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Research Article

Optimization and Benefit Analysis of Intelligent Networked Vehicle Supply Chain Based on Stackelberg Algorithms

Cheng Che, Xin Geng, Huixian Zheng, Yi Chen, and Xiaoguang Zhang

School of Economics and Management, China University of Petroleum, Qingdao 266580, Shandong, China

Correspondence should be addressed to Xin Geng; 1371178916@qq.com

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With the rapid development of intelligent technology, the construction of smart cities with the goal of creating a harmonious human life has become a new hot spot in the world. A new round of information technology revolution, represented by the Internet, big data, cloud computing, artificial intelligence (AI), and fifth-generation mobile communications (5G), is driving profound changes in the automotive industry. Smart vehicles (also known as intelligent connected vehicles) that integrate many high-tech technologies to provide safer, more convenient, and low-carbon comprehensive travel solutions have become an inevitable form of future vehicles. This paper constructs a three-level supply chain consisting of high-performance chip suppliers, smart car manufacturers, and retailers. On the basis of considering the level of product innovation and sales effort, Stackelberg game method is used to study the influence of each player in the supply chain on each parameter and the profit of each player under three scenarios: centralized decision making, nonsharing of innovation cost, and sharing of innovation cost. The results show that: when the level of sales effort has nothing to do with the level of innovation, the level of product innovation and the total profit of the supply chain increase with the improvement of the retailer's sales ability; when the level of sales effort is related to the level of innovation, the level of product innovation under the cost-sharing decision model is greater than the case of no cost sharing, but the total profit of the supply chain is less than the case of no cost sharing.

1. Introduction

From smart buildings to smart residential quarters, how to realize the sustainable development of cities has always been the focus of human attention and exploration. At present, with the rapid development of intelligent technology, the construction of smart cities with the goal of creating a harmonious human life has become a new hot spot in the world. In the construction of smart cities, new energy vehicles have become an important part of construction and promotion in recent years due to the energy saving and environmental protection. In 2020, the new energy vehicle industry has made breakthrough progress, transforming from the primary stage of development to the middle and advanced stage, from focusing on solving the "three electricity problems" to promoting the integration of electrification and renewable energy, intelligent transportation, and smart city. The coordinated development of intelligent connected vehicles and smart cities constitutes a vehicle-city-integrated development system. The development of smart cities requires cars as the entry point and driving force, and the development of smart cars requires the supporting support and guarantee of urban energy and digital infrastructure more than ever, so as to further optimize urban infrastructure, improve travel services, and enhance urban operating efficiency. In the future, intelligent networked vehicles will become the "neurons" moving in smart cities, connecting with intelligent traffic control systems to form an integrated smart travel service system. Intelligent transportation refers to an efficient integrated transportation system that integrates information, communication, sensing, control, computer technology, and transportation management system [1]. Smart city (SC) refers to the use of Internet of Things, cloud computing, and other technologies to change the interaction mode of various entities urban subjects, quickly respond to various social needs, and build a new type of livable city that operates efficiently [2]. In a smart city, transportation is a necessary part of residents' life, so the intelligent development of transportation is an important foundation for a smart city [3].

At present, the world's energy demand is highly dependent on fossil fuels, namely coal, oil, and natural gas [4]. Due to the continuous growth of energy demand, the use of fossil fuels has led to a rapid increase in the total amount of global carbon emissions, which has caused serious damage to the Earth's ecological environment [5]. In response to global climate change, many countries have taken joint actions and successively announced the timetable for banning the sale of gasoline-powered vehicles. The Netherlands will completely ban the sale of fuel vehicles in 2025, India, England, and France will also fully implement the ban in 2030–2040, and China will soon formulate a timetable for banning the sale of fuel vehicles. Accelerating the development of the intelligent connected vehicle industry, including intelligent connected vehicles, has become one of the important strategies to solve global environmental problems [6, 7]. ICV has not only involved the automobile industry, but also the communication, electronic parts, and other industries. It has become a competitive highland for the development of automobile technology in various countries. It has received the attention of the Chinese government and has risen to the height of national strategy [8]. Intelligent connected vehicle is the integration of the Internet and the Internet of Things, which are two high and new technologies. It deeply integrates the innovation achievements of the Internet and the Internet of Things technology into the field of intelligent vehicles. Relying on the development of modern communication information technology and the Internet, the multidirectional docking between vehicles and X elements (vehicles, people, roads, network platforms, etc.) is realized, and the intelligent automatic driving function of vehicles is comprehensively improved, so as to improve traffic congestion and provide intelligent, efficient, safe, comfortable, energy-saving, and environment friendly user experience [9]. With the promotion of China's intelligent and connected automobile industry to the national strategic level, the industry positioning is shifting from automatic driving and Internet of vehicles to intelligent manufacturing and intelligent network integration. In recent years, relying on 5G, AI industry, and O_2O service industry, China has made good progress in the field of intelligent and connected market operations [10].

The ICV industry is the product of the deep integration of the automotive industry and the new generation of information technology. It integrates technologies in many fields such as automobiles, transportation, communications, the Internet, and big data, forming an industrial chain that integrates multiple industries [9, 11]. The industrial chain of intelligent networked vehicles is divided into three parts: upper, middle, and lower. Upstream is mainly the technology layer, including perception, communication, decision-making, and execution system, involving information fusion, cloud platform and big data, vehicle-integrated control, and other technologies; On the basis of technology integration, midstream provides vehicle, intelligent cockpit, and autonomous driving solutions, involving a large number of system integration technology, interaction technology, vehicle involvement, and manufacturing technology. Downstream is the application level, including car sales and other related application services [12]. Intelligent connected vehicles will be an inevitable form in the future automotive industry market. In the era of intelligent connected vehicles, it is very important to do a good job in the marketing and service of automobiles. As a new type of automotive product, intelligent connected vehicles are quite different from traditional fuel vehicles in terms of technology and handling performance. These differences will affect whether consumers are willing to accept such products. Therefore, consumers should increase their awareness of intelligent connected vehicles. The cognition of the automobile market and the understanding of the policy will promote the selection of this type of automobile [13]. In the actual marketing environment, consumers' perceived value of cars can be used as the result of consumers' evaluation of the product and then affect their purchase intentions [14, 15]. In the automotive market, because intelligent connected vehicles are new technology-oriented products, in the early stage of development, technology-related attributes have become the focus of customers' attention. Empirical studies by some scholars have found that the improvement of car performance and the reduction of price will increase consumers' willingness to buy, thereby further expanding the consumer market [16]. Egbue et al. also confirmed that car performance has a positive impact on customer acceptance [17]. Intelligent connected vehicles are an opportunity recognized by the global automotive industry as an opportunity with huge social benefits. In the future, it is worth exploring how the automotive industry can upgrade its technology to improve car performance and introduce it into consumers' lives through good marketing methods [18].

Based on the above background, this paper studies the supply chain of intelligent networked vehicles. Different from previous literature, this paper considers the impact of retailers' sales efforts and product innovation levels on the supply chain. By constructing a three-level supply chain model consisting of high-performance chip suppliers, car manufacturers, and retailers in the automotive market, this paper analyzes the maximum profit level of each subject in the supply chain under three different situations. First of all, compared with the secondary supply chain in most previous studies, we study the tertiary supply chain, which is more in line with the industrial chain structure of intelligent connected vehicles. Second, unlike previous studies, we also considered retailers' sales efforts and product innovation levels. Because we understand that consumers' knowledge of intelligent connected vehicles and the performance and quality of the chips installed in the car will affect the market demand for cars. Finally, through the establishment of the Stackelberg game model to analyze different situations, it further broadens the research ideas of ICV supply chain and enriches related research theories.

2. Literature Review

This paper focuses on the impact on the profit of each entity in the three-tier supply chain of intelligent connected vehicles when the factors of product innovation level and sales effort are considered. There are three categories of domestic and foreign literature related to this study: intelligent connected vehicles and their industrial chain composition, automotive secondary supply chain, and research on collaborative innovation decision-making in automotive supply chain. In this section, we will review relevant literature and summarize these three parts.

2.1. Intelligent Connected Vehicle and Its Industrial Chain Composition. Smart city and intelligent transportation are the themes of urban development in the new century. In particular, the use of the Internet and big data to improve the operational efficiency of cities and improve traffic efficiency is the goal pursued by city managers. In this context, automobile manufacturers reposition their products and turn to provide more information-based and intelligent products and services, so that enterprises can adapt to the new living environment in the future [19]. As a strategic emerging industry involving multiindustry intersection, the research and development of its key technologies has a very significant impact on industrial development [10]. In the future, intelligent connected vehicles will be able to effectively ensure traffic safety, and the intelligent cockpit system in the car will also bring extraordinary experience and fun to drivers and passengers. Moreover, due to the integration of multiple technologies, intelligent connected vehicles have become the strategic commanding heights of technological transformation in the automotive industry [20, 21]. In recent years, the field of smart cars has seen tremendous growth in the lot market. The number of intelligent connected vehicles will continue to increase in the next few years. This is due to the continuous upgrading of Internet of Things technology, which provides more innovation opportunities for applications in the automotive field. In the construction of smart cities in the future, the role of intelligent connected vehicles will become more and more prominent [22, 23].

At the stage of rapid development of science and technology in China, the application of various new technologies in the automotive field has promoted the development of the automotive industry, and intelligent connected vehicles will be the competitive point of future automotive development. Modern intelligent connected cars are more in line with people's expectations. At present, intelligent connected vehicles have formed a complete industrial chain. According to the research on its industrial chain, we can think that the industrial chain of ICV is from the supply of chips to the distribution and manufacture of vehicle parts, and then to the sales link in the downstream market [24]. Wang et al. mentioned in their research that the ICV industry chain involves many fields, but according to the relationship between the upstream and downstream of the industry chain, it specifically covers upstream key systems such as decision-making and execution, and midstream system integration such as intelligent cockpit and intelligent connected vehicle. And downstream application services such as sales [25]. At present, the key upstream area of the ICV industry chain is automotive chips, but there are still technical barriers, and the development is constrained by foreign first-tier suppliers [26]. Zeng believes that chips, as the key components of automobiles, are the foundation of automobiles and the foundation of a strong country. If the chips of intelligent connected vehicles are not strong, then the whole vehicle is not strong, and the car is not strong [27]. The R&D and production of key components represented by connected and intelligent technologies will be a key link in the future ICV industry chain, and chips will become the core components of the car to realize the interconnection between people, vehicles, and homes [28].

By reviewing the related literature on intelligent connected vehicles and their industrial chains, we can find that with the continuous advancement of technology in the future, intelligent interconnection technology will support a new automobile civilization, and its complete industrial chain structure will further promote automobiles. The transformation and progress of the industry have brought new development opportunities to the existing traditional automobile industry. Therefore, intelligent connected vehicles are regarded by major auto-industries as a major opportunity for future development and become the focus of industrial layout. From the above analysis of the industrial chain structure of intelligent connected vehicles, we can think that its supply chain is a three-level supply chain system composed of chip suppliers that dominate the upstream, vehicle manufacturers in the midstream, and sellers in the downstream.

2.2. Secondary Supply Chain of Automobiles. Although intelligent connected vehicles have good market prospects, they are faced with many practical problems such as imperfect market development, low consumer maturity, and not yet fully opened demand. In order to increase the market demand for intelligent connected vehicles, it is very important to design a reasonable supply chain system. In recent years, there has been a lot of literature on automotive secondary supply chains. In the related research on the automobile supply chain under the subsidy policy, Shen et al. studied two supply chain models of direct government subsidies to automobile manufacturers and direct subsidies to distributors. Through comparison, they found that manufacturers, as the dominant player in the market, have more bargaining power. Moreover, with the payment transfer of subsidies, the profits of one enterprise will also drive the profits of the other [29, 30]. Ju et al. incorporated policy features such as industrial quantity targets and subsidy budget constraints into the model for research [31]. Sheuet al. studied the impact of government subsidies and green taxes on competition in green supply chains [32]. In the research on this aspect, some scholars discuss from the perspective of government subsidy policy and efficiency, and some scholars study the problem of subsidy strategy from the perspective of automobile supply chain. In order to promote the transformation and upgrading of the automobile industry, many countries have implemented active automobile subsidy policies for their development in order to reduce the price of automobiles. And many governments directly provide subsidies to car buyers or sellers. In the related research on the automotive secondary supply chain model under the “double points” policy, Lu et al. considered new energy vehicles under the two-level supply chain model composed of two automobile manufacturers and one autodealer. They considered the impact of emission reduction and endurance of new energy vehicles on the supply chain [33, 34]. Yu et al. studied the importance of the quality game of electric vehicles under the policy of retreat and double points, and deeply explored the production decision optimization problem of the secondary supply chain [35, 36]. Tang et al. introduced the double-point system implemented by the government and consumer preferences into the supply chain model. Considering the impact of the two on the optimal decision-making of the supply chain, the market size of the development of the automotive industry and the benefits obtained by the supply chain are closely both related to the fluctuation of the point price [37, 38]. Kang and Zhang studied the game change process between fuel vehicle and electric vehicle manufacturers under the two models of centralized decision-making and decentralized decision-making under the double-point trading policy, and further introduced consumers’ concern about low carbon as an important factor affecting purchasing behaviour [39]. Wang constructed a production R&D game model for traditional automakers and the new energy vehicle market entered in two ways: self-production and outsourcing [40]. As the government’s low-carbon subsidy policy “recedes,” the “double credit” policy came into being. In the future, the double credit policy will play an indispensable role in the transformation of the automobile industry from fuel vehicles to new energy vehicles and intelligent connected vehicles. In the related research on the automotive supply chain from the perspective of “closed-loop supply chain,” Ma et al. constructed a two-channel battery recycling game model between automobile manufacturers and retailers to implement cost-sharing contract and liability sharing contract, and studied the impact of different conditions on automobile retail price, market demand, and profit of each member of the supply chain [41]. Qiu et al. used evolutionary game method to analyze the choice of battery recycling strategy of new energy vehicles in the two-level supply chain composed of original equipment manufactures and 4S stores, and found that the key factor affecting the subsidy strategy is the revenue increase rate of both sides after the subsidy [42]. Covindan et al. studied the patterns of coordination among agents in a two-level closed-loop supply chain, classified them, and compared their advantages and disadvantages [43, 44]. Xie et al. focused on the revenue sharing contract of forward and reverse supply chains. Considering the closed-loop supply chain system composed of a single manufacturer and a single retailer in the market without consumption preference, they studied the influence of different sharing ratios on the profit maximization of manufacturers and retailers [45, 46]. From the research of the above scholars, it can be found that the closed-loop supply chain has advantages in environmental protection and resource conservation, and can improve the efficiency of resource recovery, thereby bringing huge social and economic benefits. However, most of the current researches on closed-loop supply chain and coordination mechanism are relatively scattered, and there are many studies on different dominant modes and recycling modes, but they fail to summarize the characteristics of automobile sales and recycling and build a corresponding supply chain system.

Through the summary and review of the above literature, we can find that scholars have conducted a large number of researches on the secondary supply chain of automobiles and achieved a lot of research results. It can be seen that most of the relevant researches on automobile supply chain are conducted from the perspective of government subsidy policy, “double integral” policy, and closed-loop supply chain. With the development of science and technology in the future, the traditional automobile industry will accelerate industrial transformation and upgrading, and intelligent connected vehicles will become the leader of the automobile industry in the future. For intelligent connected vehicles, the three-level supply chain is more in line with its industrial chain structure, but the relevant research on the three-level supply chain of intelligent connected vehicles is still in its infancy. Based on the existing research, we try to construct a three-level supply chain model composed of high-performance chip suppliers, intelligent vehicle manufacturers, and retailers in the automobile market, and we also discuss the influence on the profits of each body in the supply chain under different circumstances.

2.3. Research on Collaborative Innovation Decision-Making in Automotive Supply Chain. The collaborative innovation of the supply chain has become an important strategy for companies to deal with market competition. The collaborative innovation between the main bodies of the supply chain can make the operation of the supply chain more efficient and then benefit each member. Therefore, scholars have conducted a lot of research on collaborative innovation decision-making in the automotive supply chain. In the literature that studies the impact of collaborative innovation on the automotive supply chain under different circumstances, Jing et al. discussed the optimal allocation and promotion effort level of the automotive supply chain under decentralized decision-making, centralized decision-making, revenue sharing, and cost-sharing contracts. The study found that system coordination cannot be achieved under decentralized decision-making, while the combined contract of cost sharing and benefit sharing can achieve coordination and achieve Pareto improvement [47]. Zhang et al. studied the choice of supply chain entities in R&D investment and technological innovation mode under two innovation modes. The study showed that when the market demand for new products was very high, the profits would be the largest when the subjects cooperated with each other, and a win-win situation could be achieved [48]. Gong and Xiong pointed out that knowledge sharing promotes collaborative innovation in supply chains, and in the case of centralized decision-making in supply chains, supply chains can be coordinated by promising wholesale price contracts when knowledge costs are high [49]. Zhu and Sun studied the issue of how to make product quality decisions when automakers make decentralized and centralized decision-making, and analyzed three distribution strategies of online direct sales, traditional retail, and mixed channels [50]. By establishing models in which auto-suppliers independently carry out product innovation under dominant and nondominant conditions and obtain financing from retailers for product innovation, Yu and Li obtained the optimal decision of each subject in the supply chain under different product innovation strategies and analyzed the impact of innovation ability on profits [35]. From what has been discussed above, we can find that by suppliers, manufacturers and sellers in the car on a full range of collaborative innovation, product lifecycle each member of the supply chain can improve the innovation ability of new products, new technologies and innovation efficiency, and market marketing ability, so as to improve enterprise profit and consumer satisfaction. At the same time, each enterprise in the automotive supply chain can also share the cost of technological innovation through collaborative innovation, thereby reducing the innovation risk of a single enterprise and achieving a win-win situation for multiple parties. In consideration of the automotive supply chain sales efforts and green low-carbon aspects, Jiang studied the influence of retailer's sales effort behaviour on the decision-making of each subject in the supply chain, and found that retailer's sales effort cost and recycler's recovery difficulty were positively correlated with wholesale price, but negatively correlated with the profit of each subject in the supply chain [51]. Liu et al. studied the secondary supply chain considering consumers' green preferences and retailers' sales efforts [52]. Shang and Teng discussed product greenness, sales effort, price decision, and the profit of each member of the supply chain in three cases [53]. Jia et al. introduced two cost contracts and combined contracts, respectively, to study the decision-making and coordination problem of automobile supply chain based on bilateral sales efforts [54].

By summarizing relevant literature, we found that these studies have considered the impact of different situations and factors on the supply chain. Most of the existing scholars' studies have explored the automotive supply chain from the perspectives of consumers' green and low-carbon preference, retailers' sales efforts, and price decisions. There were few literature that included both product innovation and sales effort into the market demand function and discussed the relationship between the two factors and their impact on the supply chain. Therefore, on the basis of constructing the three-level supply chain of intelligent connected vehicles, Stackelberg game is used to study the influence of each body of the supply chain on various parameters and the profit of each body of the supply chain under centralized decision-making, nonsharing of innovation cost, and sharing of innovation cost, considering the innovation level and sales effort of products.

3. Problem Description and Model Hypotheses

3.1. Problem Description. Based on the summary of the upper, middle, and lower reaches of the ICV industry chain [15, 24, 25], this paper will discuss the three-level supply chain system of ICV. Compared with traditional fuel vehicles, the degree of electronization and informatization of intelligent connected vehicles is greatly improved, which increases the demand for automotive chips in the automotive industry. However, due to the influence of supply chain and long chip production cycle, the chips should be produced according to the demand [55]. At present, the level of innovation and research and development of chips is not enough, and there is still a gap with the international leading level. In the future, chip suppliers must also continuously improve the quality and performance of automotive chips in order to meet the future development needs of ICV [56]. At the same time, the realization of the value of smart cars also requires publicity efforts in the sales link to make consumers perceive and generate purchase intentions, which will further motivate suppliers and manufacturers to increase investment in innovative products and form a virtuous circle [57].

To sum up, the research object of this paper is a three-level supply chain system consisting of high-performance chip suppliers, car manufacturers, and retailers in the auto-trading market. Chip suppliers in the supply chain upstream intelligent chip made car production, and sales at a wholesale price to auto-vehicle manufacturers in the middle reaches of the intelligent snatched, again by the smart car manufacturers to produce sales at wholesale price for the car market retailers, finally by the retailers sold at retail prices to consumers.

For the intelligent and connected automobile industry, the quantity of chips produced by high-performance chip suppliers is mainly based on the actual demand of vehicle manufacturers, that is, production on demand. Due to the need of future development, chip suppliers are also constantly innovating to improve the quality and performance of automotive chips. As a result, the increasing cost of innovation is also inhibiting the development of advanced chips. In the main body of the supply chain, the retailer in the auto-market is the main body closest to the consumer. In the future popularization and promotion of intelligent connected vehicles, the sales effort of retailers will also affect the sales of cars. Therefore, this paper uses the Stackelberg game model to analyze the game models of the ICV supply chain under the three modes of centralized decision-making, nonsharing of innovation costs and sharing of innovation costs, taking into account the level of product innovation and sales effort. And obtain the maximum profit function and maximum profit value of each subject, and finally summarize some conclusions through analysis and comparison.

3.2. Model Hypotheses

Assumption 1. This paper adopts the Stackelberg game model. According to [49, 58, 59] mentioned in the literature, suppliers and vehicle manufacturers participate in the production mode of intelligent connected vehicles. This prioritization enables followers to infer information and make corresponding choices based on the behaviour of the predecessors [60]. As the core component of the car in the intelligent connected car [61], the importance of the chip in the automobile manufacturing industry is becoming more and more obvious [62], and it is an indispensable part for the vehicle manufacturer to produce the car. Therefore, we set the high-performance chip supplier as the leader in the game model, and the manufacturers and retailers of ICV as the followers in this game model.

Assumption 2. According to literature [51,63], we set the market demand function as: $q = a - bp + \alpha\theta + \lambda e$, where a represents the potential demand in the intelligent connected vehicle market, b represents the sensitivity coefficient of consumers to product prices, and [44, 45], p represents the retail price of intelligent connected vehicles, α represents the innovation effect of products, and θ represents the innovation level of products. Referring to the research of Zerang et al. [64, 65], it is assumed that market demand is a linear function of price and sales effort, and then e of retailers' sales effort is introduced, and the marginal impact of sales effort on market demand is λ. Sales efforts refer to sales policies or measures taken to expand market demand. Intelligent vehicle manufacturers maximize profits by determining the optimal wholesale price, while retailers sell intelligent connected vehicles to consumers by determining the optimal retail price p and sales effort level e, thus maximizing their profits [66].

Assumption 3. The cost of innovation input of chip supplier is $\theta^2/2k_1$ [67, 68], θ represents the level of product innovation, which can be measured by the level of product technical quality. k_1 represents the innovation capability of the chip supplier. From this function model, it can be seen that the higher the innovation level of the product, the higher the innovation cost of the chip supplier, which is unfavourable to the chip supplier, because they will bear more capital expenditure [69]. Similarly, we can assume that the retailer's sales effort cost is $e^2/2\omega$ [51].

Assumption 4. When an intelligent connected vehicle manufacturer and a chip supplier adopt a cooperative innovation decision, the two innovative technical standards are the same, that is, the degree of innovation of the two is the same [70, 71].

Assumption 5. In this paper, the profit function of chip supplier is expressed by parameter π_s. Similarly, the profit function of intelligent connected vehicle manufacturers is expressed by parameter π_m. The profit function of automobile retailers is expressed by parameter π_r, and the profit function of the whole supply chain is expressed by π_c. This article discusses the profit situation of the supply chain in three decision-making situations. If the mark c above the parameter corresponding to the profit function of the main body of the supply chain represents the centralized decision model, the mark d above the parameter represents the cost nonsharing decision model, the cost-sharing model includes two models, one is that the sales effort is independent of the product innovation level, which is represented by the parameter cs. The other is that the sales effort is related to the level of product innovation, expressed by the parameter cd. For example, π_s^c represents the profit function of the chip supplier in the case of centralized decision-making, and π_r^{cs} represents the profit function of the automobile retailer when the degree of sales effort in the cost-sharing decision model is independent of the level of product innovation [72].

3.3. Model Parameters. A summary of all the parameters and their definitions involved in this article is shown in Table 1.

4. Decision Model of Intelligent Connected Vehicle

4.1. Centralized Decision-Making in the Supply Chain of Intelligent Connected Vehicle (Case C). Under the centralized decision-making model, the main bodies of the supply chain cooperate closely to make joint decisions. Taking the maximum profit of the entire supply chain as the ultimate goal of decision-making, jointly determine the market retail price p of intelligent connected vehicle, the product innovation level θ, and the sales effort level e. From the above basic assumptions, we can see that the retailer's sales effort cost is $e^2/2\omega$.

The profit maximization function of the whole intelligent connected vehicle supply chain is

$$\max_{p,\theta,e} \pi_c^c = (p-c)(a - bp + \alpha\theta + \lambda e) - \frac{e^2}{2\omega} - \frac{\theta^2}{2k_1} - \frac{\theta^2}{2k_2}. \tag{1}$$

(1) can be obtained as follows:

$$\begin{aligned}
\frac{\partial \pi_c^c}{\partial \theta} &= (p-c)\alpha - \frac{\theta}{k_1} - \frac{\theta}{k_2} \\
&= p\alpha - c\alpha - \frac{\theta}{k_1} - \frac{\theta}{k_2}, \\
\frac{\partial \pi_c^c}{\partial p} &= a - bp + \alpha\theta - pb + cb, \\
\frac{\partial^2 \pi_c^c}{\partial e} &= \lambda p - \lambda c - \frac{e}{\omega}, \\
\frac{\partial^2 \pi_c^c}{\partial p^2} &= -b - b \\
&= -2b, \\
\frac{\partial^2 \pi_c^c}{\partial \theta^2} &= -\frac{1}{k_1} - \frac{1}{k_2} \\
&= -\frac{k_2 + k_1}{k_1 k_2}, \\
\frac{\partial^2 \pi_c^c}{\partial e^2} &= -\frac{1}{\omega}.
\end{aligned} \tag{2}$$

Table 1: Parameter meaning.

Parameters	Definition
p	Intelligent connected vehicle market retail prices
q	Intelligent connected vehicle market demand
θ	Product innovation level
w_1	The wholesale price of high-performance chips
w_2	The wholesale price of intelligent connected vehicle
k_1	Chip supplier innovation capability
k_2	Innovation capacity of intelligent connected vehicle manufacturers
α	Product innovation effect
c	The unit cost of the chip produced by the chip supplier
a	Potential market demand
b	The price sensitivity of a consumer to a product
β	The proportion of innovation costs borne by carmakers
π_s	Profits of chip suppliers
π_m	Profits of intelligent connected vehicle manufacturers
π_r	Retailer's profit
π_c	Total profit in the supply chain
e	Retailer's sales effort
ω	Retailer's sales ability
λ	The marginal influence of retailer's sales effort on market demand
φ	The influence coefficient of innovation level on retailers' sales effort
Annotation	$k_1 \in [0,1]$, $k_2 \in [0,1]$, $b \in [0,1]$, $\beta \in [0,1]$, $a > 0$

The result is: $\partial^2\pi_c^c/\partial p\,\partial e = \lambda$, $\partial^2\pi_c^c/\partial p\,\partial\theta = \alpha$, $\partial^2\pi_c^c/\partial e\,\partial p = \lambda$, $\partial^2\pi_c^c/\partial e\,\partial\theta = 0$, $\partial^2\pi_c^c/\partial\theta\,\partial p = \alpha$, $\partial^2\pi_c^c/\partial\theta\,\partial e = 0$.

In conclusion, the Hessian matrix of π_c^c is

$$H = \begin{pmatrix} \dfrac{\partial^2\pi_c^c}{\partial p^2} & \dfrac{\partial^2\pi_c^c}{\partial p\,\partial e} & \dfrac{\partial^2\pi_c^c}{\partial p\,\partial\theta} \\ \dfrac{\partial^2\pi_c^c}{\partial e\,\partial p} & \dfrac{\partial^2\pi_c^c}{\partial e^2} & \dfrac{\partial^2\pi_c^c}{\partial e\,\partial\theta} \\ \dfrac{\partial^2\pi_c^c}{\partial\theta\,\partial p} & \dfrac{\partial^2\pi_c^c}{\partial\theta\,\partial e} & \dfrac{\partial^2\pi_c^c}{\partial\theta^2} \end{pmatrix} \quad (3)$$

$$= \begin{pmatrix} -2b & \lambda & \alpha \\ \lambda & -\dfrac{1}{\omega} & 0 \\ \alpha & 0 & -\dfrac{k_1+k_2}{k_1k_2} \end{pmatrix}.$$

When $2b-\lambda^2\omega>0$, $\alpha^2k_1k_2<(2b-\lambda^2\omega)(k_1+k_2)$, the determinant of the first-order subform is $H_1=-2b<0$, the determinant of the second-order subform is $H_2=2b-\lambda^2\omega/\omega>0$, the determinant of the third-order subform is $H_3=\alpha^2k_1k_2-(2b-\lambda^2\omega)(k_1+k_2)/k_1k_2\omega<0$, because the Hessian matrix is negative definite, the function has a maximum value. It can be seen that π_c^c is a concave function of p, e, θ, so π_c^c has a maximum value and there is a maximum profit.

Combining the first-order partial derivatives $\partial\pi_c^c/\partial p=0, \partial\pi_c^c/\partial e=0, \partial\pi_c^c/\partial\theta=0$ of p, e, θ obtained above and solving the equation, the optimal retail price of intelligent connected vehicles in the market can be obtained as

$$p^{c*}=\frac{(a-\mathrm{bc})(k_1+k_2)}{(2b-\lambda^2\omega)(k_1+k_2)-\alpha^2k_1k_2}+c. \quad (4)$$

The retailer's optimal sales effort is

$$e^{c*}=\frac{(a-bc)(k_1+k_2)\lambda\omega}{(2b-\lambda^2\omega)(k_1+k_2)-\alpha^2k_1k_2}. \quad (5)$$

The optimal product innovation level is

$$\theta^{c*}=\frac{\alpha k_1k_2(a-bc)}{(2b-\lambda^2\omega)(k_1+k_2)-\alpha^2k_1k_2}. \quad (6)$$

Substituting $p^{c*}, e^{c*}, \theta^{c*}$ into formula (1), the maximum total profit of the intelligent connected vehicle supply chain can be obtained as

$$\pi_c^{c*}=\frac{(a-bc)^2(k_1+k_2)}{2\left[(2b-\lambda^2\omega)(k_1+k_2)-\alpha^2k_1k_2\right]}. \quad (7)$$

4.2. Decision-Making Model for Nonsharing of Innovation Costs in the Supply Chain of Intelligent Connected Vehicles (Case D). In the nonsharing decision-making model of supply chain innovation costs, intelligent connected vehicle manufacturers, chip supplier, and auto-retailers all only consider the maximization of their own interests, and all three use their own objective function of maximizing profit to make the final decision. In the Stackelberg model, chip supplier is the leader in the game.

(1) As the leader in the Stackelberg game, chip suppliers consider the principle of maximizing their own interests and determine the product innovation level θ and the wholesale price of batteries w_1. At this time, the objective function of the chip supplier's maximum profit is

$$\max_{w_1,\theta}\pi_s^d=(w_1-c)(a-bp+\alpha\theta+\lambda e)-\frac{\theta^2}{2k_1}. \quad (8)$$

(2) As chip suppliers determine their own product innovation level, intelligent connected vehicle manufacturers also need to determine their own level of innovation based on the chip innovation level θ. The intelligent connected vehicle manufacturer here considers maximizing their own interests and decides their own wholesale price w_2. The objective function of the maximum profit of an intelligent connected vehicle manufacturer is

$$\max_{w_2} \pi_m^d = (w_2 - w_1)(a - bp + \alpha\theta + \lambda e) - \frac{\theta^2}{2k_2}. \quad (9)$$

(3) Intelligent connected vehicle retailers wholesale vehicles to intelligent connected vehicle manufacturers. The retailer will consider the degree of sales effort based on the level of product innovation, and determine its own retail price p in consideration of maximizing its own interests. The objective function of the retailer's maximum profit is

$$\max_{p,e} \pi_r^d = (p - w_2)(a - bp + \alpha\theta + \lambda e) - \frac{e^2}{2\omega}. \quad (10)$$

The entire supply chain function is

$$\pi_c^d = \pi_s^d + \pi_m^d + \pi_r^d. \quad (11)$$

According to (10),

$$\frac{\partial \pi_r^d}{\partial p} = a - 2bp + \alpha\theta + \lambda e + bw_2, \quad (12)$$

$$\frac{\partial \pi_r^d}{\partial e} = \lambda p - \lambda w_2 - \frac{e}{\omega}. \quad (13)$$

Further derivation: $\partial^2\pi_r^d/\partial p^2 = -2b$, $\partial^2\pi_r^d/\partial e^2 = -(1/\omega)$, $\partial^2\pi_r^d/\partial p\ \partial e = \lambda$, $\partial^2\pi_r^d/\partial e\ \partial p = \lambda$

The Hessian matrix of π_r^d is: $H = \begin{pmatrix} -2b & \lambda \\ \lambda & -(1/\omega) \end{pmatrix}$

When $2b - \lambda^2\omega > 0$, $|H| = 2b - \lambda^2\omega/\omega > 0$ and the determinant of the first-order subform of a matrix is $H_1 = -2b < 0$, it can be seen that π_r^d is a concave function of p and e, so π_r^d has a maximum value, and the maximum profit of the function can be obtained at the maximum value point.

Let (12) and (13) be equal to zero, that is, make the function equal to zero with respect to p and e, and obtain the two formulas together:

$$p = \frac{a + \alpha\theta - bw_2}{2b - \lambda^2\omega} + w_2, \quad (14)$$

$$e = \frac{(a + \alpha\theta - bw_2)\lambda\omega}{2b - \lambda^2\omega}. \quad (15)$$

Substituting (14) and (15) into (9), find the first-order partial derivative of w_2:

$$\frac{\partial \pi_m^d}{\partial w_2} = \frac{b(a + \alpha\theta + bw_1 - 2bw_2)}{2b - \lambda^2\omega}. \quad (16)$$

Due to $\partial^2\pi_m^d/\partial w_2^2 < 0$, So, (9) has a maximum value. Let (16) be equal to zero, we get:

$$w_2 = \frac{a + \alpha\theta + bw_1}{2b}. \quad (17)$$

Substituting (14) (15) (17) into (8), we get:

$$\max_{w_1,\theta} \pi_s^d = \frac{b(w_1 - c)(a + \alpha\theta - bw_2)}{2(2b - \lambda^2\omega)} - \frac{\theta^2}{2k_1}. \quad (18)$$

From (18), we can see that the Hessian matrix of π_s^d is

$$H = \begin{pmatrix} -\frac{b^2}{2b - \lambda^2\omega} & \frac{\alpha b}{2(2b - \lambda^2\omega)} \\ \frac{\alpha b}{2(2b - \lambda^2\omega)} & -\frac{1}{k_1} \end{pmatrix}. \quad (19)$$

When $4(2b - \lambda^2\omega) - \alpha^2 k_1 > 0$, $|H| = b^2[4(2b - \lambda^2\omega) - \alpha^2 k_1]/2k_1(2b - \lambda^2\omega)^2 > 0$, and the determinant of the first-order subform of the matrix $H_1 = -(b^2/2b - \lambda^2\omega) < 0$, it can be seen that π_s^d is a concave function of w_1 and θ, and π_s^d has a maximum value, and the value obtained at the maximum value point is the maximum profit of this function.

Calculating the first-order partial derivatives of w_1 and θ in (19) gives:

$$\frac{\partial \pi_s^d}{\partial w_1} = \frac{b(a + \alpha\theta + bc - 2bw_1)}{2(2b - \lambda^2\omega)}, \quad (20)$$

$$\frac{\partial \pi_s^d}{\partial \theta} = \frac{\alpha b(w_1 - c)}{2(2b - \lambda^2\omega)} - \frac{\theta}{k_1}. \quad (21)$$

Let (20) and (21) be equal to 0, and the simultaneous equations can be solved:

$$w_1^{d*} = \frac{2(a - bc)(2b - \lambda^2\omega)}{b[4(2b - \lambda^2\omega) - \alpha^2 k_1]} + c, \quad (22)$$

$$\theta^{d*} = \frac{\alpha k_1 (a - bc)}{4(2b - \lambda^2\omega) - \alpha^2 k_1}. \quad (23)$$

Substituting (22) and (23) into (17), we get:

$$w_2^{d*} = \frac{3(a - bc)(2b - \lambda^2\omega)}{b[4(2b - \lambda^2\omega) - \alpha^2 k_1]} + c. \quad (24)$$

Substituting (23) and (24) into (14) and (15) can be obtained:

$$p^{d*} = \frac{b(7a + bc) - (3a + bc)\lambda^2\omega - \alpha^2 k_1 bc}{b[4(2b - \lambda^2\omega) - \alpha^2 k_1]}, \quad (25)$$

$$e^{d*} = \frac{(a - bc)\lambda\omega}{4(2b - \lambda^2\omega) - \alpha^2 k_1}. \quad (26)$$

Substituting $p^{d*}, e^{d*}, w_1^{d*}, w_2^{d*}, \theta^{d*}$ into (8), (9), (10), and (11), respectively, we get:

$$\pi_s^{d*} = \frac{(a-bc)^2}{2\left[4\left(2b-\lambda^2\omega\right)-\alpha^2 k_1\right]},$$
$$\pi_m^{d*} = \frac{(a-bc)^2\left[2k_2\left(2b-\lambda^2\omega\right)-\alpha^2 k_1^2\right]}{2k_2\left[4\left(2b-\lambda^2\omega\right)-\alpha^2 k_1\right]^2}, \tag{27}$$

$$\pi_r^{d*} = \frac{(a-bc)^2\left(2b-\lambda^2\omega\right)}{2\left[4\left(2b-\lambda^2\omega\right)-\alpha^2 k_1\right]^2}, \tag{28}$$

$$\pi_c^{d*} = \frac{(a-bc)^2\left[7k_2\left(2b-\lambda^2\omega\right)-\alpha^2 k_1\left(k_1+k_2\right)\right]}{2k_2\left[4\left(2b-\lambda^2\omega\right)-\alpha^2 k_1\right]^2}. \tag{29}$$

Nature 1: Under the supply chain cost-sharing decision model, the retail price of intelligent connected vehicles p, the product innovation level θ, the wholesale price of chip w_1, the wholesale price of intelligent connected vehicles w_2, and the retailer's sales effort e have no relationship between the manufacturer's innovative ability k_2.

Prove: In the supply chain cost nonsharing decision model, the above (22), (23), (24), (25), and (26) can be seen that there are no parameters in the function expression. And the first-order partial derivatives of $\partial\theta^{d*}/\partial k_2 = 0$, $\partial w_1^{d*}/\partial k_2 = 0$, $\partial w_2^{d*}/\partial k_2 = 0$, $\partial p^{d*}/\partial k_2 = 0$, $\partial e^{d*}/\partial k_2 = 0$ are all zero, so nature 1 is correct. Regardless of the innovative capabilities of intelligent connected vehicle manufacturers, it has no impact on supply chain innovation. In the intelligent connected vehicle supply chain, the innovation capabilities of chip suppliers will only have an impact on this supply chain.

4.3. Decision Model for Cost Sharing of Intelligent Connected Vehicle Supply Chain Innovation

4.3.1. The Degree of Sales Effort has Nothing to do with the Level of Product Innovation (Case CS). The chip suppliers and intelligent connected vehicle manufacturers in the main body of the supply chain cooperate to innovate together, and at the same time share the cost of innovation together. In the Stackelberg game model, the chip suppliers are still the leader of the game. Intelligent connected vehicle manufacturers take the initiative to propose innovation cooperation, assuming that the proportion of cooperative innovation costs borne by intelligent connected vehicle manufacturers is β and $\beta \in [0,1]$, the innovation cost is $\beta(k_1+k_2)\theta^2/2k_1k_2$. After the chip suppliers and the car manufacturer reach a cooperation agreement, the proportion of the innovation cost shared by the chip suppliers is $(1-\beta)$, and the innovation input cost is $(1-\beta)(k_1+k_2)\theta^2/2k_1k_2$. Chip suppliers will determine the product innovation level θ according to the maximum benefits they can obtain, and at the same time determine the wholesale price w_1 of their batteries to intelligent connected vehicle manufacturers.

In the case of shared cost sharing between the two entities, the innovation level of the intelligent connected vehicle manufacturer in the production of intelligent connected vehicles should be determined according to the innovation level θ of the batteries. In this case, the vehicle manufacturer determines the intelligent connected vehicle's innovation level. Wholesale price is w_2. For the intelligent connected vehicle retailer in the main body of the supply chain, its decision variable is the degree of sales effort e, and the cost of the sales effort is $e^2/2\omega$. Determine your final market retail price p and sales effort level e based on the wholesale price given by the manufacturer and on the premise of guaranteeing the maximum profit. It can be concluded that the objective function of the maximum profit of the chip suppliers is

$$\max_{w_1,\theta} \pi_s^{cs} = \left(w_1-c\right)(a-bp+\alpha\theta+\lambda e)-(1-\beta)\frac{\left(k_1+k_2\right)}{2k_1k_2}\theta^2. \tag{30}$$

The objective function of the maximum profit of an intelligent connected vehicle manufacturer is

$$\max_{w_2} \pi_m^{cs} = \left(w_2-w_1\right)(a-bp+\alpha\theta+\lambda e)-\beta\frac{\left(k_1+k_2\right)}{2k_1k_2}\theta^2. \tag{31}$$

The objective function of the retailer's maximum profit in the intelligent connected vehicle market is

$$\max_{p,e} \pi_r^{cs} = \left(p-w_2\right)(a-bp+\alpha\theta+\lambda e)-\frac{e^2}{2\omega}. \tag{32}$$

The profit function of the total supply chain is

$$\pi_c^{cs} = \pi_s^{cs}+\pi_m^{cs}+\pi_r^{cs}. \tag{33}$$

Derivation of (32) can be obtained:

$$\frac{\partial\pi_r^{cs}}{\partial p} = a+\alpha\theta+\lambda e+bw_2-2bp, \tag{34}$$

$$\frac{\partial\pi_r^{cs}}{\partial e} = \lambda\left(p-w_2\right)-\frac{e}{\omega}. \tag{35}$$

And then we get: $\partial^2\pi_r^{cs}/\partial p^2 = -2b$, $\partial^2\pi_r^{cs}/\partial e^2 = -(1/\omega)$, $\partial^2\pi_r^{cs}/\partial p\,\partial e = \lambda$, and $\partial^2\pi_r^{cs}/\partial e\,\partial p = \lambda$.

The Hessian matrix of π_r^{cs} is

$$H = \begin{pmatrix} -2b & \lambda \\ \lambda & -\dfrac{1}{\omega} \end{pmatrix}. \tag{36}$$

When $2b-\lambda^2\omega>0$, $|H| = 2b-\lambda^2\omega/\omega>0$. The first-order subdeterminant of a matrix $H_1 = -2b<0$, π_r^{cs} is the concave function of p and e. At this time, π_r^{cs} has a maximum value, and the function obtains the maximum profit at the maximum value point. Combine the above (34) and (35) together, set $\partial\pi_r^{cs}/\partial p = 0$ and $\partial\pi_r^{cs}/\partial e = 0$, and obtain:

$$p = \frac{a+\alpha\theta-bw_2}{2b-\lambda^2\omega}+w_2, \tag{37}$$

$$e = \frac{\left(a+\alpha\theta-bw_2\right)\omega\lambda}{2b-\lambda^2\omega}. \tag{38}$$

Substituting (37) and (38) into (31), and calculating the first-order partial derivative of w_2, we get:

$$\frac{\partial \pi_m^{cs}}{\partial w_2} = \frac{b\left(a + \alpha\theta + bw_1 - 2bw_2\right)}{2b - \lambda^2 \omega}. \tag{39}$$

Because $\partial^2 \pi_m^{cs} / \partial w_2^2 < 0$. Therefore, (31) has a maximum value. Set (39) equal to 0 to solve:

$$w_2 = \frac{a + \alpha\theta + bw_1}{2b}. \tag{40}$$

In summary, substituting (37), (38), and (40) into (30) can be obtained:

$$\max_{w_1, \theta} \pi_s^{cs} = \frac{b\left(w_1 - c\right)\left(a + \alpha\theta - bw_1\right)}{2\left(2b - \lambda^2 \omega\right)} - (1 - \beta)\frac{k_1 + k_2}{2k_1 k_2}\theta^2. \tag{41}$$

Calculating the first-order partial derivative of w_1 and θ from (41) can be obtained:

$$\frac{\partial \pi_s^{cs}}{\partial w_1} = \frac{b\left(a + \alpha\theta + bc - 2bw_1\right)}{2\left(2b - \lambda^2 \omega\right)}, \tag{42}$$

$$\frac{\partial \pi_s^{cs}}{\partial \theta} = \frac{\alpha b\left(w_1 - c\right)}{2\left(2b - \lambda^2 \omega\right)} - (1 - \beta)\frac{k_1 + k_2}{k_1 k_2}\theta. \tag{43}$$

And then we get: $\partial^2 \pi_s^{cs} / \partial w_1^2 = -(b^2/2b - \lambda^2 \omega)$, $(\partial^2 \pi_s^{cs} / \partial \theta^2) = -(1 - \beta)(k_1 + k_2/k_1 k_2)\partial^2 \pi_s^{cs} / \partial w_1 \partial \theta = \alpha b/2(2b - \lambda^2 \omega)$, and $\partial^2 \pi_s^{cs} / \partial \theta \, \partial w_1 = \alpha b/2(2b - \lambda^2 \omega)$

From the above derivation, we can see that the Hessian matrix of π_s^{cs} is

$$H = \begin{pmatrix} -\dfrac{b^2}{2b - \lambda^2 \omega} & \dfrac{\alpha b}{2\left(2b - \lambda^2 \omega\right)} \\ \dfrac{\alpha b}{2\left(2b - \lambda^2 \omega\right)} & -(1 - \beta)\dfrac{k_1 + k_2}{k_1 k_2} \end{pmatrix}. \tag{44}$$

When $4(1 - \beta)(k_1 + k_2)(2b - \lambda^2 \omega) - \alpha^2 k_1 k_2 > 0$, the determinant of the first-order subform of the matrix is $H_1 = -(b^2/2b - \lambda^2 \omega) < 0$, therefore, it can be seen that π_s^{cs} is a concave function of w_1 and θ. At this time, there is a maximum value, and the maximum profit can be obtained when the function reaches the maximum value. By finding the first-order partial derivatives of w_1 and θ, and then setting (42) and (43) equal to 0, the simultaneous equations can be obtained:

$$w_1^{cs*} = \frac{2(a - bc)(1 - \beta)(k_1 + k_2)\left(2b - \lambda^2 \omega\right)}{b\left[4(1 - \beta)(k_1 + k_2)\left(2b - \lambda^2 \omega\right) - \alpha^2 k_1 k_2\right]} + c, \tag{45}$$

$$\theta^{cs*} = \frac{\alpha^2 k_1 k_2 (a - bc)}{4(1 - \beta)(k_1 + k_2)\left(2b - \lambda^2 \omega\right) - \alpha^2 k_1 k_2}. \tag{46}$$

Substituting (45) and (46) into (40), we can get:

$$w_2^{cs*} = \frac{3(a - bc)(1 - \beta)(k_1 + k_2)\left(2b - \lambda^2 \omega\right)}{b\left[4(1 - \beta)(k_1 + k_2)\left(2b - \lambda^2 \omega\right) - \alpha^2 k_1 k_2\right]} + c. \tag{47}$$

Substituting (47) and (46) into (37) and (38), we get:

$$p^{cs*} = \frac{b((7a + bc) - (3a + bc)\lambda^2 \omega - \alpha^2 k_1 k_2 bc}{b\left[4(1 - \beta)(k_1 + k_2)\left(2b - \lambda^2 \omega\right) - \alpha^2 k_1 k_2\right]}, \tag{48}$$

$$e^{cs*} = \frac{(a - bc)(1 - \beta)(k_1 + k_2)\lambda\omega}{4(1 - \beta)(k_1 + k_2)\left(2b - \lambda^2 \omega\right) - \alpha^2 k_1 k_2}. \tag{49}$$

Substituting (48), (45), (47), (49), and (46) into (30), (31), (32), and (33), the maximum profits of different entities can be obtained:

$$\pi_s^{cs*} = \frac{(a - bc)^2 (1 - \beta)(k_1 + k_2)}{2\left[4(1 - \beta)(k_1 + k_2)\left(2b - \lambda^2 \omega\right) - \alpha^2 k_1 k_2\right]}, \tag{50}$$

$$\pi_m^{cs*} = \frac{(a - bc)^2\left[2(1 - \beta)^2 (k_1 + k_2)^2\left(2b - \lambda^2 \omega\right) - \beta\alpha^2 k_1 k_2 (k_1 + k_2)\right]}{2\left[4(1 - \beta)(k_1 + k_2)\left(2b - \lambda^2 \omega\right) - \alpha^2 k_1 k_2\right]^2}, \tag{51}$$

$$\pi_r^{cs*} = \frac{\left(2b - \lambda^2 \omega\right)(a - bc)^2 (1 - \beta)^2 (k_1 + k_2)^2}{2\left[4(1 - \beta)(k_1 + k_2)\left(2b - \lambda^2 \omega\right) - \alpha^2 k_1 k_2\right]^2}, \tag{52}$$

$$\pi_c^{cs*} = \frac{(a - bc)^2 (k_1 + k_2)\left[7\left(2b - \lambda^2 \omega\right)(1 - \beta)^2 (k_1 + k_2) - \alpha^2 k_1 k_2\right]}{2\left[4(1 - \beta)(k_1 + k_2)\left(2b - \lambda^2 \omega\right) - \alpha^2 k_1 k_2\right]^2}. \tag{53}$$

Nature 2: In the above three models, when the retailer's sales effort has nothing to do with the product innovation level, the retailer's sales effort e, product innovation level θ, market retail prices p, and total supply chain profits π_c all increase with the increase of retailer's sales ability.

Prove: $\partial\theta^{c*}/\partial\omega = \alpha k_1 k_2 (a - bc)(k_1 + k_2)\lambda^2/[(2b - \lambda^2\omega)(k_1 + k_2) - \alpha^2 k_1 k_2]^2 > 0$, $\partial\theta^{d*}/\partial\omega = 4\alpha k_1 (a - bc)\lambda^2/[4(2b - \lambda^2\omega) - \alpha^2 k_1]^2 > 0$, $\partial\theta^{cs*}/\partial\omega = 4\alpha k_1 k_2 (a - bc)(1 - \beta)(k_1 + k_2)\lambda^2/[4(1 - \beta)(k_1 + k_2)(2b - \lambda^2\omega) - \alpha^2 k_1 k_2]^2 > 0$. Because the first-order partial derivatives are all greater than 0, the function is monotonically increasing. Similarly, it can be proved that e, p, π_c increase with the increase in sales ability ω. When the degree of sales effort has nothing to do with the level of product innovation, no matter what, as long as the retailer improves its own sales ability, it will increase the overall profit for the supply chain. Increased retailer sales capacity will reduce the retailer's sales input costs, but strong sales capacity will increase market demand. Increased demand will increase the profits of the main supply chain entities, and chip suppliers will also improve product innovation. The improvement of the level, product performance and quality has increased the wholesale price of batteries. Eventually, retail businesses will increase the retail price of their cars to protect their profits.

4.3.2. The Degree of Sales Effort Is Related to the Level of Product Innovation (Case CD). In this case, it is assumed that the retailer's sales effort level in the automobile market increases with the improvement of the product innovation level. At this time, the retailer's sales effort level is $e = \varphi\theta$. The profit maximization function of chip suppliers, intelligent connected vehicle manufacturers, retailers, and the entire supply chain is as follows:

$$\max_{w_1,\theta} \pi_s^{cd} = (w_1 - c)(a - bp + \alpha\theta + \lambda\varphi\theta) - (1 - \beta)\frac{(k_1 + k_2)}{2k_1 k_2}\theta^2, \tag{54}$$

$$\max_{w_2} \pi_m^{cd} = (w_2 - w_1)(a - bp + \alpha\theta + \lambda\varphi\theta) - \beta\frac{(k_1 + k_2)}{2k_1 k_2}\theta^2, \tag{55}$$

$$\max_{p} \pi_r^{cd} = (p - w_2)(a - bp + \alpha\theta + \lambda\varphi\theta) - \frac{(\varphi\theta)^2}{2\omega}, \tag{56}$$

$$\pi_c^{cd} = (p - w_2)(a - bp + \alpha\theta + \lambda\varphi\theta) - \frac{(\varphi\theta)^2}{2\omega}. \tag{57}$$

To find the first-order partial derivative with respect to (56), we can get:

$$\frac{\partial\pi_r^{cd}}{\partial p} = a + \alpha\theta + \lambda\varphi\theta + bw_2 - 2bp. \tag{58}$$

Because $\partial^2\pi_r^{cd}/\partial p^2 < 0$, therefore (56) has a maximum value, let (58) equal to 0, and the solution is: $p = a + \alpha\theta + \lambda\varphi\theta + bw_2/2b$, substituting (55) and finding the partial derivative of, we can get:

$$\frac{\partial\pi_m^{cd}}{\partial w_2} = \frac{1}{2}(a + \alpha\theta + \lambda\varphi\theta + bw_1 - 2bw_2). \tag{59}$$

Because $\partial^2\pi_m^{cd}/\partial w_2^2 < 0$, therefore, (55) has a maximum value, let (59) equal to 0, and the solution is: $w_2 = a + \alpha\theta + \lambda\varphi\theta + bw_1/2b$, substituting it into (54), we can get:

$$\max_{w_1,\theta} \pi_s^{cd} = \frac{1}{4}(w_1 - c)(a + \alpha\theta + \lambda\varphi\theta) - (1 - \beta)\frac{(k_1 + k_2)}{2k_1 k_2}\theta^2. \tag{60}$$

From (60), the Hessian matrix of π_s^{cd} is: $H = \begin{pmatrix} -(b/2) & \alpha + \lambda\varphi/4 \\ \alpha + \lambda\varphi/4 & -(1 - \beta)((k_1 + k_2)/k_1 k_2) \end{pmatrix}$, $|H| = 8b(1 - \beta)(k_1 + k_2) - (\alpha + \lambda\varphi)^2 k_1 k_2/16k_1 k_2 > 0$, the determinant of the first-order principal and subform is $H_1 = -(b/2) < 0$. At this time, π_s^{cd} is the concave function of w_1 and θ, so π_s^{cd} has a maximum value, and the maximum profit is obtained at the maximum value point. Find the first-order partial derivative of w_1 and θ:

$$\frac{\partial\pi_s^{cd}}{\partial w_1} = \frac{1}{4}(a + \alpha\theta + \lambda\varphi\theta + bc - 2bw_1), \tag{61}$$

$$\frac{\partial\pi_s^{cd}}{\partial\theta} = \frac{(\alpha + \lambda\varphi)(w_1 - c)}{4} - (1 - \beta)\frac{(k_1 + k_2)}{k_1 k_2}\theta. \tag{62}$$

Set (61) and (62) equal to 0, and solve the equations in parallel, we can solve:

$$w_1^{cd*} = \frac{4(a - bc)(1 - \beta)(k_1 + k_2)}{8b(1 - \beta)(k_1 + k_2) - (\alpha + \lambda\varphi)^2 k_1 k_2} + c, \tag{63}$$

$$\theta^{cd*} = \frac{(\alpha + \lambda\varphi)k_1 k_2 (a - bc)}{8b(1 - \beta)(k_1 + k_2) - (\alpha + \lambda\varphi)^2 k_1 k_2}, \tag{64}$$

$$e^{cd*} = \varphi\theta^{cd*} = \frac{\varphi(\alpha + \lambda\varphi)k_1 k_2 (a - bc)}{8b(1 - \beta)(k_1 + k_2) - (\alpha + \lambda\varphi)^2 k_1 k_2}. \tag{65}$$

Substituting (63) and (64) into w_2, we get:

$$w_2^{cd*} = \frac{6(a - bc)(1 - \beta)(k_1 + k_2)}{8b(1 - \beta)(k_1 + k_2) - (\alpha + \lambda\varphi)^2 k_1 k_2} + c. \tag{66}$$

Substituting (63) and (64) into p, we get:

$$p^{cd*} = \frac{7(a-bc)(1-\beta)(k_1+k_2)}{8b(1-\beta)(k_1+k_2)-(\alpha+\lambda\varphi)^2k_1k_2} + c. \quad (67)$$

Substituting (67), (63), (66), and (64) into (54), (55) (56), (57), respectively, we can get:

$$\begin{aligned} \pi_s^{cd*} &= \frac{(a-bc)^2(1-\beta)(k_1+k_2)}{2\left[8b(1-\beta)(k_1+k_2)-(\alpha+\lambda\varphi)^2k_1k_2\right]}, \\ \pi_m^{cd*} &= \frac{(a-bc)^2\left[4b(1-\beta)^2(k_1+k_2)^2-\beta(\alpha+\lambda\varphi)^2k_1k_2(k_1+k_2)\right]}{2\left[8b(1-\beta)(k_1+k_2)-(\alpha+\lambda\varphi)^2k_1k_2\right]^2}, \end{aligned} \quad (68)$$

$$\pi_r^{cd*} = \frac{(a-bc)^2\left[2b\omega(1-\beta)^2(k_1+k_2)^2-\varphi^2(\alpha+\lambda\varphi)^2k_1^2k_2^2\right]}{2\omega\left[8b(1-\beta)(k_1+k_2)-(\alpha+\lambda\varphi)^2k_1k_2\right]^2}, \quad (69)$$

$$\pi_c^{cd*} = \frac{(a-bc)^2\left[14b\omega(1-\beta)^2(k_1+k_2)^2-\varphi^2(\alpha+\lambda\varphi)^2k_1^2k_2^2-\omega(\alpha+\lambda\varphi)^2(k_1+k_2)k_1k_2\right]}{2\omega\left[8b(1-\beta)(k_1+k_2)-(\alpha+\lambda\varphi)^2k_1k_2\right]^2}. \quad (70)$$

Nature 3: In the cost-sharing decision-making model of the main body of the supply chain, when the degree of sales effort is related to the innovation level of the product, the degree of sales effort e, the level of product innovation θ, and the retail price of intelligent connected vehicles in the market p have nothing to do with the retailer's sales ability ω, the total profit of the supply chain increases as the retailer's sales capacity increases.

Prove: Find the first-order partial derivative with respect to ω for $\theta^{cd*}, e^{cd*}, p^{cd*}$, we can get: $\partial\theta^{cd*}/\partial\omega = 0$, $\partial e^{cd*}/\partial\omega = 0$, $\partial p^{cd*}/\partial\omega = 0$, this shows that the level of product innovation, the degree of sales effort, and the retail price of the intelligent connected vehicle market have nothing to do with the retailer's sales ability.

$\partial\pi_c^{cd*}/\partial\omega = (a-bc)^2\varphi^2(\alpha+\lambda\varphi)^2k_1^2k_2^2\omega^2/2[8b(1-\beta)(k_1+k_2)-(\alpha+\lambda\varphi)^2k_1k_2]^2 > 0$, it can be seen that the first-order partial derivative of the function is greater than 0, and the function is monotonically increasing, so the total profit of the supply chain increases with the increase of the retailer's sales ability. In the supply chain cost-sharing decision-making model, when the retailer's sales effort is related to the product innovation level, the retailer's sales ability ω can only affect the retailer's sales input cost $e^2/2\omega$, and has no effect on other parameters. Because in the game model, the chip supplier is still the leader of the game and determines the level of product innovation. For retailers, the stronger the sales ability ω, the lower the sales input cost, the weaker the sales ability, and the higher the sales input cost. When the sales input cost is low, the maximum profit that the retailer can obtain will increase, and the overall profit of the supply chain will also increase.

5. Numerical Simulation

In order to better verify the change relationship between the various parameters, this section assigns values to each parameter, and compares and analysis various indicators under different models, to more clearly express and verify the properties described above. Refer to the previously related literature and set the values of fixed parameters. These values are as follows: $a = 50$, $b = 1$, $c = 5$, $k_1 = 0.6$, $k_2 = 0.4$, $\alpha = 0.8$, $\lambda = 0.4$, $\omega = 0.4$, $\varphi = 1$, $\beta = 0.7$ [72–74]. In the drawings in this section, the centralized decision-making model is represented by model C, and the cost-sharing model is represented by model D. There are two situations in the cost-sharing model. The first is the case where the degree of sales effort has nothing to do with the level of innovation, using model CS Representative, the second is the situation where the degree of sales effort is related to the level of innovation is represented by the model CD.

5.1. *The Impact of Auto-Retailers' Sales Capabilities on the Supply Chain.*

As can be seen from Figure 1, model C, model D, and model CS, as the retailer's sales ability improves, the degree of sales effort has also become an upward trend. In the case of model CD, the retailer's sales effort has nothing to do with sales ability, but it is much greater than the retailer's sales effort when the sales effort is not related to the innovation level. Regardless of sales ability, if auto-retailers want to achieve a higher degree of sales effort, they should sell based on the level of product innovation.

It can be seen from Figure 2 that in the case of Model C, Model D, and Model CS, the innovation level of products increases with the increase of retailer's sales ability. In the model CD, the product innovation level has nothing to do with the retailer's sales ability, and it is a horizontal straight line. However, the product innovation level is higher than the other three cases at this time, because the retailer's decision variable is not the sales ability but the chip supplier's product innovation level, and the chip suppliers does not consider the retailer's investment when determining the product's innovation level how much sales cost and profit. If

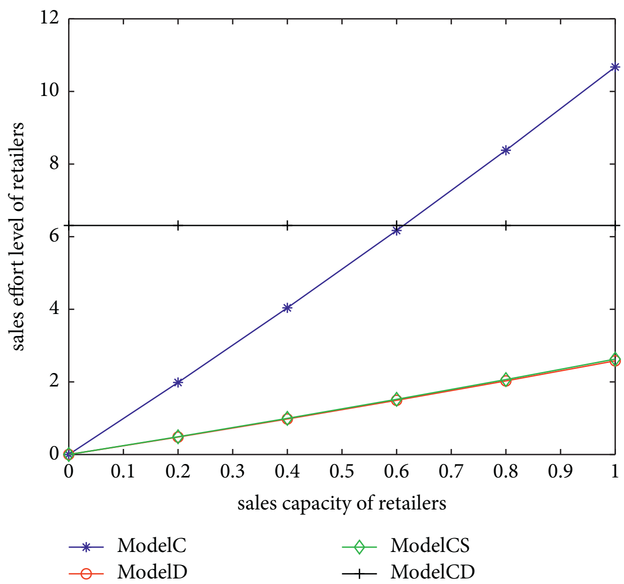

Figure 1: Sales effort level of retailers with the changing trend of sales capacity.

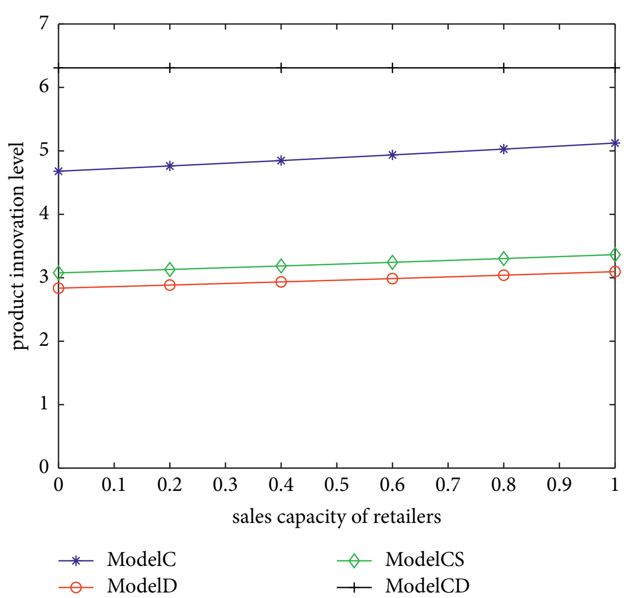

Figure 2: Product innovation level with the changing trend of sales capacity.

the overall profit of the supply chain of intelligent connected vehicles is improved, automobile retailers with stronger sales capacity should be selected.

From (28), (52), and (69), the relationship between the profit of the automobile retailer and the retailer's sales ability is obtained. In the three models in Figure 3, we can see that the retailer's profit level increases with the improvement of sales capabilities. By comparing Model D and Model CS, when the degree of sales effort has nothing to do with the level of product innovation, the cost sharing of each main body of the supply chain is more profitable than when the cost is not shared. This is because when chip suppliers in the

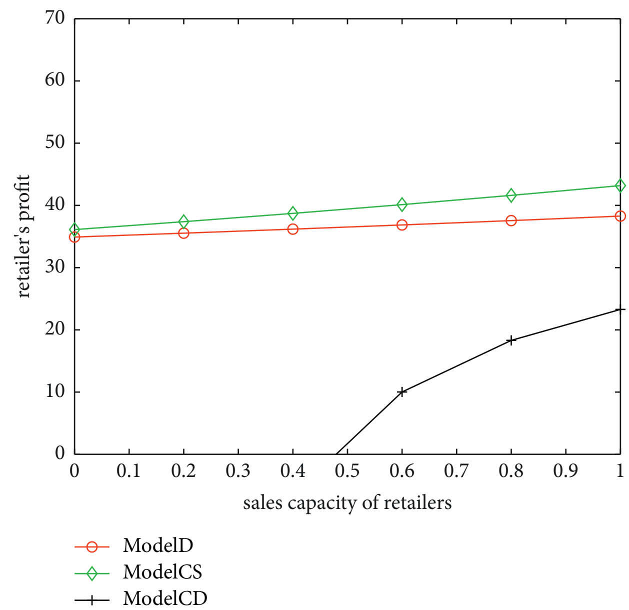

Figure 3: Retailer's profit with the changing trend of sales capacity.

supply chain cooperate with intelligent connected vehicle manufacturers to share the cost of innovation, the innovation level of batteries will increase, and the performance improvement of batteries will promote the increase in market demand. At this time, retailer's higher profits can also be obtained, so the profit of the retailer is higher when the cost is shared than when the cost is not shared. It can be seen from the model CD that when the auto-retailer is weak in its own sales ability, the retailer's profit will still show a negative value. With the improvement of the sales ability, the retailer's profit will increase, but the magnitude is small. Because the degree of sales effort is related to product innovation at this time, chip suppliers will vigorously promote the improvement of product innovation under the cost-sharing model, but will not consider the relevant investment and profit level of the retailer. The retailer is costly due to a large amount of sales effort. As a result, the profit level is not high.

5.2. The Impact of the Proportion of Innovation Costs Borne by Automakers in the Supply Chain Innovation Cost Sharing Model. From (8), (23), (46), and (64), the relationship between the level of product innovation and the proportion of innovation costs borne by automakers is obtained. As shown in Figure 4, the model CS and model CD can be seen that regardless of whether the degree of sales effort is related to the innovation level of the product, the innovation level of the product increases with the increase in the proportion of the innovation cost borne by the automaker, and the two are directly proportional, the model CS is always higher than the model CD. It shows that auto-retailers determine their own marketing efforts based on the level of product innovation, which is more conducive to the improvement of product innovation level. When automakers bear a greater proportion of innovation costs, the cost-sharing model CS and

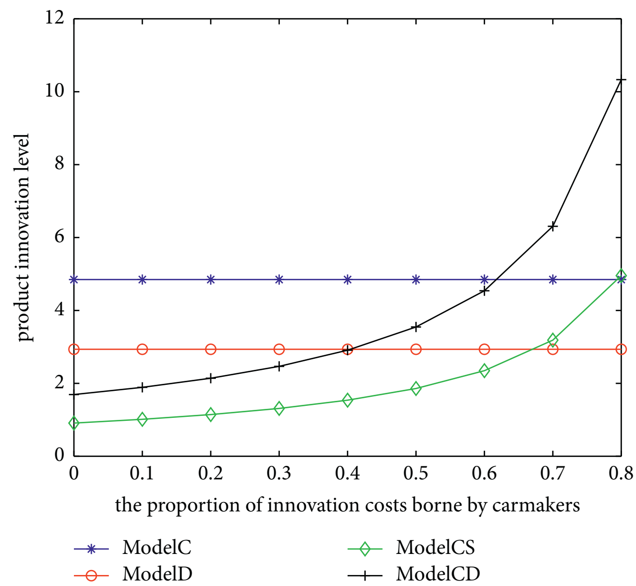

Figure 4: Innovation level changes with the proportion of innovation cost borne by manufacturers.

model CD even surpass the centralized decision-making model C and the non-cost-sharing model D.

From (7), (29), (53), and (70), the relationship between the total profit of the supply chain and the proportion of innovation costs borne by automakers is obtained. In the case of the main body of the supply chain sharing costs, namely the model CS and the model CD, as the proportion of automakers' innovation costs increases, (Figure 5 the total profit of the supply chain gradually decreases. When the retailer's sales effort is not related to the level of product innovation, the total profit of the supply chain is greater than the situation when the cost is not shared, indicating that the total profit of the supply chain has also increased after the introduction of retail sales efforts. When the degree of sales effort is related to the level of product innovation, it can be seen that the total profit of the supply chain is lower than the total profit of the supply chain of the non-cost-sharing model.

Because of the excessively high cost of sales and product innovation costs, the profit of each main body of the supply chain has decreased, which has led to a decrease in the total profit of the supply chain.

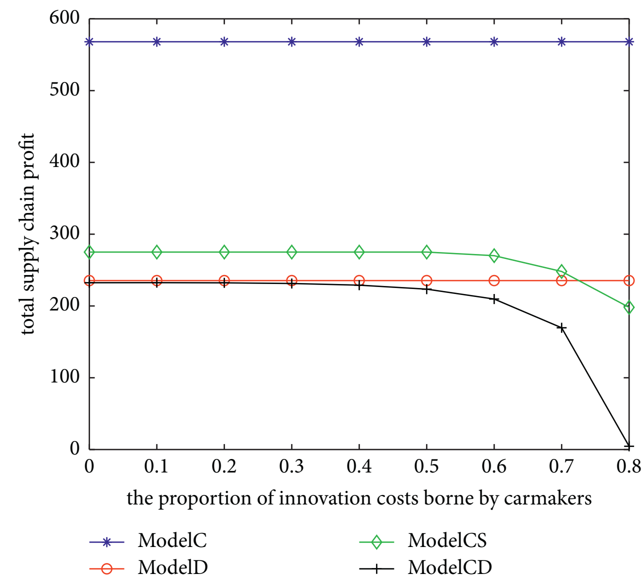

Figure 5: Total supply chain profit changes with the proportion of innovation cost borne.

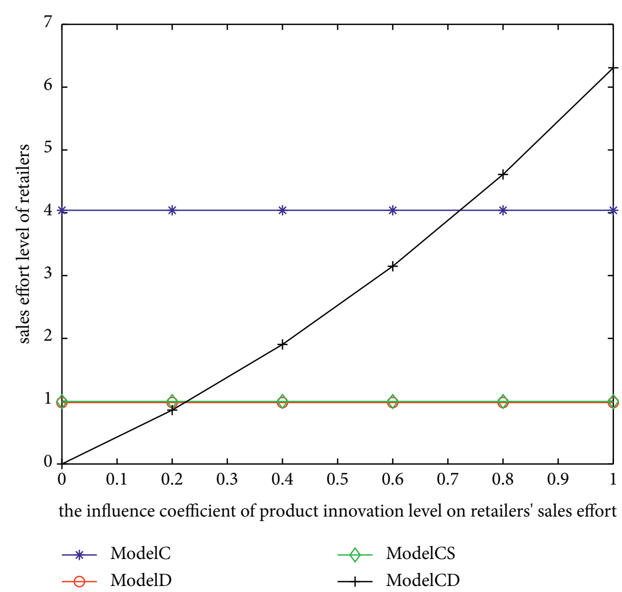

Figure 6: Sales effort level of retailers changes with the influence coefficient of sales effort.

5.3. The Influence of the Influence Coefficient of Retailer's Sales Effort on Supply Chain Decision-Making. From (5), (26), (49), and (65), the relationship between the in fluence factor φ of product innovation level on retailer's marketing effort and the degree of sales effort is obtained. When the retailer's sales effort is correlated with the product innovation level, it can be seen in Figure 6 that the sales ability level increases with the increase. When the value of φ is very small, since the level of product innovation has little impact on the retailer's marketing efforts, the auto-retailer will not invest too much marketing cost at this time, so the degree of sales effort is less than the other three cases. When the value of φ increases, the product innovation level at this time has a great impact on the retailer's marketing efforts. In model CD, the chip supplier and the car manufacturer share the cost of innovation, and the product innovation level is high, and the retailer. The degree of marketing effort will also increase and be greater than the case of model D. When the value increases to a certain value, the degree of marketing effort exceeds that of model C.

From (6), (23), (46), and (64), the relationship between the product innovation level and the influence factor φ of the product innovation level on the retailer's marketing efforts can be obtained as shown in Figure 7. When the retailer's sales effort is related to the product innovation level, the

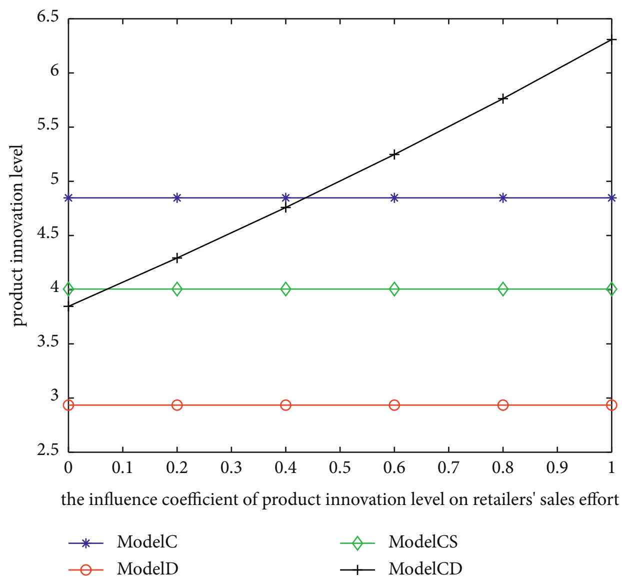

FIGURE 7: Product innovation level changes with the influence coefficient of sales effort.

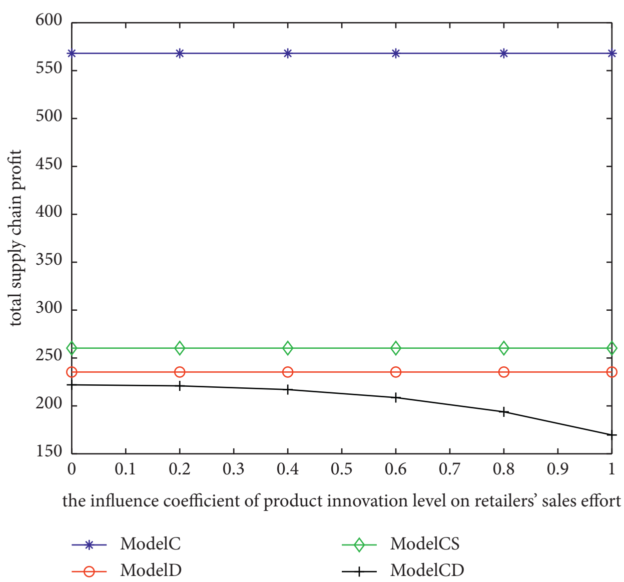

FIGURE 8: Total supply chain profit changes with the influence coefficient of sales effort.

product innovation level increases with the increase of φ, that is, the product innovation level and the product innovation level have a positive relationship with the retailer's influence factor φ on the retailer's marketing effort. When all entities in the supply chain share the cost of innovation, the product innovation level of the two cases is greater than the case of no cost sharing.

It can be seen from Figure 8 that when the retailer's sales effort is related to the product innovation level, there is an inverse relationship between the total profit of the supply chain and the product innovation level's impact factor φ on the retailer's marketing effort. As φ increases, the supply chain total profit gradually decreases and is less than the total profit of the supply chain in the other three situations. Because the retailer's sales effort is related to the chip supplier's product innovation level, the greater the impact factor φ of the innovation level on the marketing effort, the greater the sales effort will lead to an increase in demand in the automotive market. To obtain more profits, chip suppliers will further increase their investment in product innovation costs. The larger the impact factor φ, the more cost input of each main body of the supply chain. When the growth rate of cost input is greater than the rate of profit increase, the overall profit of the supply chain will become a downward trend. The analysis shows that from the perspective of the total profit of the supply chain, the retailer's sales effort should not be determined by the level of product innovation. But from the perspective of product innovation, if you want to improve the performance and functions of batteries, retailers can choose this situation to sell.

6. Conclusion

In this article, the Stackelberg game model is used to form a three-tier supply chain for chip suppliers, intelligent connected vehicle manufacturers, and retailers in the automotive market. They are in the centralized decision model, the supply chain cost nonsharing model, and the supply chain cost-sharing model. Under the two marketing methods of the model, the influence of retailer's sales effort and chip product innovation level on the supply chain is especially considered, and the model is simulated and analyzed to study the relationship between various parameters. As well as the profit situation of each main body of the supply chain, the following conclusions are obtained.

(1) When automakers and chip suppliers share the cost of innovation, and the retailer's sales effort has nothing to do with the product innovation level, the product innovation level and the total profit of the supply chain are greater than the innovation in the non-cost-sharing model It is beneficial for the supply chain to share the cost of innovation by all parties in the supply chain. In this case, the improvement of auto-retailer's sales ability can further improve the product innovation level, the retailer's sales effort, and the retailer's profit.

(2) When the automaker and the chip supplier share the cost of innovation, and the retailer's sales effort is related to the product innovation level, the product innovation level is greater than the case where the cost is not shared, but the total profit of the supply chain is less than the cost without sharing the situation, and chip suppliers will not choose to cooperate with car manufacturers. In this case, the level of product innovation and marketing effort has nothing to do with the retailer's sales ability. The total profit of the intelligent connected vehicle supply chain increases with the increase in the capacity of retailers and sellers.

(3) When the degree of sales effort is related to the level of product innovation, the retailer's sales effort and

product innovation level increase with the increase of the product innovation level's influence factor φ on the retailer's marketing effort, forming a positive correlation. The total profit of the supply chain decreases as the innovation level increases the retailer's marketing effort factor φ, which is negatively correlated.

Based on the above research conclusions, the following management enlightenment is put forward.

For chip suppliers and automakers, according to their respective development goals, retailers should be guided to choose to improve the level of product innovation to obtain innovation benefits, establish corporate image, or pursue higher profits. If chip suppliers and automobile manufacturers want a higher level of product innovation, they should choose retailers who are willing to make marketing efforts based on the level of product innovation; if the profit of the supply chain is considered, the retailer with stronger marketing ability should be selected.

For retailers in the automotive market, marketing activities have allowed consumers to have more knowledge about the use of intelligent connected vehicles and the performance and advantages of innovative products. Different levels of sales effort have different effects on the automotive market demand. When determining the level of sales effort, retailers should comprehensively consider the impact on the level of product innovation and supply chain profits. If you want to improve your own sales efforts and quickly improve product reputation in a short time, regardless of the retailer's sales capabilities, a series of sales activities should be carried out based on the innovation level of intelligent connected vehicles products. But if you consider the profitability of the supply chain when retailers choose to determine their own sales efforts, they need to improve their sales capabilities. For example, they need to promote more information about intelligent connected vehicles, increase consumers' environmental awareness, and guide consumers to buy green, low-carbon and environmentally friendly travel tools, and also increase the sales of green products in the entire automotive market.

There are several limitations in this research. Firstly, this article does not consider the impact of government subsidies and tax incentives on the supply chain of intelligent connected vehicles, future research can explore how to achieve a win-win cooperation between all parties in the intelligent connected vehicles supply chain under the effect of government subsidies and tax preferential policies and other external incentives, and further improve the level of product innovation. Secondly, the supply chain studied in this article only considers the situation that is dominated by chip suppliers. In reality, there are also situations in which automobile manufacturers dominate, and this aspect can be continued in the future [75].

Data Availability

The original contributions presented in the study are included within the article and can be obtained from the corresponding author.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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