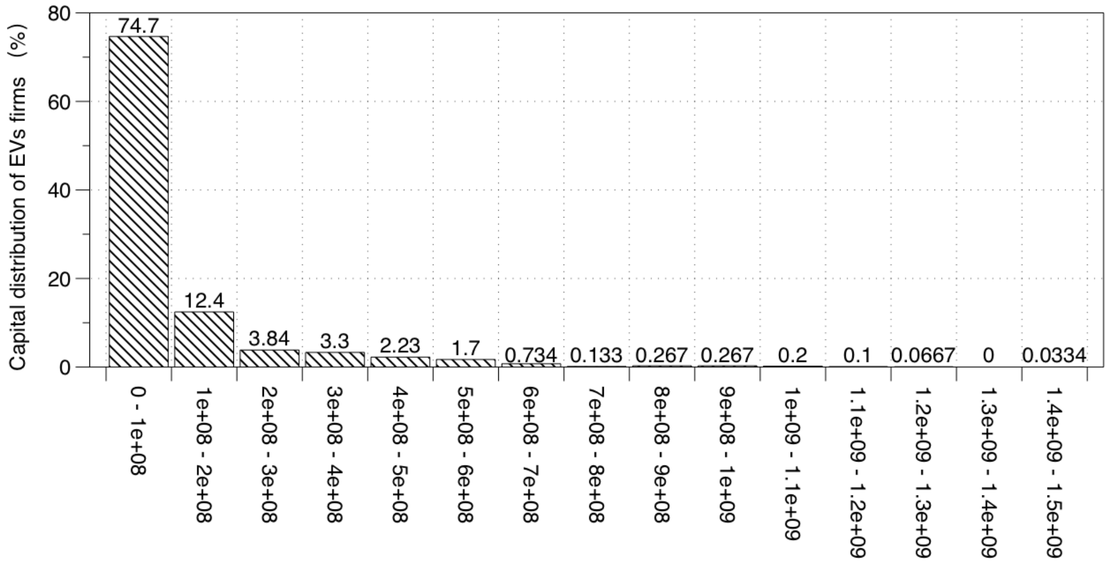


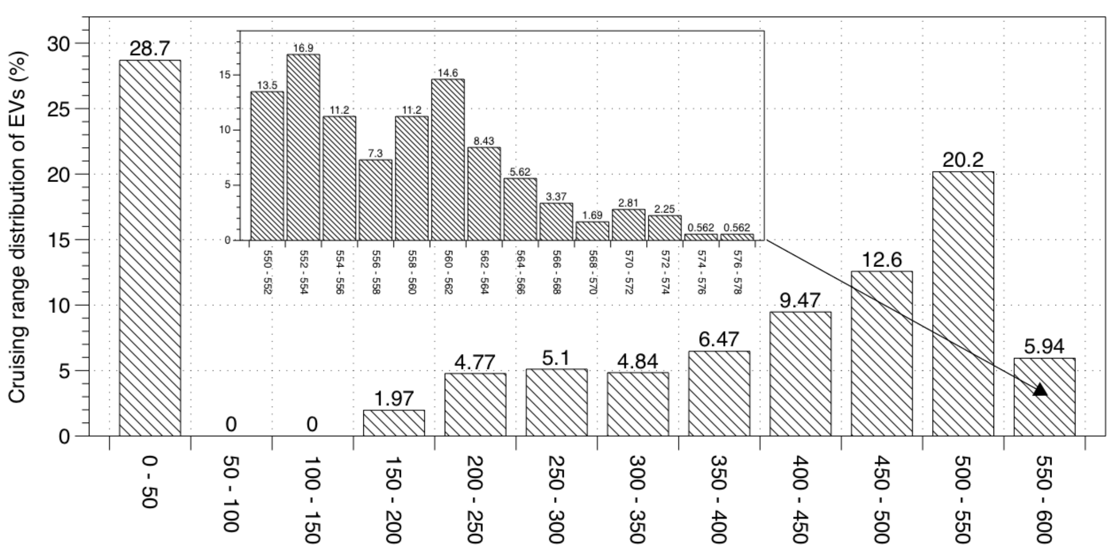
(c)

Fig. 26 Effects on EV diffusion from different subsidy schemes combining a consumer subsidy and a Top 10 R&D subsidy.

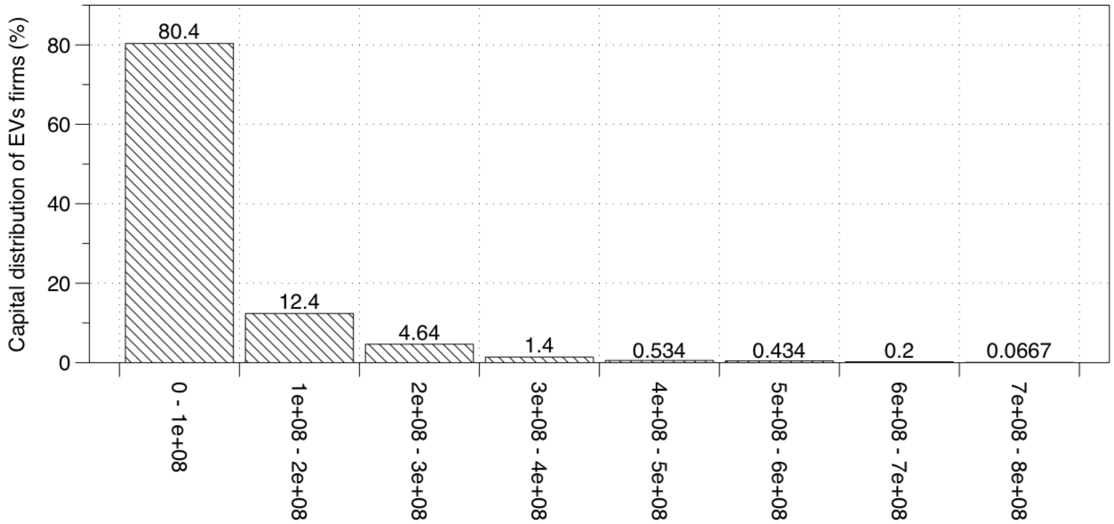
By comparing the capital distribution of EV firms under two subsidy schemes in 2014 (T=2) from Fig. 27(a) and Fig. 27(c), it is apparent that EV firms accumulate more capital in the first two years because of the implementation of a consumer subsidy. That subsidy leads to higher sales volume initially. Moreover, high-capital firms already sprout in the early stage under the '2+8' subsidy scheme. As described above, higher capital levels will cause firms to invest more in the R&D process, which will engender faster product performance improvements. Figures 27(b) and (c) present the distribution of the cruising range in these two subsidy schemes in 2014. Comparison to the Top 10 R&D subsidy scheme shows that the EV firms with a cruising range in the interval of [550, 600] are slightly fewer in the '2+8' subsidy scheme. However, exploration of the distribution of firms within this interval reveals that, under the '2+8' subsidy scheme, firms are more distributed in the interval [550, 544] and [574, 578] than in the Top 10 R&D scheme. That result indicates EV firms as more polarized. Actually, EV firms with high capital levels and high-performance products are more likely to emerge in the '2+8' scheme. Overall, the rapid growth bonus period brought by two years of consumer subsidy has allowed a small group of EV firms to move to a leading position gradually and to accumulate large amounts of capital, which will also allow these firms to remain in the leading position, will put pressure on the survival of other EV firms. This bonus period cannot be too long because it will engender an inability of other firms to grow and develop. Furthermore, a too-short term will produce a small group of firms that cannot accumulate capital or develop quickly. It therefore cannot improve sales promptly.



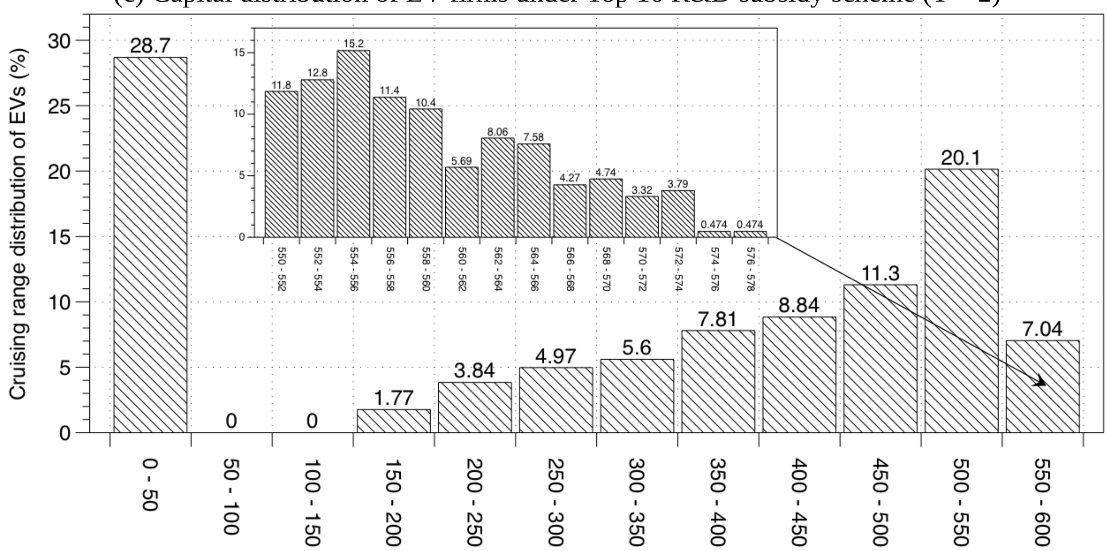
(a) Capital distribution of EV firms under '2+8' subsidy scheme (T = 2)



(b) Cruising range distribution of EVs under '2+8' subsidy scheme (T = 2)



(c) Capital distribution of EV firms under Top 10 R&D subsidy scheme (T = 2)



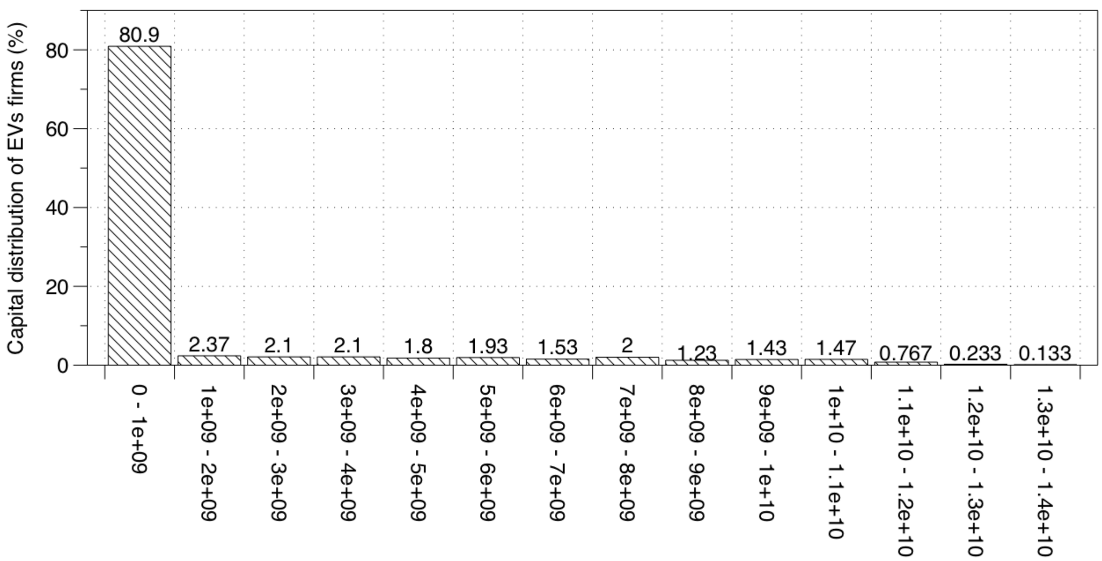
(d) Cruising range distribution of EVs under the Top 10 R&D subsidy scheme (T = 2)

Fig. 27 Capital distribution of EV firms and the EV cruising range distribution under two subsidy schemes (T = 2).

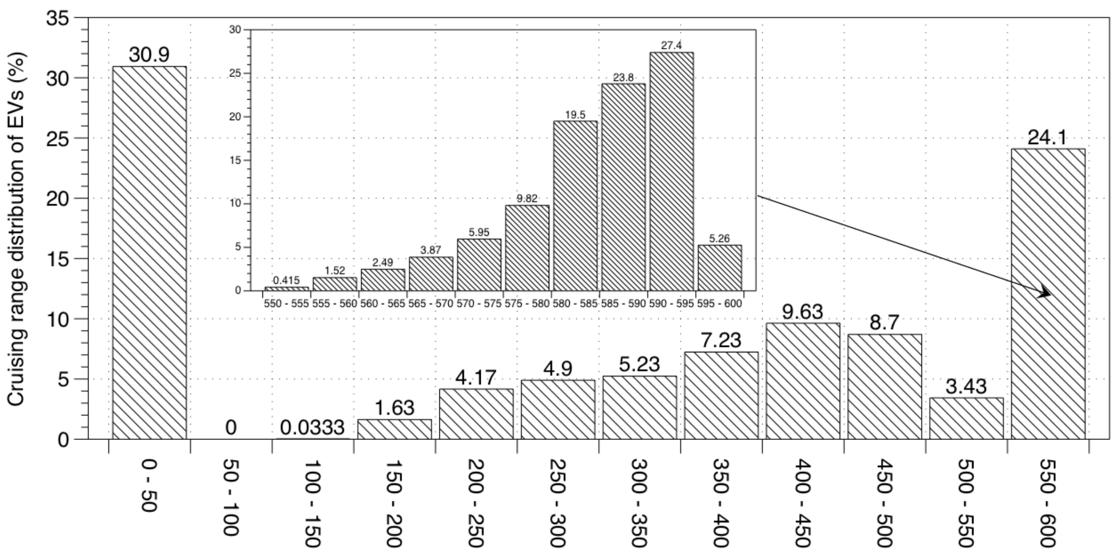
In 2022 (T = 10), sales under the '2+8' subsidy scheme can be expected to exceed the sales under the Top 10 R&D subsidy scheme. Because of growth in EV sales, the firm's capital continues to grow under these two subsidy schemes. From Figs. 28(a) and (c), it is readily apparent that, in the '2+8' subsidy scheme, the overall capital level of EV firms will be higher than in the Top 10 R&D subsidy scheme. More firms will gather in the high capital level than in the Top 10 R&D subsidy scheme. This is true because EV sales are greater under the '2+8' scheme than under the Top 10 R&D subsidy scheme, which allows the firm to accumulate greater amounts of capital. In addition, EV firms in the leading position will account for more orders, thereby enabling development of the capital level and product performance to a higher level.

Figures 28(b) and (c) show the cruising range distributions under these two subsidy schemes. Generally, in the Top 10 R&D subsidy scheme, more firms' products are distributed in the range of [550,600] than under the '2+8' subsidy scheme. When considering the distribution of firms in these two subsidy schemes on the cruising range interval [550, 600], we found more firms' products distributed in the high-performance interval [590, 600] under the ‘2+8’ subsidy scheme. These firms with high-performance products can generate higher EV sales, leading to higher sales in the ‘2+8’ scheme than under the Top 10 R&D subsidy scheme at T = 10. However, this also constitutes a hidden danger that the number of firms with medium performance levels [350, 450] is greater under the ‘2+8’ subsidy scheme. These firms might be bankrupt and might thereafter exit the market in the future because of a lack of orders.

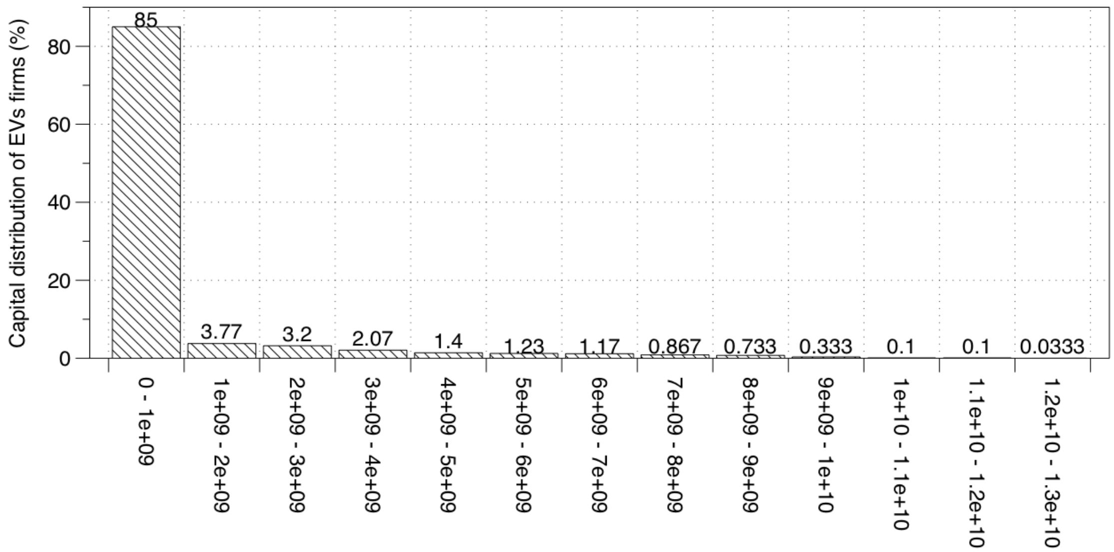
During 2014–2022, we observed growth of capital under both subsidy schemes, but in the ‘2+8’ scheme, more firms with high capital levels and high-performance products emerged. These firms are expected to have a large production capacity and more R&D investment to remain in the leading position, which leaves more pressure on the growth of middle-level firms. In the Top 10 R&D scheme, middle-level firms are apparently under less pressure to survive. Moreover, they have more space for growth.



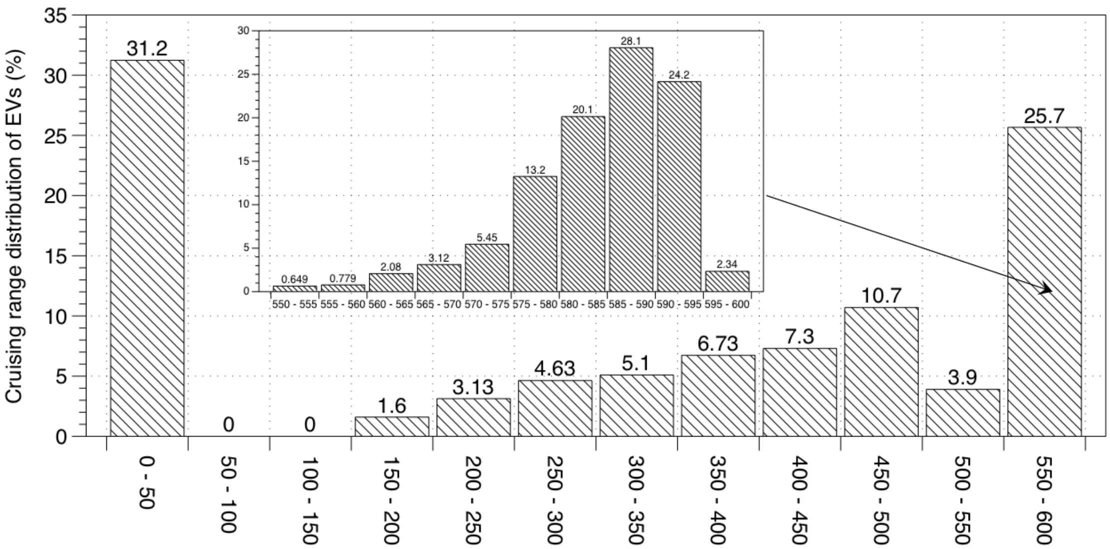
(a) Capital distribution of EV firms under '2+8' subsidy scheme (T = 10)



(b) Cruising range distribution of EVs under '2+8' subsidy scheme (T = 10)



(c) Capital distribution of EV firms under Top 10 R&D subsidy scheme (T = 10)



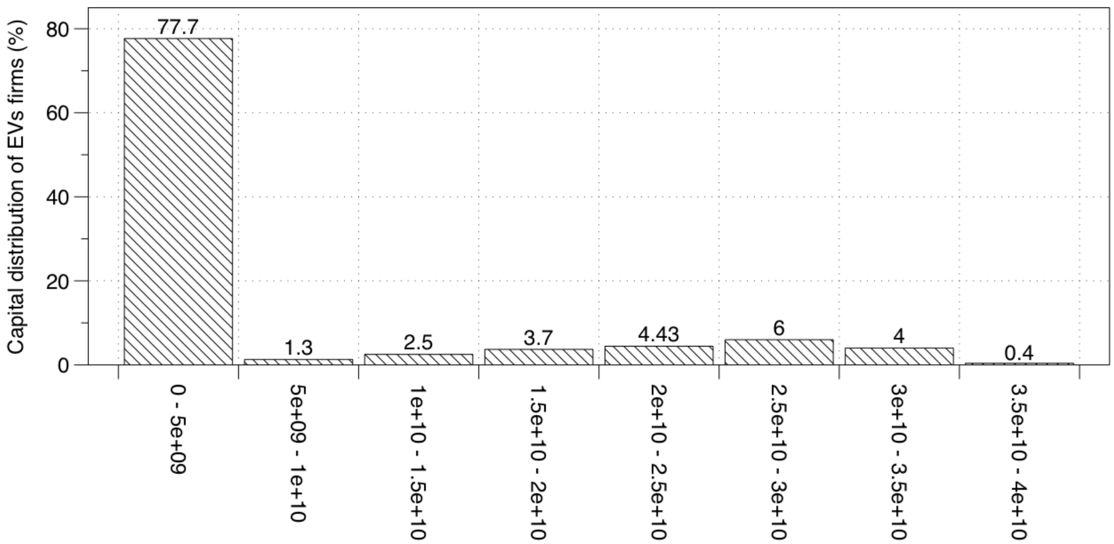
(d) Cruising range distribution of EVs under Top 10 R&D subsidy scheme (T = 10)

Fig. 28 Capital distribution of EV firms and the EV cruising range distribution under two subsidy schemes (T = 10).

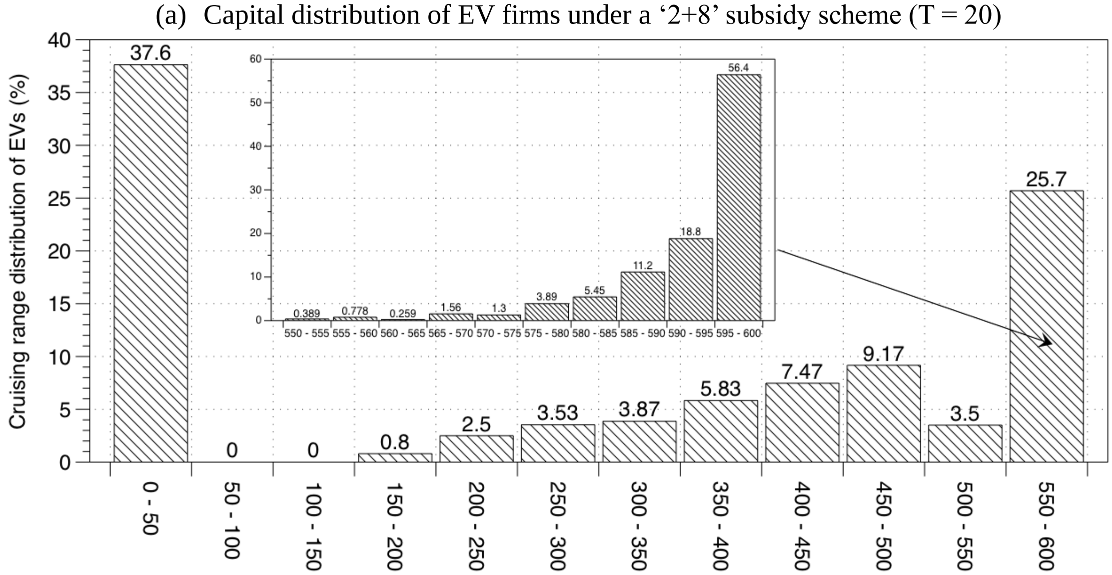
The figures show that in 2032, the EV sales are almost equal under both subsidy schemes. From Figs. 28(a) and (c), the capital levels of firms are still higher under the ‘2+8’ subsidy scheme than under the Top 10 subsidy scheme. Furthermore, firms with high capital levels in the ‘2+8’ subsidy scheme are more than under the Top 10 subsidy scheme because firms can obtain more orders and thus accumulate more capital under the ‘2+8’ subsidy scheme.

Figures 28(b) and (c) show that firms are gradually improving product performance; more firms have products with cruising ranges of [595, 600]. However, compared to the Top 10 subsidy scheme, more firms than under the ‘2+8’ subsidy scheme will have products with cruising range of [595, 600], but of those in the range of [590, 595], more firms that under the Top 10 subsidy scheme will be of this range. This finding also leads to equal sales under both subsidy schemes. At that time, the Top 10 subsidy scheme is more promising because more firms have products in the range of [575, 595]. These firms are hopeful of generating more sales by upgrading their products to a higher level of performance in the future.

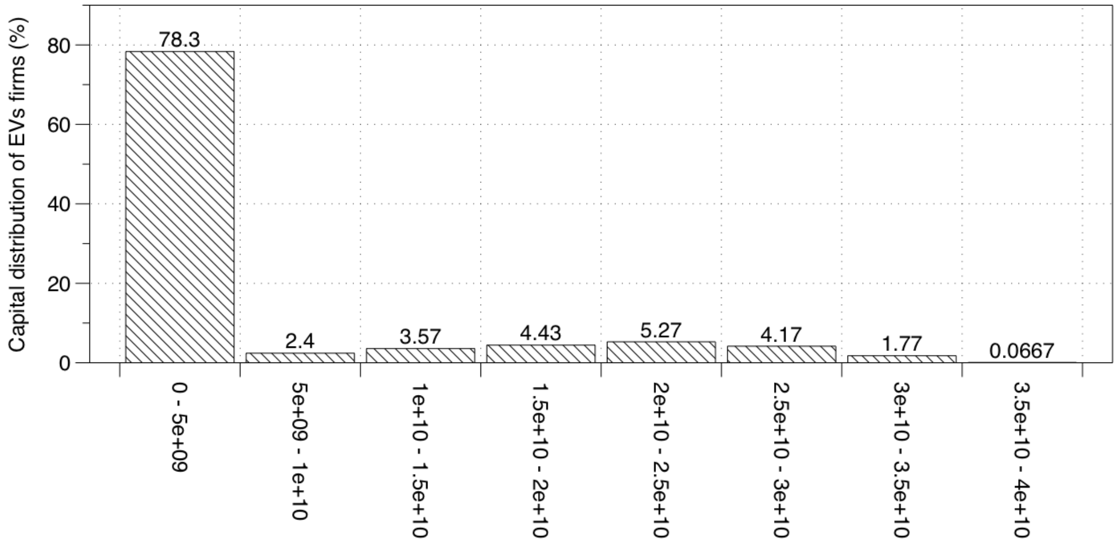
During 2022–2032, when under the '2+8' scheme, more firms upgrade their products to the frontier level because of higher sales and higher R&D investment. However, too many firms with high capital and with high-performance products can hinder the development of other firms in the market, thereby making more firms go bankrupt and eventually leading to a lack of development potential.



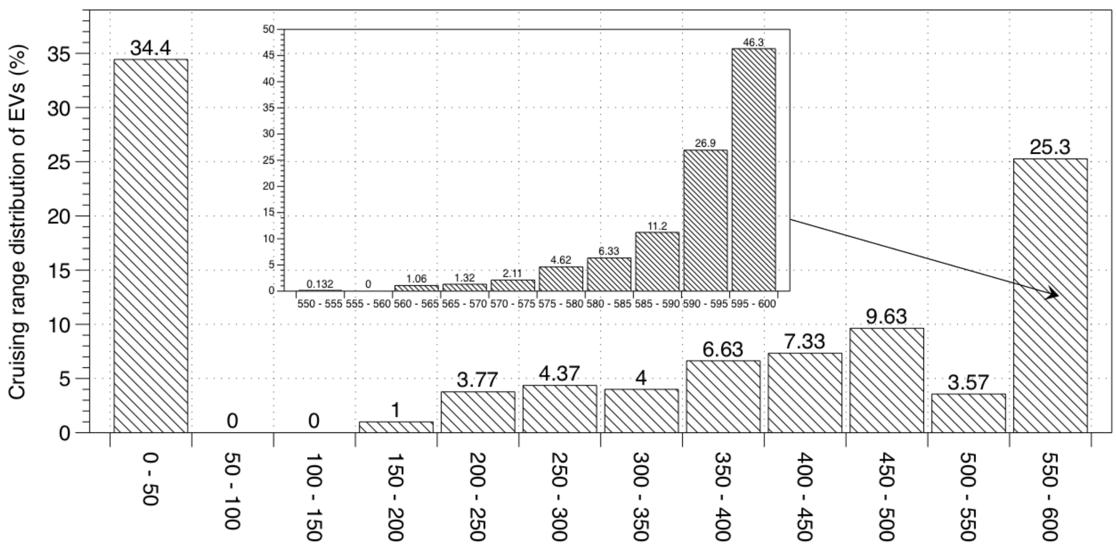
(a) Capital distribution of EV firms under a '2+8' subsidy scheme (T = 20)



(b) Cruising range distribution of EVs under '2+8' subsidy scheme (T = 20)



(c) Capital distribution of EV firms under Top 10 R&D subsidy scheme (T = 20)



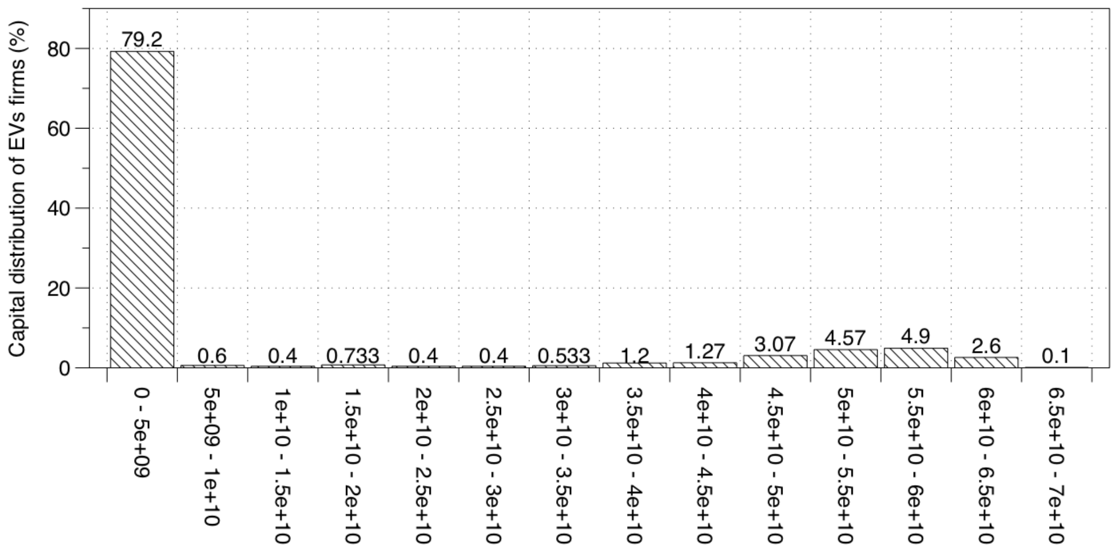
(d) Cruising range distribution of EVs under Top 10 R&D subsidy scheme (T = 20)

Fig. 29 Capital distribution of EV firms and EV cruising range distributions under two subsidy schemes (T = 20).

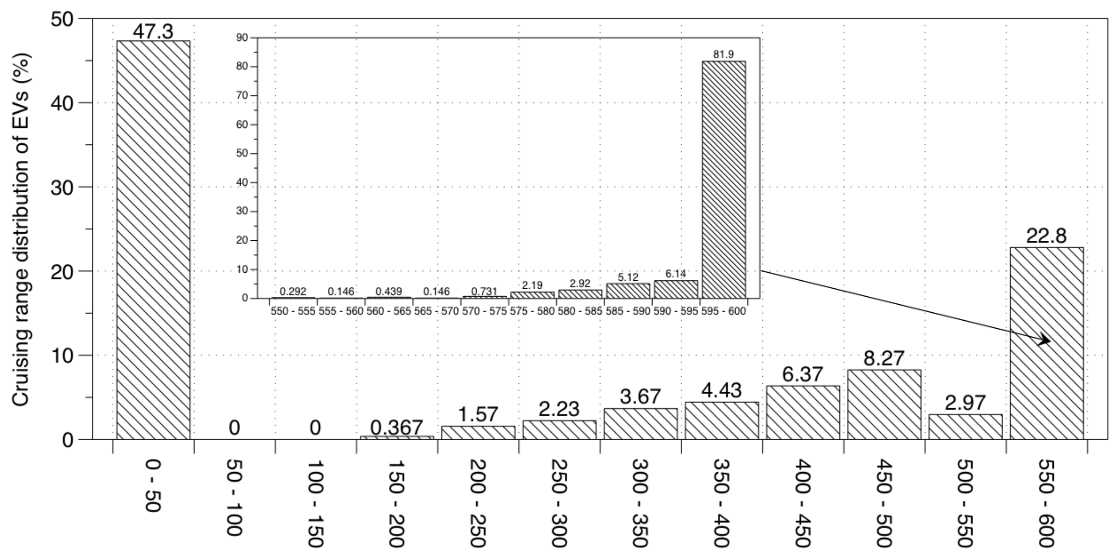
In 2042 (T = 30), sales of EVs under the Top 10 R&D subsidy scheme can be expected to be greater than under the ‘2+8’ subsidy scheme. Figures 30(a) and (c) show that the capital level of EV firms under the ‘2+8’ subsidy scheme is higher than under the Top 10 R&D subsidy scheme. This higher capital level prevails because EV firms have greater early capital accumulation and because there is no large sales volume gap between the two schemes, making the capital of firms under the ‘2+8’ subsidy scheme always larger than under the Top 10 R&D subsidy scheme.

The distribution of EV cruising ranges under these two subsidy schemes is presented in Fig. 30(b) and (d). Results show more firms’ product performance distributed in [595, 600] under the Top 10 R&D subsidy scheme. Furthermore, more firms exit the market under the ‘2+8’ scheme. These reasons led to sales being reversed in the ‘2+8’ subsidy scheme.

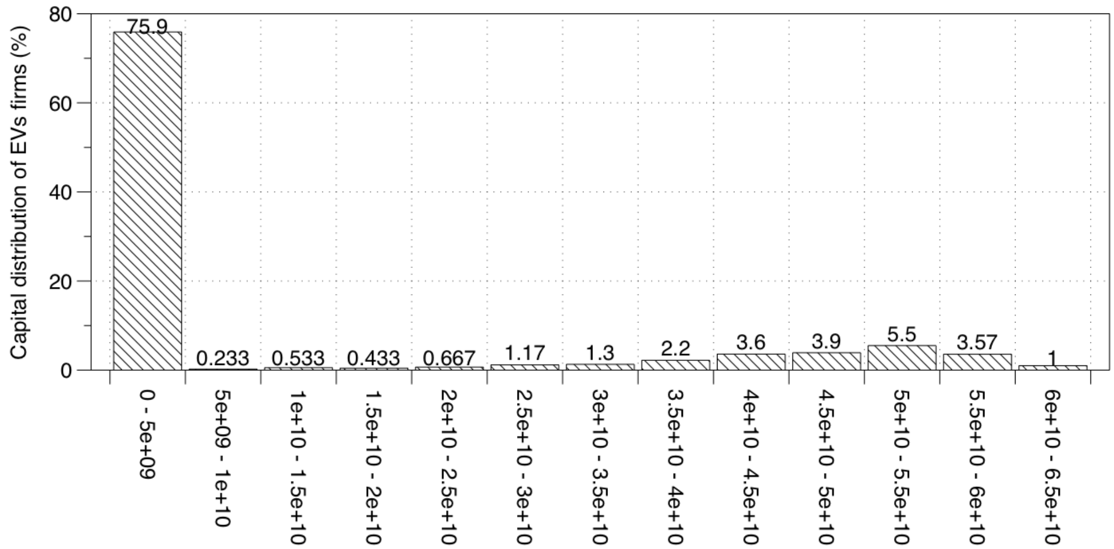
However, sale reversal by the Top 10 R&D subsidy scheme is a predictable outcome. In 2032(T = 20), the growth potential in the ‘2+8’ scheme is insufficient, probably because of the fact that too many firms with high capital and high-performance products monopolize the market, making it difficult for other firms to catch up. The dilemma in obtaining orders and improving product performance led to the eventual bankruptcy of these firms. Consequently, no more firms can improve their products to the frontier level; no more sales can be created.



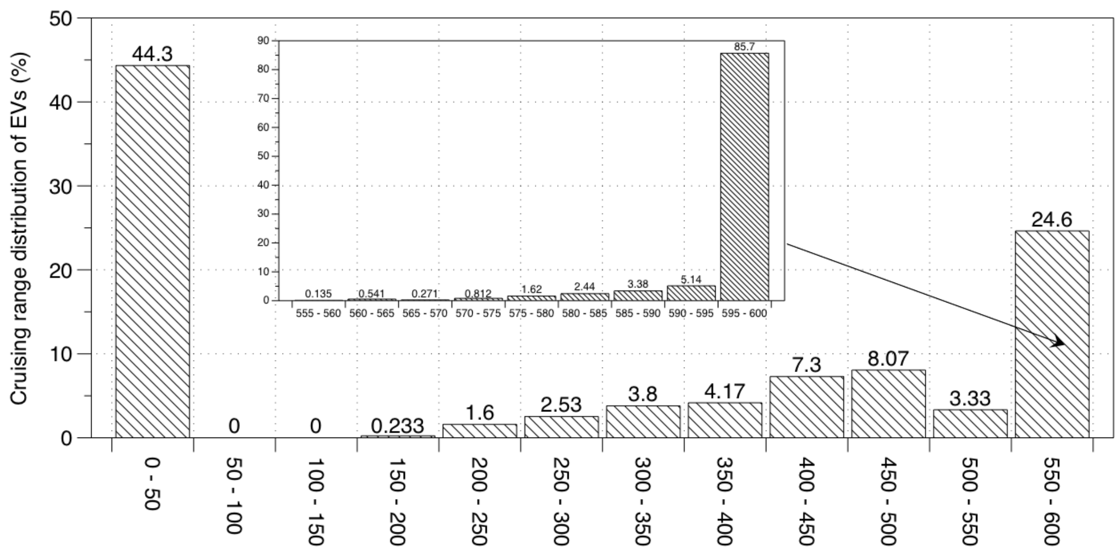
(a) Capital distribution of EV firms under ‘2+8’ subsidy scheme (T = 30)



(b) Cruising range distribution of EVs under ‘2+8’ subsidy scheme (T = 30)



(c) Capital distribution of EV firms under Top 10 R&D subsidy scheme (T = 30)



(d) Cruising range distribution of EVs under Top 10 R&D subsidy scheme (T = 30)

Fig. 30 Capital distribution of EV firms and EVs cruising range distribution under two subsidy schemes (T = 30).

Furthermore, the correspondence between the cruising range of EVs and EV firm capital shows that firms with large amounts of capital will produce high-performance products, whereas firms with product performance that is slightly behind the frontier level will only have a lower level of capital. Figure 31 shows that many firms have product performance concentrated on [400, 500]. These firms eventually exit the market because of their lower capital level and product performance, which cannot compete with those of the oligopolies.

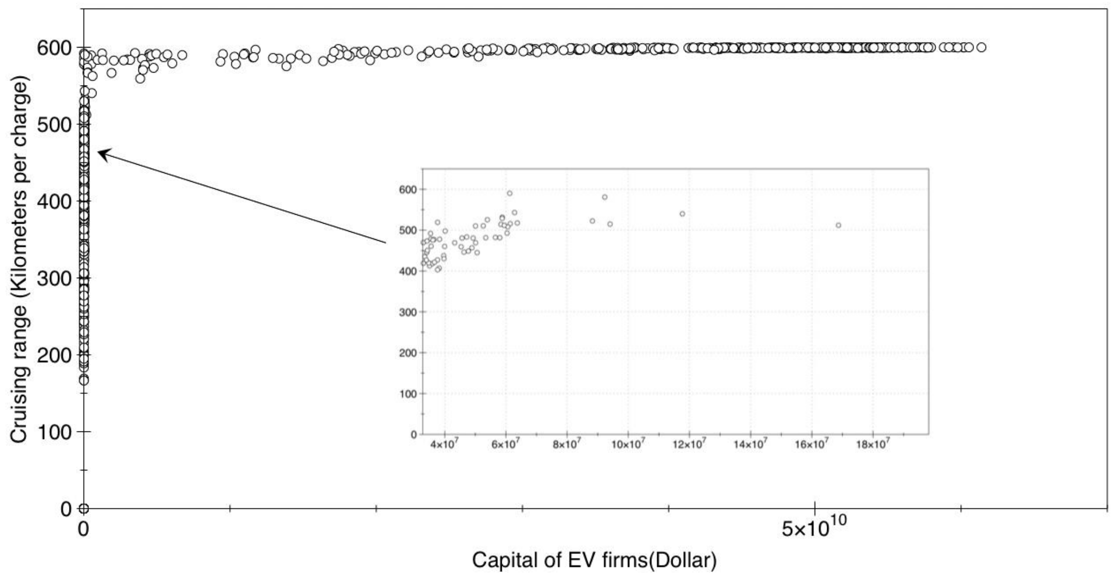


Fig. 31 Relation between capital and cruising range under ‘2+8’ subsidy scheme (T= 30).

Generally, the ‘2+8’ subsidy scheme created a bonus period through an initial consumer subsidy that allowed a small number of firms to accumulate large amounts of capital, increasing production capacity and R&D investment, and leading firms with high capital levels and high-performance products to sprout earlier. The emergence of these firms can bring greater orders and sales to the market. At the same time, these firms pose a threat to the survival and growth of other firms, limiting the market development potential in the middle period. When the firm’s non-profit period is adjusted to 15 years, as Fig. 32 shows, the ‘2+8’ subsidy scheme will maintain strong growth potential to grow in the middle period, with sales consistently ahead of the Top 10 R&D subsidy scheme. This finding also confirms that, under the ‘2+8’ subsidy scheme, firms will be adversely affected by greater pressure from oligopolistic firms.

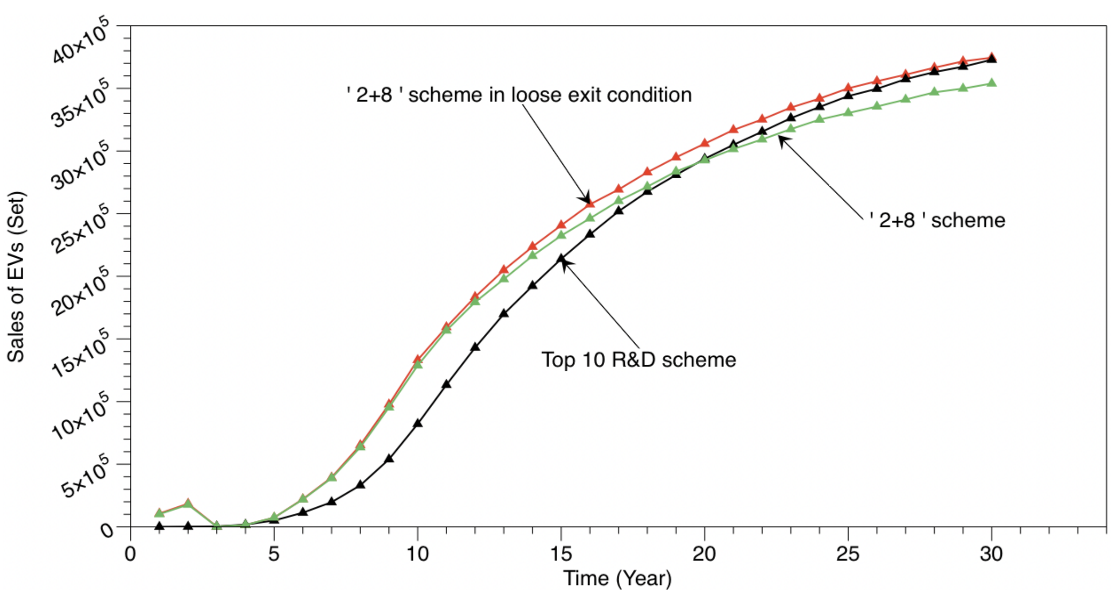


Fig. 32 Sales of EVs under different subsidy schemes during 2013–2042.

In summary, this chapter presented exploration of optimal subsidy policy through different combinations. Ultimately, results show that the '2+8' subsidy scheme had a good effect on promoting EV diffusion. By discussing the diffusion effects of the '2+8' subsidy scheme and the Top 10 R&D subsidy scheme in different periods, it is apparent that the '2+8' subsidy scheme stimulates the emergence of oligopolies in the early stage. In the middle stage of diffusion, the firms undergo pressure from oligopolies, which will lead firms to bankruptcy, thereby rendering the market development potential insufficient. This finding suggests that, when implementing the '2+8' subsidy policy, the government must devote more attention to those firms which offer the promise of improving the performance of their products and their growth potential. More lenient lending and other incentives can be offered to these firms. In addition, a disincentive must apply for oligarchic expansion.

Chapter 6 Conclusions and Future Work

6.1 Conclusions

Public subsidies play a crucially important role in supporting cultivation of the EV industry. Various empirical studies have evaluated effects of consumer subsidy incentives in China. Nevertheless, the different effects of consumer subsidies, R&D subsidies, and selective R&D subsidy have not been clarified.

This study mainly compares the respective effects of a consumer subsidy, an R&D subsidy and a selective R&D subsidy on the diffusion and development of the EV industry and then explores an optimal subsidy policy for EV diffusion. To compare different effects of these subsidy schemes, an agent-based model was constructed considering the heterogeneous decisions and behaviors of consumers and firms. The EV diffusion dynamics during 2013–2042 are simulated. The results were inferred as described below.

First, we forecast the trend of EV sales under three consumer subsidy withdrawal scenarios: loose subsidy policy, moderately strict subsidy policy, and strict subsidy policy. Sales reflect a continuous growth trend under the loose consumer subsidy policy, but with heavy financial burdens on the government. Strict and moderately strict consumer subsidy policies are expected to produce EV sales that are decreasing slowly and then increasing slowly, but the final sales level cannot reach the earlier highest level. Although consumer subsidies stimulated sales growth in the early stage, with abolition of consumer subsidies, the price discount advantage brought by the subsidies will not exist, which will engender huge market shock and turbulence. It is not conducive to long-term development and diffusion of EVs.

Second, after comparing the respective effects of a consumer subsidy, R&D subsidies, and a selective R&D subsidy, the Top 10 R&D subsidy was found to be the effective. We also explore the optimal coverage of R&D subsidy when the number of firms, R&D efficiency, and subsidy intensity change. Fundamentally, a consumer subsidy has a good upfront effect on EV diffusion, but it will engender market shock once withdrawn, whereas a Top 10 R&D subsidy has excellent long-term effects, but with sales subdued in the early stage.

Third, we explore the optimal combined subsidy policy to bestow benefits of a consumer subsidy and a Top 10 R&D subsidy in two combinations: 1. allocate subsidy funding to both the consumer subsidy and the Top 10 R&D subsidy; 2. apply the consumer subsidy and the Top 10 R&D subsidy at a specified time. Eventually, results show that the ‘2+8’ subsidy scheme (two years of consumer subsidy and eight years of Top 10 R&D subsidy) has a good effect on promoting EV diffusion. By comparison of effects of the ‘2+8’ subsidy scheme and Top 10 R&D subsidy scheme on EV diffusion under different periods, we found that the ‘2+8’ subsidy scheme can be expected to cause the emergence of firms with high capital high-performance products in the early stage; other firms will be affected by greater pressure from oligopolies during the middle period. Therefore, when implementing the ‘2+8' subsidy policy, the government should intervene in the market by application of incentives to firms with growth potential and by limiting the expansion of oligopolies.

Overall, the '2+8' subsidy policy is the optimal subsidy policy for EV diffusion in the Chinese market. It can induce earlier adoption of EVs in the short term and lead to more EV sales in the long term. Furthermore, it can engender rapid technological progress so that the firm can accumulate more capital. At the same time, the government must implement more lenient incentives for SMEs and be wary of excessive oligarchic expansion. Without proposing a policy recommendation for the future development and diffusion of EVs, this study explores what subsidy policy should be implemented in the initial stages of EV diffusion in the Chinese EV market. This study can provide suggestions to policymakers in other countries, helping them determine the coverage of a selective R&D subsidy based on the current state of EVs in their country and therefore helping them ascertain which combined policy should be implemented.

6.2 Future work

The baseline model simulates the EV market dynamics and interaction between consumers and manufacturers, several points can be enhanced to make the model more realistic and reliable.

1) Network connections can be established among consumers to reflect the reality of consumer interactions. For instance, a global network can reflect the effects of EV adoption on individual consumers at a macroscopic level [44]. A local network can reflect the effects of EV adoption on consumers as connected agents at a personal to regional level [43].
2) Imitation and learning mechanisms can be introduced among firms. Firms have some probability of imitating the technologies of firms with advanced development [45]. A certain probability exists that the company will fail during the R&D process. Firms can also mutually collaborate. Links can be formed among firms to share technology and knowledge.
3) The charging infrastructure was not considered in the baseline model. Charging facilities, as an important factor influencing consumer purchases, should be captured in the model [46]. We can consider addition of a new agent as a charging facility agent, which can judge the number of charging facilities to be built based on EV diffusion. Furthermore, the number of charging facilities can be expected to affect consumer purchase intentions.

This study specifically examines the Chinese EV market. Future studies will include consideration of effects of different subsidy policies on EV development and diffusion in the Japanese EV market and will lead to a proposal for an optimal subsidy policy for the Japanese EV market. It will also consider when the government should implement which restrictive policies for oligarchs and stimulating policies for SMEs. Furthermore, parameters will be set more closely to the actual situation such as the price changes of gasoline and electricity.

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Appendix

```
clear

%% PARAMETERS
Ncv = 150;
Nev = 30;
Nall = Ncv    +    Nev;
Ncon = 1000; %EV:1 agent for 10000 real consumers CV: 1 agent for 70000 real consumers
T = 150;
TT = 500;
Fcost0 = 9465;
Fcost1 = 13193;
Frange0 = 817.5;
Frange1 = 600;
Feff0 = 54.5;
Feff1 = 15;
size1 = 40;
size0 = 15;
alpha_m1 = 63;
alpha_m0 = 35;
a1 = 15;
b1 = 0.01005 ;
a0 = 36;
b0 = 0.0545;
discount0 = 0.99;
con_debt0 =    0.1;
con_order0 = 0.0001;
con_debt1 = 0.1;
con_order1 = 0.0001;
top =9;




%% Record
k1 = zeros(1,Nev);
record_k1 =    zeros(Nev,T);
RD1 =    zeros(1,Nev);
record_RD1 = zeros(Nev,T);
rev1 = zeros(1,Nev);
record_rev1 = zeros(Nev,T);
profit1 = zeros(1,Nev);
record_profit1 = zeros(Nev,T);
RPC1 = zeros(1,Nev);
RPD1 = zeros(1,Nev);
record_RPC1 = zeros(Nev,T);
record_RPD1 = zeros(Nev,T);
decrease_cost1 =    zeros(1,Nev);
increase_eff1 = zeros(1,Nev);
```

```
cost1 = zeros(1,Nev);
record_cost1 = zeros(Nev,T);
eff1 = zeros(1,Nev);
record_eff1 = zeros(Nev,T);
range1 = zeros(Nev,1);
record_range1 = zeros(Nev,T);
market1 = zeros(1,Nev);
record_market1 = zeros(Nev,T);
price1 = zeros(1,Nev);
record_price1 = zeros(Nev,T);
u1 = zeros(1,Nev);
k0 = zeros(1,Ncv);
record_k0 =    zeros(Ncv,T);
RD0 =    zeros(1,Ncv);
record_RD0 = zeros(Ncv,T);
rev0 = zeros(1,Ncv);
record_rev0 = zeros(Ncv,T);
profit0 = zeros(1,Ncv);
record_profit0 = zeros(Ncv,T);
RPC0 = zeros(1,Ncv);
RPD0 = zeros(1,Ncv);
record_RPC0 = zeros(Ncv,T);
record_RPD0 = zeros(Ncv,T);
decrease_cost0 =    zeros(1,Ncv);
increase_eff0 = zeros(1,Ncv);
cost0 = zeros(1,Ncv);
record_cost0 = zeros(Ncv,T);
eff0 = zeros(1,Ncv);
record_eff0 = zeros(Ncv,T);
range0 = zeros(1,Ncv);
record_range0 = zeros(Ncv,T);
market0 = zeros(1,Ncv);
record_market0 = zeros(Ncv,T);
price0 = zeros(1,Ncv);
record_price0 = zeros(Ncv,T);
u0 = zeros(1,Ncv);
order1 = zeros(1,Nev);
record_order1 = zeros(Nev,T);
order0 = zeros(1,Ncv);
record_order0 = zeros(Ncv,T);
order_max0 = zeros(1,Ncv);
order_max1 = zeros(1,Nev);
record_order_max0 = zeros(Ncv,T);
record_order_max1 = zeros(Nev,T);
mile = zeros(1,Ncon);
budget    = zeros(1,Ncon);

WTP0 = zeros(1,Ncv);
WTP1 = zeros(1,Nev);
ec0 = zeros(Ncon,Ncv);
ec1 = zeros(Ncon,Nev);
resales0 = zeros(Ncv);
resales1 = zeros(Nev);
TCO0 = zeros(Ncon,Ncv);
TCO1 = zeros(Ncon,Nev);
utility = zeros(Ncon,Nall);
```

```
invest1 = zeros(1,Nev);
debt_b1 = zeros(1,Nev);
debt_r1 = zeros(1,Nev);
debt1 = zeros(1,Nev);
debt0 = zeros(1,Ncv);
debt_b0 = zeros(1,Ncv);
debt_r0 = zeros(1,Ncv);
sale0 = zeros(1,Ncv);
sale1 = zeros(Nev,1);
unprofit_period0 = zeros(1,Ncv);
unprofit_period1 = zeros(1,Nev);
record_WTP0 = zeros(Ncon,Ncv,T);
record_WTP1 =    zeros(Ncon,Nev,T);
record_ec0 = zeros(Ncon,Ncv,T);
record_ec1 = zeros(Ncon,Nev,T);
record_resales1 = zeros(Nev,T);
record_TCO0 = zeros(Ncon,Ncv,T);
record_TCO1 = zeros(Ncon,Nev,T);
record_utility0 = zeros(Ncon,Ncv,T);
record_utility1 = zeros(Ncon,Nev,T);
record_invest1 = zeros(Nev,T);
record_debt_b1 = zeros(Nev,T);
record_debt_r1 = zeros(Nev,T);
record_debt1 = zeros(Nev,T);
record_debt0 = zeros(Ncv,T);
record_debt_b0 = zeros(Ncv,T);
record_debt_r0 = zeros(Ncv,T);
record_order_total = zeros(T,1);
%%%%
record_avgprice0 = zeros(T,1);
record_avgprice1 = zeros(T,1);
record_avgcost0 = zeros(T,1);
record_avgcost1 = zeros(T,1);
record_avgrange0 = zeros(T,1);
record_avgrange1 = zeros(T,1);
record_market_share0 = zeros(T,1);
record_firms0 = zeros(T,1);
record_firms1 = zeros(T,1);
record_avgk1 = zeros(1,T);
record_avgk0 = zeros(1,T);
record_avgprofit1 = zeros(T,1);
record_avgu1 = zeros(T,1);
record_u1 = zeros(Nev,T);
record_sumsale1 = zeros(1,T);
record_sumsale0 = zeros(1,T);
record_market_share1 = zeros(T,1);
record_avg_RPC0 = zeros(T,1);
record_avg_RPD0 = zeros(T,1);
record_avg_RPC1 = zeros(T,1);
record_avg_RPD1 = zeros(T,1);
record_avgrev1 = zeros(T,1);
record_avgrev0 = zeros(T,1);
record_avgprofit0 = zeros(T,1);
record_budget = zeros(Ncon,T);
record_firm1 = zeros(T,1);
subc = zeros(T,1);
```

```
subm = zeros(T,1);
sum_subf = zeros(1,T);
record_sum_subf = zeros(1,T);
max_budget = zeros(1,T);
record_test = zeros(T,1);
record_test_tt = zeros(T,TT);
in_debt1=zeros(Nev,T);
in_debt0=zeros(Ncv,T);
record_per_indebt1 = zeros(T,1);
record_per_indebt0 = zeros(T,1);
record_per_indebt1_tt = zeros(T,TT);
record_per_indebt0_tt = zeros(T,TT);
record_firm1_tt = zeros(T,TT);
record_firm0_tt = zeros(T,TT);
record_sumsale1_tt = zeros(T,TT);
record_sumsale0_tt = zeros(T,TT);
record_avgprice1_tt = zeros(T,TT);
record_avgprice0_tt = zeros(T,TT);
record_total_subc = zeros(T,1);
record_total_subc_tt = zeros(T,TT);
record_avgk1_tt = zeros(T,TT);
record_avgk0_tt = zeros(T,TT);
record_avgrange1_tt = zeros(T,TT);
record_avgrange0_tt = zeros(T,TT);
record_k130 = zeros(Nev,1);
  record_k130_tt =zeros(Nev,TT);
  record_range130 =zeros(Nev,1);
  record_range130_tt = zeros(Nev,TT);

for tt = 1 : TT
rng('shuffle'); %% make sure for different rand()
%% Initialization
  start_or_not = 0;
  time_of_start = 9999;
  total_subc = 0;
  record_k0 = record_k0 * 0;
  record_k1 = record_k1 * 0;

  for i = 1 : Nev
        order1(i) = 0;
        k1(i) = randi([1000000000,10000000000]);
        rev1(i) = 0;
        sale1(i) = 0;
        cost1(i) = 49193;
        price1(i) = 0;
        eff1(i) = 0;
        range1(i) = 0;
        profit1(i) = 0;
        debt1(i) = 0;
        market1(i) = 0;
        RPC1(i) = 0;
        RPD1(i) = 0;
        unprofit_period1(i) = 0;
        u1(i) = 0;
        RD1(i) = 0;
```

```
      decrease_cost1(i) = 0;
      increase_eff1(i) = 0;
      subc(i) = 0;
      subm(i) = 0;


  end
  for i    = 1 : Ncv
       order0(i) = 0;
       k0(i) = randi([1000000000,10000000000]);
       rev0(i) =    0;
       sale0(i) = 0;
       cost0(i) =    10822;
       price0(i) = 0;
       eff0(i) = 27;
       profit0(i) = 0;
       debt0(i)    = 0;
       market0(i) = 1;
       RPC0(i) = 0;
       RPD0(i) = 0;
       unprofit_period0(i) = 0;
       u0(i) = 0;
       RD0(i) = 0;
       decrease_cost0(i) = 0;
       increase_eff0(i) = 0;
  end

for i = 1 : Ncon
         mile(i) = 10609 + 5995 * randn();
         budget(i) = 15660 + 10560 * randn();

end

%% Main Cycle
  for t = 1 : T

      %% Update
      for i = 1 : Nev
          order_max1(i) = con_order1 * k1(i);
          subc(i) = 0;
      end

      for i = 1 : Ncv
          order_max0(i) =    con_order0 * k0(i);
      end

      for i = 1 : Ncon
          mile(i) = 10609 + 5995 * randn();
          budget(i) = (15660 + 10560 * randn()) * (1    +    0.02 * t);
          max_budget = max(budget(:));
      end
```

```
    %% manufacturer subsidy (top 10 scheme)
    subm = subm * 0;
%      if t == time_of_start + 2
%            for i = 1: Nev
%                 [range,index]=sort(range1(:),'descend');
%                   rank = find(index == i);
%                 if rank <= 10
%                     if market1(i) < 2
%                   subm(i) = floor(931180668 / 10);
%                     end
%                 else
%                         subm(i) = 0;
%                 end
%            end
%      end
%      if t == time_of_start + 3
%            for i = 1: Nev
%                   [range,index]=sort(range1(:),'descend');
%                   rank = find(index == i);
%                 if rank <= 10
%                   if market1(i) < 2
%                   subm(i) = floor(1467570563 / 10);
%                   end
%               else
%                         subm(i) = 0;
%                 end
%            end
%      end
%      if t == time_of_start + 4
%            for i = 1: Nev
%                   [range,index]=sort(range1(:),'descend');
%                   rank = find(index == i);
%                 if rank <= 10
%                   if market1(i) < 2
%                   subm(i) = floor(2115470913 / 10);
%                   end
%               else
%                         subm(i) = 0;
%               end
%
%            end
%      end
%      if t == time_of_start + 5
%            for i = 1: Nev
%                 [range,index]=sort(range1(:),'descend');
%                   rank = find(index == i);
%                 if rank <= 10
%                   if market1(i) < 2
%                   subm(i) = floor(4488693046 / 10);
%                   end
%                 else
%                         subm(i) = 0;
%                 end
%            end
%      end
%      if t == time_of_start + 6
```

```
%           for i = 1: Nev
%                 [range,index]=sort(range1(:),'descend');
%                 rank = find(index == i);
%               if rank <= 10
%                 if market1(i) < 2
%                 subm(i) = floor(5586216805 / 10);
%                 end
%               else
%                         subm(i) = 0;
%               end
%           end
%     end
%     if t == time_of_start + 7
%           for i = 1: Nev
%                 [range,index]=sort(range1(:),'descend');
%                 rank = find(index == i);
%               if rank <= 10
%                 if market1(i) < 2
%                 subm(i) = floor(7339866362 / 10);
%                 end
%               else
%                         subm(i) = 0;
%               end
%           end
%     end
%     if t == time_of_start + 8
%           for i = 1: Nev
%                 [range,index]=sort(range1(:),'descend');
%                 rank = find(index == i);
%               if rank <= 10
%                 if market1(i) < 2
%                 subm(i) = floor(4536925821 / 10);
%                 end
%               else
%                         subm(i) = 0;
%               end
%           end
%     end
%     if t == time_of_start + 9
%           for i = 1: Nev
%                 [range,index]=sort(range1(:),'descend');
%                 rank = find(index == i);
%               if rank <= 10
%                 if market1(i) < 2
%                 subm(i) = floor(4735692386 / 10);
%                 end
%               else
%                         subm(i) = 0;
%               end
%           end
%     end
%     if t == time_of_start + 10
%           for i = 1: Nev
%                 [range,index]=sort(range1(:),'descend');
%                 rank = find(index == i);
%               if rank <= 10
```

```
%                   if market1(i) < 2
%                   subm(i) = floor(3719585821 / 10);
%                   end
%                 else
%                       subm(i) = 0;
%                 end
%             end
%     end
%     if t == time_of_start + 11
%             for i = 1: Nev
%                   [range,index]=sort(range1(:),'descend');
%                   rank = find(index == i);
%                 if rank <= 10
%                   if market1(i) < 2
%                   subm(i) = floor(2299729100 / 10);
%                   end
%                 else
%                       subm(i) = 0;
%                 end
%             end
%     end



  %% R&D
   decrease_cost0 = decrease_cost0 * 0;
   decrease_cost1 = decrease_cost1 * 0;
   increase_eff1 = increase_eff1 * 0;
   increase_eff0 = increase_eff0 * 0;
   u0 = u0 * 0;
   u1 = u1 * 0;
   RD1 = RD1 * 0;
   RD0 = RD0 * 0;

   for i    = 1 : Nev

      if market1(i)<2
            if profit1(i) <=    0
                  RD1(i) = 0.05 * k1(i)+ subm(i) ;
            else
                  RD1(i) =    0.05 * rev1(i) + subm(i) ;
            end

            if market1(i) ==    0
                if price1(i) <=    max_budget && range1(i)< 75
                      RPD1(i) = RD1(i);
                      RPC1(i) = 0;

                elseif price1(i) > max_budget && range1(i) >= 75
                      RPC1(i) = RD1(i);
                      RPD1(i) = 0;

                else
                    RPC1(i) =    rand() * RD1(i);
```

```
                RPD1(i) =    RD1(i) - RPC1(i);
            end
         end
        if market1(i) == 1
           RPC1(i) =    rand() * RD1(i);
           RPD1(i) =    RD1(i) - RPC1(i);
        end

        decrease_cost1(i) = a1 * 10^-6 * RPC1(i) * (1- Fcost1/cost1(i));
        increase_eff1(i) = b1 * 10^-6 * RPD1(i) * (1 - eff1(i)/Feff1);

        if increase_eff1(i) < 0
              increase_eff1(i) = 0;
        end
        if decrease_cost1(i) < 0
              decrease_cost1(i) = 0;
        end
        cost1(i) =    cost1(i) - decrease_cost1(i);
        eff1(i) = eff1(i)    +    increase_eff1(i);
        if eff1(i)> Feff1
              eff1(i) = Feff1;
        end
        if cost1(i)< Fcost1
              cost1(i) = Fcost1;
        end
        range1(i) = size1 * eff1(i);
     end
end

for i = 1 : Ncv
       if market0(i) < 2

        if profit0(i) <=    0
              RD0(i) = 0.05 * k0(i);
        else
              RD0(i) =    0.05 * rev0(i);
        end

        RPC0(i) =    rand() * RD0(i);
        RPD0(i) =    RD0(i) - RPC0(i);
        decrease_cost0(i) = a0 * 10^-6 * RPC0(i) * (1- Fcost0/cost0(i));
        increase_eff0(i) = b0 * 10^-6 * RPD0(i)    * (1 - eff0(i)/Feff0);
        if increase_eff0(i)<0
              increase_eff0(i) = 0;
        end
        if decrease_cost0(i)<0
              decrease_cost0(i) = 0;
        end
        cost0(i) =    cost0(i) - decrease_cost0(i);
        eff0(i) = eff0(i)    +    increase_eff0(i);
        if eff0(i)> Feff0
              eff0(i) = Feff0;
        end
        if cost0(i)< Fcost0
              cost0(i) = Fcost0;
```

```
        end
        range0(i) = size0 * eff0(i);
        u0(i) = range0(i)/ max(range0( : )) * 0.5;
        price0(i) = cost0(i) * (1   +   u0(i));
    end
end




%% entry
for i = 1 : Nev
        if market1(i) < 2
                u1(i) = range1(i)/max(range1( : )) *   0.5;
                price1(i) = cost1(i) * (1   +   u1(i));
                  if price1(i) <= max_budget && range1(i) >= 75
                        if market1(i)    == 0
                                market1(i)   = 1;
                        end
                  end
        end
end

%% Purchase

utility = utility * 0;
order0 = order0 * 0;
order1 = order1 * 0;
subc = subc * 0;

for i = 1 : Ncon
        %calculate utility
        for j = 1 : Ncv

                if market0(j) == 2
                        utility(i,j) = -inf;
                end
                if market0(j) ==   1
                        WTP0(j) = alpha_m0 * (range0(j) - 75)   + 22006;
                        ec0(i,j) = mile(i) / eff0(j) * 2.7424;
                        resales0(j) = (1 -0.067 * 6) * price0(j);
                        TCO0(i,j) = price0(j)   +   6.048 *   ec0(i,j) - resales0(j)/1.019;
                        utility(i,j) = WTP0(j) - TCO0(i,j);
                        if price0(j) > budget(i)
                                utility(i,j) =   -inf;
                        end
                end
        end

        for j = 1 : Nev

          %% consumer subsidy
```

```
if t == time_of_start + 2
        if range1(j)>=80 && range1(j)<150
                subc(j)= 5400 ;

        elseif range1(j)>=150 && range1(j)<250
                subc(j)=7700;

        elseif range1(j)>=250
                subc(j)=9200;
        else
                subc(j) = 0;
        end
  end
if t == time_of_start + 3
        if range1(j)>=80 && range1(j)<150
                subc(j)=4860;

        elseif range1(j)>=150 && range1(j)<250
                subc(j)=6940;

        elseif range1(j)>=250
                subc(j)=8334;
        else
                subc(j) = 0;
        end
end
if t == time_of_start + 4
        if range1(j)>=80 && range1(j)<150
                subc(j)=4321;

        elseif range1(j)>=150 && range1(j)<250
                subc(j)=6173;

        elseif range1(j)>=250
                subc(j)=7408;
        else
                subc(j) = 0;
        end
end
if t == time_of_start + 5
        if range1(j)>=100 && range1(j)<150
                subc(j)=3858;

        elseif range1(j)>=150 && range1(j)<250
                subc(j)=6945;

        elseif range1(j)>=250
                subc(j)=8489;
        else
                subc(j) = 0;
        end
end
if t == time_of_start + 6
```

```
        if range1(j)>=100 && range1(j)<150
            subc(j)=3086;

        elseif range1(j)>=150 && range1(j)<250
            subc(j)=5556;

        elseif range1(j)>=250
            subc(j)=6791;
        else
            subc(j) = 0;
        end
    end
     if t == time_of_start + 7
        if range1(j)>=100 && range1(j)<150
            subc(j)=2701;

        elseif range1(j)>=150 && range1(j)<250
            subc(j)=4681;

        elseif range1(j)>=250
            subc(j)=5942;
        else
            subc(j) = 0;
        end
     end
     if t == time_of_start + 8
        if range1(j)>=250 && range1(j)<400
            subc(j)=2778;

        elseif range1(j)>= 400
            subc(j)=3858;
        else
            subc(j) = 0;
        end
     end
     if t == time_of_start + 9
         if range1(j)>=300 && range1(j)<400
            subc(j)=2500;
         elseif range1(j)>= 400
            subc(j)=3472;
         else
            subc(j) = 0;
        end
     end
     if t == time_of_start + 10
         if range1(j)>=300 && range1(j)<400
            subc(j)=2006;

         elseif range1(j)>= 400
            subc(j)=2778;
         else
             subc(j) = 0;
         end
     end
     if t == time_of_start + 11
```

```
            if range1(j)>=300 && range1(j)<400
                subc(j) = 1404;
            elseif range1(j)>= 400
              subc(j)= 1945;
            else
                subc(j) = 0;
            end
  end


  %% utility calculates

        if market1(j) == 0    ||    market1(j) == 2
            utility(i,j + Ncv) = -inf;
        end
        if market1(j) ==    1
            WTP1(j) =    alpha_m1 * (range1(j)-75)    +    22006;
            ec1(i,j) = mile(i) / eff1(j) * 0.1154;
            resales1(j) = (1 - 0.125 *    6) * price1(j);
            TCO1(i,j) =    price1(j) - subc(j)    +    6.048 *    ec1(i,j) - resales1(j)/1.019;
            utility(i,j + Ncv) = WTP1(j) - TCO1(i,j);
            if price1(j) - subc(j) > budget(i)
                utility(i,j + Ncv) = -inf;
            end
        end
end



%% make order
a = 0;
a = a * 0;
order_rank = unidrnd(10);
[urank,rank] = sort(utility(i,:),'descend');

for x = 1 : 10
        if urank(x) == -inf
            a = a + 1;
        end
end
if a == 10
      continue
else
        while urank(order_rank) == -inf
            order_rank = unidrnd(10);
        end
        if rank(order_rank) <=    Ncv
        order0(rank(order_rank)) = order0(rank(order_rank)) + 70000;
        else
        order1(rank(order_rank)- Ncv) = order1(rank(order_rank)-Ncv) + 10000;
        end
end
```

```
    end

 %% Sales and Profit
    sale0 = sale0 * 0;
    sale1 = sale1 * 0;
    rev0 = rev0 * 0;
    rev1 = rev1 * 0;
    profit0 = profit0 * 0;
    profit1 = profit1 * 0;

    for i = 1 : Ncv
        if market0(i) == 1
            sale0(i) = floor(min(order0(i),order_max0(i)));
            profit0(i) = (price0(i)-cost0(i)) * sale0(i) - 0.0343 * debt0(i);%% interest cost 0.0343 *
debt0(i)
            rev0(i) = price0(i) * sale0(i);
        end
    end

    for i = 1 : Nev
        if market1(i) == 1
            sale1(i) = floor(min(order1(i),order_max1(i)));
            profit1(i) = (price1(i)-cost1(i)) * sale1(i) - 0.0343 * debt1(i) ;%% interest cost 0.0343
*debt1(i)
            rev1(i) = price1(i) * sale1(i);
        end
    end
  %% caculate total consumer subsidy
  total_subc = total_subc * 0;
  for i = 1 : Nev
      if market1(i) == 1
          total_subc = total_subc + subc(i) * sale1(i);
      end
  end

 %% Debt and Investment
    debt_b1 = debt_b1 * 0;
    debt_b0 = debt_b0 * 0;
    debt_r1 = debt_r1 * 0;
    debt_r0 = debt_r0 * 0;
    subf = 0;


    for i = 1 : Nev

      if market1(i) <2
        if order1(i) >= order_max1(i)
            debt_b1(i) = con_debt1 * k1(i);
        end
        if debt1(i) > 0    &&    profit1(i) > 0
            if debt1(i) > 0.15 * profit1(i)
                debt_r1(i) = 0.15 * profit1(i);
            else
                debt_r1(i) = debt1(i);
```

```
            end
        end
        k1(i) = 0.99 *    k1(i)    +    debt_b1(i)    +    profit1(i) - RD1(i) + subm(i) - debt_r1(i);
        debt1(i) = debt1(i) - debt_r1(i) + debt_b1(i);
        if debt1(i) > 0
            in_debt1(i) = 1;
        else
            in_debt1(i) = 0;
        end

    %Calculate period of nonprofit
        if profit1(i) < 0
            unprofit_period1(i) = unprofit_period1(i) + 1;
        else
            unprofit_period1(i) = 0;
        end
     end
    end



    for i = 1 : Ncv
      if market0(i) == 1
        if order0(i) >= order_max0(i)
            debt_b0(i) = con_debt0 * k0(i);
        end
          if debt0(i) > 0    &&    profit0(i) > 0
            if debt0(i) > 0.15    * profit0(i)
                debt_r0(i) = 0.15 *    profit0(i);
            else
                debt_r0(i) = debt0(i);
            end
         end

       k0(i) =    discount0 * k0(i)    +    debt_b0(i)    +    profit0(i) - RD0(i) - debt_r0(i);
       debt0(i) = debt0(i) - debt_r0(i)    + debt_b0(i);
        if debt0(i) > 0
            in_debt0(i) = 1;
        else
            in_debt0(i) = 0;
        end

   %Calculate period of unprofit
        if profit0(i) <0
            unprofit_period0(i) = unprofit_period0(i) + 1;
        else
            unprofit_period0(i) = 0;
        end
      end
    end

%% exit
   for i = 1 : Nev
       if market1(i)<2
            %three conditions
```

```
            if    k1(i)<= 5000000 || debt1(i)/k1(i) >= 2 || unprofit_period1(i) >=5
                    market1(i) = 2;
            end
        end
        if    market1(i) == 2
                range1(i) =    0;
                price1(i) =    0;
                k1(i) = 0;
                debt1(i) = 0;
                RD1(i) = 0;
                RPC1(i) = 0;
                RPD1(i) = 0;
                profit1(i) = 0;
                rev1(i) = 0;
                subc(i) = 0;
                subm(i) = 0;
                debt_r1(i) =0;
        end
  end


   for i = 1 : Ncv
      if market0(i) == 1
                %three conditions

         if    k0(i)< 5000000 ||    debt0(i)/k0(i) >= 2 || unprofit_period0(i) >=5
                    market0(i) = 2;
         end



      end
         if market0(i) == 2
                range0(i) = 0;
                price0(i) = 0;
                k0(i) = 0;
                debt0(i) = 0;
                RD0(i) = 0;
                RPC0(i) = 0;
                RPD0(i) = 0;
                profit0(i) = 0;
                rev0(i) = 0;
         end
   end




%% record

if sum(sale1(:)) > 0    && start_or_not == 0 %% warming up
        start_or_not = 1;
        time_of_start = t;
end
```

```
if start_or_not == 1

    record_market_share0(t) = sum(sale0(:))/(sum(sale0(:)) + sum(sale1(:)));
    record_market_share1(t) = 1 - record_market_share0(t);
    record_order_total(t) = sum(order0(:)) + sum(order1(:));
    record_firms0(t) = sum(market0( : ) == 1);
    record_firms1(t) = sum(market1( : ) == 1) + sum(market1(:) == 0);
    record_firm1(t) = sum(market1( : ) == 1);
    record_avgprice0(t) = sum(price0( : ))/record_firms0(t);
    record_avgrange0(t) = sum(range0( : ))/record_firms0(t);
    record_avgprice0(t - time_of_start +1) = record_avgprice0(t);
    record_avgprice0(t)=0;
    record_avgrange0(t-time_of_start +1) = record_avgrange0(t);
    record_avgrange0(t) =0;
    record_avgprice1(t) = sum(price1( : ))/record_firms1(t);
    record_avgprice1( t - time_of_start + 1) = record_avgprice1(t);
    record_avgprice1(t) = 0;
    record_avgrange1(t) = sum(range1( : ))/record_firms1(t);
    record_avgrange1(t - time_of_start + 1) = record_avgrange1(t);
    record_avgrange1(t) = 0;
    record_avg_RPC0(t) = sum(RPC0( : ))/record_firms0(t);
    record_avg_RPD0(t) = sum(RPD0( : ))/record_firms0(t);
    record_avg_RPC1(t) = sum(RPC1( : ))/record_firms1(t);
    record_avg_RPD1(t) = sum(RPD1( : ))/record_firms1(t);
    record_range1( : ,t) = range1( : );
    record_price1( : ,t) = price1( : );
    record_cost1( : ,t) =    cost1( : );
    record_cost0( : ,t) =    cost0( : );
    record_k1( : ,t) = k1( : );
    record_k0( : ,t) = k0( : );
    record_u1( : ,t) = u1( : );
    record_avgk1(t) = sum(k1( : ))/record_firms1(t);
    record_avgk1(t - time_of_start + 1) = record_avgk1(t);
    record_avgk1(t) = 0;
    record_avgk0(t) = sum(k0( : ))/record_firms0(t);
    record_avgk0(t - time_of_start + 1) = record_avgk0(t);
    record_avgk0(t) = 0;
    record_avgprofit1(t) = sum(profit1( : ))/record_firm1(t);
    record_avgprofit0(t) = sum(profit0( : ))/record_firms0(t);
    record_profit0( : ,t) = profit0( : );
    record_sumsale0(:,t) = sum(sale0(:));
    record_sumsale0(:,t - time_of_start + 1) = record_sumsale0(:,t);
    record_sumsale1( : ,t) = sum(sale1( : ));
    record_sumsale0(:,t) = 0;
    record_sumsale1(:,t - time_of_start + 1) = record_sumsale1(:,t);
    record_sumsale1(:,t) = 0;
    record_budget( : ,t) = budget( : );
    record_debt0( : ,t) = debt0( : );
    record_debt1( : ,t) = debt1( : );
    record_per_indebt1(t) = sum(market1(:)==2);
    record_per_indebt0(t) = sum(market0(:)==2);
    record_total_subc(t) = total_subc;
    record_total_subc(t- time_of_start + 1) = record_total_subc(t);
    record_total_subc(t) = 0;
```

```
      record_firm1(t - time_of_start +1) = record_firm1(t);
      record_firm1(t) = 0;
      record_firms0(t - time_of_start +1) = record_firms0(t);
      record_firms0(t) = 0;

      if t == time_of_start + 30
          record_k130(:) = k1(:);
          record_range130(:) = range1(:);
      end

    end
end

  record_avgk1_tt(:,tt) = record_avgk1;
  record_avgk1 = record_avgk1 * 0;
  record_avgk0_tt(:,tt) = record_avgk0;
  record_avgk0 = record_avgk0 * 0;
  record_avgrange1_tt(:,tt) = record_avgrange1;
  record_avgrange1 = record_avgrange1 * 0;
  record_avgrange0_tt(:,tt) = record_avgrange0;
  record_avgrange0 = record_avgrange0 * 0;
  record_avgprice0_tt(:,tt) = record_avgprice0;
  record_avgprice0 = record_avgprice0 * 0;
  record_firm1_tt(:,tt) = record_firm1;
  record_firm0_tt(:,tt) = record_firms0;
  record_sumsale1_tt(:,tt) = record_sumsale1;
  record_sumsale0_tt(:,tt) = record_sumsale0;
  record_avgprice1_tt(:,tt) = record_avgprice1;
  record_sumsale1 = record_sumsale1 * 0;
  record_sumsale0 = record_sumsale0 * 0;
  record_avgprice1 = record_avgprice1 * 0;
  record_firm1 = record_firm1 * 0;
  record_firms0 = record_firms0 * 0;
  record_total_subc_tt(:,tt) = record_total_subc;
  record_total_subc = record_total_subc * 0;
  record_k130_tt(:,tt) = record_k130;
  record_k130 = record_k130 * 0;
  record_range130_tt(:,tt) = record_range130;
  record_range130 = record_range130 * 0;

end
record_range1 = record_range1';
record_sumsale1 = record_sumsale1';
record_cost1 = record_cost1';
record_debt0 = record_debt0';
record_profit0 = record_profit0';
record_k0 = record_k0';
record_k1 = record_k1';
% plot(record_firms1);
% plot(record_avg_RPD1);
% plot(record_avgrange1);
% plot(record_market_share1);
% plot(record_k0);
% %plot(record_avgprice1_tt);
```