Comput Syst Sci & Eng (2020) 3: 151–172


International Journal of
Computer Systems
Science & Engineering

# Data Mining of Urban New Energy Vehicles in an Intelligent Government Subsidy Environment Using Closed-Loop Supply Chain Pricing Model

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Given the government subsidies for new energy vehicles, this study is conducted to study the closed-loop supply chain comprising individual manufacturers, individual retailers and individual third-party recyclers. In this paper, combine the reality of new energy vehicles with the relevant research of game theory, and establish an no government subsidy model (Model N), a government subsidized consumer model (Model C), a government subsidized manufacturer model (Model M), a government subsidized third party recycler model (Model T), and a government subsidized retailer model (Model R) for quantitative research. Then, numerical examples are used to simulate the impact of government subsidies on closed-loop supply chain pricing and profits.

Keywords: Closed-loop supply chain government subsidy new energy vehicle environmental awareness

## 1. INTRODUCTION

Government subsidies are the driving force behind the development of new energy vehicles, which will affect the choice of business and consumers' behavior. These can also provide companies with a research and development base, affect the production of new energy vehicles, and stimulate market demand so that more consumers will choose to use new energy vehicles.

On the other hand, along with the high production and high sales volumes of automobiles, in the automotive supply chain, the recycling of used vehicles is the core of reverse supply logistics. The battery in the new energy vehicle also has a high recovery value. The remanufacturing of used cars can save energy and protect the environment; so, recycling and its related problems are important issues that the automotive remanufacturing industry is facing. Hence, the relevant departments issued the 'Notice on the pilot implementation plan for the issuance of "trade-in" remanufactured products'. The central government decided to provide certain financial subsidies for the recovery of eligible scrapped vehicles. In this context, the government hopes to promote the smooth and efficient operation of the entire supply chain through subsidies. Moreover, related enterprises hope that government subsidies will enable them to maximize their own profits by adopting appropriate pricing strategies.

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With respect to the coordinated management of the supply chain, the product pricing issue of the closed-loop supply chain is important. For example, the sales pricing of the product will affect its market demand, and the recycling price of the used product will also affect the amount of recycling. Consumers' environmental awareness, together with government subsidies, will affect the pricing of closed-loop supply chains. With government subsidies in place, the pricing game between manufacturers, retailers and third-party recyclers will affect the profit levels of all three. Therefore, government subsidies have a significant impact on the pricing within a closed-loop supply chain.

The government needs to formulate appropriate subsidy policies (who will be subsidized, and how much will be subsidized) to ensure fairness. Therefore, it is necessary to explore the impact of government subsidies on member pricing and profits throughout the entire closed-loop supply chain. In the closed-loop supply chain of new energy vehicles, due to government subsidies, the recipients of the subsidy obtain income, and the previously stable profits of the members of the supply chain will change. The subsidies will affect the entire closed-loop supply chain and the balance will be upset. Therefore, an efficient coordination of the entire supply chain will be required. If the demand caused by subsidies increases, or the profits from product sales increase, understand the profit distribution in the subsidy process. Once the subsidy begins to optimize and coordinate the profit distribution plan of the supply chain members, the coordination and management ability of the entire supply chain will be enhanced, and the stable state will be restored soon after the subsidy takes effect.

In this paper, the consumers' environmental awareness is taken into account. Based on the game theory, several models are established for the government subsidies of different supply chain members: Model N for members of the supply chain without government subsidies, Model C for the subsidized consumer, Model R for the subsidized retailer, Model M for the subsidized manufacturer, and Model T for the subsidized third-party recycler. The inverse game induction method is used to solve the sub-game Nash equilibrium, so that optimal pricing and optimal profit under different models are obtained, and comparative analysis is carried out. Finally, based on the mathematical model construction, case simulation is carried out, and the MATLAB 2014 a modeling tool is used to further explore the impact of different government subsidies on the closed-loop supply chain. It is anticipated that this quantitative research will provide a theoretical basis for the government's formulation of effective subsidy policies. Assisted by government subsidies, enterprises can maximize their profits by making appropriate pricing decisions. With manufacturers leading and guiding enterprises in the closed-loop supply chain, the common goals of economic benefits, energy conservation, and environmental welfare can be achieved.

## 2. LITERATURE REVIEW

The development of new energy vehicles in China is in its infancy, and has given rise to fraud in regard to subsidies and unsatisfactory government subsidies. Hence, scholars have focused mainly on the interaction between government and enterprises, and the purchasing strategy between government and consumers. Ruguo Fan et al. [1] took the promotion of Beijing new energy vehicles as an example. Focusing on the "post-subsidy era", they considered the number of local government subsidies and constructed an optimal subsidy model for the promotion of new energy vehicles by local governments. Haixiao Wang et al. [2] discovered that information asymmetry enables enterprises to strategically obtain government subsidies, which has led to deception and other behaviors that endanger the development of the industry, and put forward suggestions for the development of new energy vehicles.

In the context of China's new energy vehicle subsidies, Taiyong Zhong, Rong Du, et al. [3] explored the problem of government and enterprise adverse selection through signal game, and proposed that government should adopt different subsidy strategies according to the level of enterprise development, and emphasize the development of new energy vehicles. They also stressed that in the early stage of the development of new energy vehicles, we should pay attention to subsidies, complete infrastructure before entering the market, and subsidize buyers after entering the market to stimulate the market.. Qian Gao and Ming Fan [4] also established a game model for government and enterprises. By changing the parameter values of the model, the game of government and enterprises jumped out of the bad "lock" and developed into a good state, thus the research conclusion can provide advice to government-subsidized manufacturers. Zuping Hu, Jianjia He, et al. [5] concluded that the factors affecting the equilibrium efficiency of the game are the cost of enterprise fraud, the expected risk cost and the misjudgment of the government on the basis of the dynamic game of incomplete information in the process of subsidy application implementation.

The government's subsidies to retailers and consumers have helped to increase market demand. Research on the game between the government and sellers, and between the government and consumers includes that of Haibin Zhang et al. [6] who constructed a multi-agent new energy vehicle government subsidy incentive sales model. They compared and analyzed the impact of factors such as government static and dynamic subsidy mechanisms, and subsidized sales targets on system performance. Guohua Cao et al. [7] established an evolutionary game model between consumers and government, explored the interaction mechanism between consumers' purchasing decisions and the government subsidy offered to consumers, and found that the evolutionary game strategy finally converges to the desired goal. Jian Yu et al. [8] explored the relationship between consumer buying behavior and new energy vehicle subsidies, and found that government subsidies and consumer utility are the main reasons that influence consumers' purchasing decisions.

The influence of government subsidies on different supply chain member is also a research hotspot. This section of the paper examines the research carried out on the strategies, decision-making and profits of members of the supply chain that were given government subsidies. This paper reviews the literature on different government subsidies. Wenqing Wu [9] established a game model of manufacturer supplier cooperative research and development (R&D) model under the condition of consumer learning and government subsidy, in which the R & D subsidy strategy of the government is analyzed and numerical simulation is carried out. Fang Miao Hou [10] found that due to the lack of high technology and pricing competitiveness, unlike traditional products, manufacturers have no incentive to produce and supply green products, so the government should provide financial subsidies to manufacturers. Based on the analysis of game theory, it is concluded that the subsidy amount changes with the scale of production, and the subsidy has a more positive impact on the supply of green products. Yushuang Zhang [11] found that corporate R&D activities are not motivated due to the public nature of such companies. The government's R&D subsidies to enterprises encourage manufacturing and innovation, and have a positive impact on the entire supply chain. In addition to encouraging research and development and improving the competitiveness of manufacturers, the government also subsidizes activities related to environmental protection and low-carbon emission reduction. There are many documents on government promotion of environmental protection and low-carbon emission reduction.

In a three-tier distributed planning stackelberg model, Ashkan Hafezalkotob [12] uses retailers and consumers as followers, and the government as the leader who determines the manufacturers' subsidies and taxation strategies in the green supply chain and the ordinary supply chain. The selection of appropriate subsidies and taxes can help to reduce the negative impact of conventional supply chains on the environment, and encourage green production. Russo Diego [13] focused on the energy conservation of manufacturers and environmental protection. He conducted an in-depth study of the supply chain of timber in southern Italy, and explored the impact of government subsidies on the management of forest timber resource supply chains. Youdong Li [14] constructed three game models to study the government subsidy problem of low carbon supply chain emission reduction cooperation, analyzed the government's optimal subsidy rate, and further studied the game relationship between subsidy behavior and corporate cooperation emission reduction. Udo Broll et al. [15] explored the optimal decision of supply chain members under the two research and development subsidy policies through game theory, namely input subsidy policy and product subsidy policy. The results show that the government should use a product subsidy strategy to encourage R&D activities of enterprises. Xiyu Cao et al. [16] considered government subsidies in different carbon emission reduction modes of manufacturers, and found that the difference in subsidy ratios affects the optimal carbon emission reduction rate, optimal expected profit, and order value under different subsidy models. W.J.V. Vermeulen et al. [17] proposed a subsidy for the market dynamics and actors in the supply chain governance model for the Dutch timber and coffee product chain. Ashkan Hafezalkotob [18] considered the price competition model of two green and conventional supply chains under the influence of government financial intervention. The researcher found that the supply chain of individual manufacturers and retailers offers both environmentally friendly and generic products, and that the government's environmental protection and social responsibility tendencies have a measurable impact on government revenues and on the profits of supply chains members. Chaogai Xue et al. [19] studied the impact of government subsidies on the straw power supply chain. Firstly, they analyzed the factors that influenced the supply chain involved in straw power generation in agricultural power plants, and established a dynamic game model of supply chain under government incentives. Second, they explored the impact of government-subsidized manufacturers on the decisions made by supply chain member. Then, the researchers discussed the changes in members' profits under different incentive conditions., the

There are also many experts who take environmental awareness into account when doing supply chain research. Zhongkai Xiong et al. [20] analyzed and compared two supply chain models: the single-manufacturer dual retailer and the dual-manufacturer single-retailer model supply. They analyzed the unit carbon emissions and optimal profits of the two models, and concluded that consumer environmental awareness will affect the impact of manufacturers' optimal unit carbon emissions. Huixiao Yang et al. [21] established a supply chain system for individual suppliers and retailers, and established four programs: a "sharing plan" (RS), a "cost sharing plan" (CS), a "combined two plans"(B),and " Non-plan"(N), and found that consumer environmental awareness together with a carbon tax will force manufacturers to invest in emission reduction measures. Focusing on the impact of product environmental protection on demand, Yongmei Xu et al. [22] established a two-stage closed-loop supply chain system consisting of a single manufacturer and a single retailer. On the basis of a decentralized and centralized decision-making model, they examined the differences in the economic benefits, environmental protection and social benefits of the supply chain system, and found that the environmental protection level and profits from product sales are positively related to the environmental awareness of consumers. ConradK [23] established a duopoly model and found that equilibrium prices and market share are affected not only by product production costs, but also by the environmental awareness of consumers. For the first time, Zhongkai Xiong and Xiaoping Liang [24] considered the environmental protection level of consumers in three different recycling modes, and found that consumers' awareness of environmental protection is improved, which is conducive to improving the profit of channel members and the conclusions of total profit, wholesale price and retail price. Zugang (Leo) Liu et al. [25] used the two-stage Starkberg game model to introduce consumers' environmental awareness into the supply chain network structure, and found that when consumers' environmental awareness is increased, manufacturing companies and retail environmental products companies will benefit from it, while companies that produce and operate ordinary products will also benefit from low levels of product competition, although they will benefit less when competition is high.

Some of the main researches that focused on the impact of consumer environmental awareness on recycling channels, are described below.

In order to determine the different consumer demand function of different products, Qingchun Xu and Yihua Chen [26] considered the environmental awareness of consumers, established a closed-loop network optimization model and, through statistics, they concluded that the public's environmental awareness will affect the optimal recovery rate. Qiaohong Fang [26–27] divided the public environmental awareness into two parts: the environmental sensitivity of the product, and the expectation of product recycling rate, and analyzed the impact on the two of environmental awareness of product remanufacturing.

**Table 1** Symbol Definition Table.

| Symbol | Meaning |
|---|---|
| $P_R^M$ | Wholesale price of the product |
| $P_C^R$ | Product sales price |
| $P_T^C$ | Third party recycling price |
| $P_M^T$ | Manufacturer recycling price |
| $\Pi_M^N, \Pi_R^N, \Pi_T^N, \Pi_N$ | Profits and total profit of manufacturers, retailers, third-party recyclers in Model N |
| $\Pi_M^C, \Pi_R^C, \Pi_T^C, \Pi_C$ | Profits and total profits of manufacturers, retailers, third-party recyclers in Model C |
| $\Pi_M^R, \Pi_R^R, \Pi_T^R, \Pi_R$ | Profits and total profit of manufacturers, retailers, third-party recyclers in Model R |
| $\Pi_M^M, \Pi_R^M, \Pi_T^M, \Pi_M$ | Profits and total profit of manufacturers, retailers, third-party recyclers in Model M |
| $\Pi_M^T, \Pi_R^T, \Pi_T^T, \Pi_T$ | Profits and total profits of manufacturers, retailers, third-party recyclers in Model T |

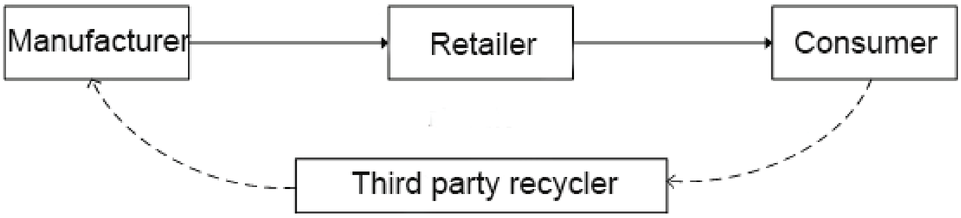


**Figure 1** Conceptual diagram of closed-loop supply chain under government subsidy conditions

# 3. MODEL BUILDING

## 3.1 Model Description and Research Hypothesis

### 3.1.1 Model Description and Symbolic Representation

It is assumed that in the closed loop supply chain of new energy vehicles, the existing members include: a single manufacturer, a single retailer, a single third-party recycler, and consumers. The retailer (R) purchases the product from the manufacturer (M) at the wholesale price $P_R^M$, then sells it to the consumer at the transaction price of $P_C^R$ (C). This is the sales channel in the model presented in this paper. In terms of recycling channels, the manufacturer (M) recovers from the consumer at the price of $P_T^C$ (the representations of R, C, M, and T are the same as below) through the outsourcing of third-party recyclers (T). Then they recycle at the recycling price of $P_M^T$ for product remanufacturing, thus forming a secondary closed-loop supply chain.

The government expands domestic demand through its subsidy policies. For different subsidy objects, this paper establishes a no government subsidy Model N. In addition, we also establish a subsidized consumer Model C, a subsidized third-party recycler Model T, a subsidized manufacturer Model M, and a subsidized retailer Model R. We conduct comparative research, and discuss the influence of government subsidies on the pricing decision of a closed-loop supply chain.

The basic symbol definitions used in this paper are listed in Table 1:

The conceptual diagram of the closed-loop supply chain under the government subsidy conditions constructed in this paper is shown in Figure 1:

### 3.1.2 Research Hypotheses

In order to explain detail the relevant situation of the closed-loop supply chain of new energy vehicles in, based on the reality of model construction and ease of processing, the basic assumptions of this paper are as follows:

**Hypothesis 1:** This article considers only a supply chain comprising individual manufacturers, retailers, and third-party recyclers, and the manufacturer entrusts only third-party recyclers to recycle.

**Hypothesis 2:** In order to ensure that recycling and remanufacturing are profitable, that is, the cost of producing remanufactured goods derived from the recycled product $C_R^M$ is less than the cost of producing a new product $C_M$, we use $\Delta = C_M - C_R^M$ to indicate the unit cost of recycling and remanufacturing, while $\Delta > 0$; and the recycled and remanufactured products are exactly the same as the new ones, their sales price are $P_C^R$.

**Hypothesis 3:** New energy vehicles are environmentally friendly. This paper assumes that consumers' environmental awareness is affecting the demand. At the same time, referring to the literature [28] on environmental awareness, the market demand for this paper is expressed as

$$Q_1 = \alpha D_1 - k_1 P_C^R + r_1 e \tag{1}$$

Here, $D_1$ is the total capacity of the automobile market, $\alpha$ is the proportion of new energy vehicles, and $k_1$ is the sensitivity coefficient of the selling price; $r_1$ indicates the consumer's sensitivity to the environmental protection of the products produced by the manufacturer, and $e$ indicates the level of environmental awareness, which is a fixed value.

**Hypothesis 4:** Assume that due to the environmental awareness of recycling, users will recycle the discarded new energy vehicles, so the recycling amount of new energy vehicles is set to

$$Q_2 = r_2 D_2 + k_2 P_T^C \tag{2}$$

where $D_2$ indicates the total amount of abandoned new energy vehicles, $r_2$ indicates consumers' recycling environmental awareness, and $k_2$ is the sensitivity coefficient to third-party recycling prices.

**Hypothesis 5:** Manufacturers, retailers, and third-party recyclers have a Stackelberg game relationship where manufacturers are dominant, while retailers and third-party recyclers are followers. All of them have neutral risks.

**Hypothesis 6:** For simplicity, we do not specifically consider local subsidy policies and restrictions on licensing and exemption from purchase tax.

**Hypothesis 7:** Assume that the retailer's operating costs are spread to $C_R$ on each product. The third-party recycler's operating cost of each product recovered is $C_T$, and each operating cost per unit sold by the manufacturer is $C_M$.

## 3.2 No Government Subsidy Model (Model N)

In order to explore the impact of government subsidies on the supply chain of new energy vehicles, we firstly study the pricing strategy and profitability of the closed-loop supply chain of new energy vehicles without any government subsidies. Based on this, a comparative study was conducted. In the closed-loop supply chain of new energy vehicles, the retailer's profit comes from the difference between sales revenue, wholesale cost and operating costs, so the retailer's profit can be expressed as:

$$\Pi_R^N = \left(P_C^R - P_R^M - C_R\right) Q_1 \quad (3)$$

Third-party recyclers' products are reclaimed from the consumer at the price of $P_T^C$ , and then sold to the manufacturer at the price of $P_M^T$, which includes certain operating costs $C_T$. Hence, the profits of a third-party recycler can be expressed as:

$$\Pi_T^N = \left(P_M^T - P_T^C - C_T\right) Q_2 \quad (4)$$

The manufacturer's income has two parts: the wholesale income from the retailer, and the cost of recycling and remanufacturing. The expenses include the purchase cost $C_M$ and the cost of recycling. Hence, the manufacturer's profits can be expressed as:

$$\Pi_M^N = \left(P_R^M - C_M\right) Q_1 + \left(\Delta - P_M^T\right) Q_2 \quad (5)$$

The total profit of the entire closed-loop supply chain member can be expressed as:

$$\Pi_N = \Pi_R^N + \Pi_T^N + \Pi_M^N \quad (6)$$

In the closed-loop supply chain of new energy vehicles, manufacturers are in a dominant position, while retailers and third-party recyclers are in a follow-up position. Enterprises take the decision initiatives, thereby leading the decisions of the entire supply chain. The game model is a complete information dynamic game. The inverse induction method can be used to solve the problem. The objective function and constraints are as follows:

$$\max_{P_R^M, P_M^T} \Pi_M^N$$

$$s.t. \begin{cases} P_C^R \in max \Pi_R^N \\ P_T^C \in max \Pi_T^N \end{cases} \quad (7)$$

First, the retailer's profit function $\Pi_R^N$ performs a first-order derivation of the sales price $P_C^R$, namely:

$$\frac{\partial \Pi_R^N}{\partial P_C^R} = \alpha D_1 - k_1 P_C^R + r_1 e - k_1 \left(P_C^R - P_R^M - C_R\right) = 0 \quad (8)$$

The relationship between the wholesale price $P_R^M$ and the sales price $P_C^R$ can be expressed as:

$$P_C^R = \frac{k_1 P_R^M + k_1 C_R + r_1 e + \alpha D_1}{2k_1} \quad (9)$$

Incorporating the result of $P_C^R$ into the manufacturer's profit function $\Pi_M^N$ and derive the $P_R^M$ to obtain the optimal solution:

$$P_R^M = \frac{\alpha D_1 + r_1 e + k_1 C_M - k_1 C_R}{2k_1} \quad (10)$$

$$P_C^R = \frac{3\alpha D_1 + 3 r_1 e + k_1 C_M + k_1 C_R}{4k_1} \quad (11)$$

Similarly, the third-party recycler's profit function $\Pi_T^N$ is used to make a first-order derivative of the recovery price $P_T^C$, namely:

$$\frac{\partial \Pi_T^N}{\partial P_T^C} = -\left(r_2 D_2 + k_2 P_T^C\right) + k_2 \left(P_M^T - P_T^C - C_T\right) = 0 \quad (12)$$

The relationship between the recovered price $P_T^C$ and $P_M^T$ can be expressed as:

$$P_T^C = \frac{k_2 P_M^T - k_2 C_T - r_2 D_2}{2k_2} \quad (13)$$

Incorporating the result of $P_T^C$ into the manufacturer's profit function $\Pi_M^N$ and derive the $P_M^T$ to get the optimal solution:

$$P_M^T = \frac{\Delta k_2 + k_2 C_T - r_2 D_2}{2k_2} \quad (14)$$

$$P_T^C = \frac{\Delta k_2 - k_2 C_T - 3 r_2 D_2}{4k_2} \quad (15)$$

The optimal solution $P_C^R$, $P_R^M$, $P_M^T$, $P_T^C$ above are the optimal selling price, the wholesale price, the price recovered from the consumer, and the pricing that is recycled to the manufacturer. Incorporating them into the profit function $\Pi_R^N$, $\Pi_T^N$, $\Pi_M^N$, $\Pi_N$, the result obtained by the following formula.

The maximum profit from the retailer can be expressed as:

$$\Pi_R^N = \frac{(\alpha D_1 + r_1 e - k_1 C_R - k_1 C_M)^2}{16k_1} \quad (16)$$

The maximum profit of third-party recyclers can be expressed as:

$$\Pi_T^N = \frac{(\Delta k_2 + r_2 D_2 - k_2 C_T)^2}{16k_2} \quad (17)$$

The manufacturer's maximum profit can be expressed as:

$$\Pi_M^C = \frac{(\alpha D_1 + r_1 e - k_1 C_R - k_1 C_M)^2}{8k_1} + \frac{(\Delta k_2 + r_2 D_2 - k_2 C_T)^2}{8k_2} \quad (18)$$

The total profit of the entire closed-loop supply chain can be expressed as:

$$\Pi_C = \frac{3\left(\alpha D_1 + r_1 e - k_1 C_R - k_1 C_M\right)^2}{16k_1} + \frac{3\left(\Delta k_2 + r_2 D_2 - k_1 C_T\right)^2}{16k_2} \quad (19)$$

## 3.3 Government-Subsidized Consumer Model (Model C)

According to the subsidy policy for the new energy vehicle, consumers can obtain corresponding government subsidies when purchasing new energy vehicles. If $P_C^G$ means the government subsidies for consumers to buy, so consumers are new to energy vehicles. The demand is transformed into:

$$Q_1^{'} = \alpha D_1 - k_1 \left(P_C^R - P_C^G\right) + r_1 e \quad (20)$$

Therefore, when the government provides unit cash subsidies to consumers, in the closed-loop supply chain of new energy vehicles, the retailer's profit can be expressed as:

$$\Pi_R^C = \left(P_C^R - P_R^M - C_R\right) Q_1^{'} \quad (21)$$

Like no government subsidies, third-party recyclers are reclaiming products from consumers at the price of $P_T^C$ and sold to manufacturers at the price of $P_M^T$. This includes certain operating costs. In the case of subsidizing consumers, the amount of recycling remains unchanged as $Q_2$, and the profit of third-party recyclers can be expressed as:

$$\Pi_T^C = \left(P_M^T - P_T^C - C_T\right) Q_2 \quad (22)$$

There are two parts to the manufacturer's income: the wholesale income from the retailer, and the cost of recycling and remanufacturing. The expenses include the cost of purchasing the product $C_M$ and the cost of recycling. Hence, the manufacturer's profit can be expressed as:

$$\Pi_M^C = (P_R^M - C_M)Q_1^{'} + (\Delta - P_M^T)Q_2 \quad (23)$$

The total profit of the entire closed-loop supply chain member can be expressed as:

$$\Pi_C = (P_C^R - C_M - C_R)Q_1^{'} + (\Delta - P_T^C - C_T)Q_2 \quad (24)$$

In the closed-loop supply chain of new energy vehicles, manufacturers are in a dominant position, while retailers and third-party recyclers are in a follow-up position. The game model is a complete information dynamic game, which can be solved by inverse induction. Under the government's cash subsidy to consumers, the objective function and constraints are as follows:

$$\max_{P_R^M, P_M^T} \Pi_M^C$$
$$s.t. \begin{cases} P_C^R \in max \Pi_R^C \\ P_T^C \in max \Pi_T^C \end{cases} \quad (25)$$

First, the retailer's profit function $\Pi_R^C$ performs a first-order derivation of the sales price $P_C^R$, namely:

$$\frac{\partial \Pi_R^C}{\partial P_C^R} = \alpha D_1 - k_1 \left(P_C^R - P_C^G\right) + r_1 e - k_1 \left(P_C^R - P_R^M - C_R\right) = 0 \quad (26)$$

The relationship between the wholesale price $P_R^M$ and the sales price $P_C^R$ can be expressed as:

$$P_C^R = \frac{k_1 P_R^M + k_1 P_C^G + k_1 C_R + r_1 e + \alpha D_1}{2k_1} \quad (27)$$

Bringing the result of $P_C^R$ into the manufacturer's profit function $\Pi_M^C$ and deriving the $P_R^M$ to get the optimal solution:

$$P_R^M = \frac{\alpha D_1 + k_1 P_C^G + r_1 e + k_1 C_M - k_1 C_R}{2k_1} \quad (28)$$

$$P_C^R = \frac{3\alpha D_1 + 3r_1 e + 3k_1 P_G^C + k_1 C_M + k_1 C_R}{4k_1} \quad (29)$$

Similarly, the profit function $\Pi_T^C$ of the third-party recycler is used to make a first-order derivation of the recovery price $P_T^C$, namely:

$$\frac{\partial \Pi_T^C}{\partial P_T^C} = -\left(r_2 D_2 + k_2 P_T^C\right) + k_2 \left(P_M^T - P_T^C - C_T\right) = 0 \quad (30)$$

The relationship between the recovered price $P_T^C$ and $P_M^T$ can be expressed as:

$$P_T^C = \frac{k_2 P_M^T - k_2 C_T - r_2 D_2}{2k_2} \quad (31)$$

Incorporating the result of $P_C^R$ into the manufacturer's profit function $\Pi_M^T$ and derive the $P_R^M$ to get the optimal solution:

$$P_M^T = \frac{\Delta k_2 + k_2 C_T - r_2 D_2}{2k_2} \quad (32)$$

$$P_T^C = \frac{\Delta k_2 - k_2 C_T - 3r_2 D_2}{4k_2} \quad (33)$$

For the optimal solution, $P_C^R$, $P_R^M$, $P_M^T$, $P_T^C$ above are the optimal selling price, the wholesale price, the price recovered from the consumer, and the pricing that is recycled to the manufacturer. Incorporating them into the profit function $\Pi_R^N$, $\Pi_T^N$, $\Pi_M^N$, $\Pi_N$, the result is as follows:

The maximum profit of the retailer can be expressed as:

$$\Pi_R^C = \frac{\left(\alpha D_1 + k_1 P_C^G + r_1 e - k_1 C_R - k_1 C_M\right)^2}{16k_1} \quad (34)$$

The maximum profit of third-party recyclers can be expressed as:

$$\Pi_T^C = \frac{\left(\Delta k_2 + r_2 D_2 - k_2 C_T\right)^2}{16k_2} \quad (35)$$

The manufacturer's maximum profit can be expressed as:

$$\Pi_M^C = \frac{\left(\alpha D_1 + k_1 P_C^G + r_1 e - k_1 C_R - k_1 C_M\right)^2}{8k_1} + \frac{\left(\Delta k_2 + r_2 D_2 - k_2 C_T\right)^2}{8k_2} \quad (36)$$

The total profit of the entire closed-loop supply chain can be expressed as:

$$\Pi_C = \frac{3\left(\alpha D_1 + k_1 P_C^G + r_1 e - k_1 C_R - k_1 C_M\right)^2}{16k_1} + \frac{3\left(\Delta k_2 + r_2 D_2 - k_2 C_T\right)^2}{16k_2} \quad (37)$$

## 3.4 Government-Subsidized Third-Party Recycler Model (Model T)

Recycling used cars can help to protect the environment by reducing consumer losses and providing manufacturers with raw materials for recycling. In order to encourage the recycling of new energy vehicles, third-party recyclers should be mobilized to promote the development of the entire supply chain. At the same time, according to the Interim Measures for the Management of Recycling and Utilization of New Energy Vehicles' Power Battery in 2017, the government also gives relevant subsidies and other policies to enterprises that recycle batteries. This paper assumes that the government also offers a certain cash subsidy $P_T^G$ to third-party recyclers. In the case of the government subsidizing third-party recyclers, in the closed-loop supply chain of new energy vehicles, third-party recyclers recycle consumers' discarded products at the price of $P_T^C$, and sell them to the manufacturer at the price of $P_M^T$. The operating cost is $C_T$. The government unit subsidy is $P_T^G$, so the profits of the third-party recycler can be expressed as:

$$\Pi_T^T = \left(P_M^T + P_T^G - P_T^C - C_T\right) Q_2 \quad (38)$$

The retailer's profit comes from the difference between sales revenue and wholesale cost and operating cost, so the retailer's profit can be expressed as:

$$\Pi_R^T = \left(P_C^R - P_R^M - C_R\right) Q_1 \quad (39)$$

The manufacturer's income has two parts: the wholesale income from the retailer, and the cost of recycling and remanufacturing. The expenses include the cost of purchasing $C_M$ and the cost of recycling. After the government subsidizes third-party recyclers, the manufacturer's profit can be expressed as:

$$\Pi_M^T = \left(P_R^M - C_M\right) Q_1 + \left(\Delta - P_M^T\right) Q_2 \quad (40)$$

The total profit of the entire closed-loop supply chain member can be expressed as:

$$\Pi_T = (P_C^R - C_M - C_R)Q_1 + (\Delta + P_T^G - P_T^C - C_T)Q_2 \quad (41)$$

In the closed-loop supply chain of new energy vehicles, where the government subsidizes third-party recyclers to encourage product reuse, manufacturers are in a dominant position, and retailers and third-party recyclers are in a follow-up position. The model is a complete information dynamic game, which can be solved by inverse induction. After the government subsidizes the third-party recycler, the objective function and constraints are as follows:

$$\max_{P_R^M, P_M^T} \Pi_M^T \quad s.t. \begin{cases} P_C^R \in \max \Pi_R^T \\ P_T^C \in \max \Pi_T^T \end{cases} \quad (42)$$

First, the retailer's profit function $\Pi_R^T$ performs a first-order derivation of the sales price $P_C^R$, namely:

$$\frac{\partial \Pi_R^T}{\partial P_C^R} = \alpha D_1 - k_1 P_C^R + r_1 e - k_1\left(P_C^R - P_R^M - C_R\right) = 0 \quad (43)$$

The relationship between the wholesale price $P_R^M$ and the sales price $P_C^R$ can be expressed as:

$$P_C^R = \frac{k_1 P_R^M + k_1 C_R + r_1 e + \alpha D_1}{2k_1} \quad (44)$$

Bringing the result of $P_C^R$ into the manufacturer's profit function $\Pi_M^T$ and derive the $P_R^M$ to obtain the optimal solution:

$$P_R^M = \frac{\alpha D_1 + r_1 e + k_1 C_M - k_1 C_R}{2k_1} \quad (45)$$

$$P_C^R = \frac{3\alpha D_1 + 3r_1 e + k_1 C_M + k_1 C_R}{4k_1} \quad (46)$$

Since the government subsidizes third-party recyclers, the profit function of third-party recyclers can be expressed as:

$$\Pi_T^T = \left(P_M^T - P_T^C - C_T + P_T^G\right) Q \quad (47)$$

Similarly, the third-party recycler's profit function $\Pi_T^T$ is used to make a first-order derivative of the recovery price $P_T^C$, namely:

$$\frac{\partial \Pi_T^T}{\partial P_T^C} = -\left(r_2 D_2 + k_2 P_T^C\right) + k_2\left(P_M^T + P_T^G - P_T^C - C_T\right) = 0 \quad (48)$$

The relationship between the recovered price $P_T^C$ and $P_M^T$ can be expressed as:

$$P_T^C = \frac{k_2 P_M^T + k_2 P_T^G - k_2 C_T - r_2 D_2}{2k_2} \quad (49)$$

Incorporating the result of $P_T^C$ into the manufacturer's profit function $\Pi_M^T$ and derive the $P_M^T$ to get the optimal solution:

$$P_M^T = \frac{\Delta k_2 + k_2 C_T - r_2 D_2 - k_2 P_T^G}{2k_2} \quad (50)$$

$$P_T^C = \frac{\Delta k_2 + k_2 P_T^G - k_2 C_T - 3r_2 D_2}{4k_2} \quad (51)$$

The optimal solution $P_C^R$, $P_R^M$, $P_M^T$, $P_T^C$ above are the optimal selling price, the wholesale price, the price recovered from the consumer, and the pricing that is recycled to the manufacturer. Bringing them into the profit function $\Pi_R^N$, $\Pi_T^N$, $\Pi_M^N$, $\Pi_N$, the result is as follows:

The maximum profit of the retailer can be expressed as:

$$\Pi_R^T = \frac{(\alpha D_1 + r_1 e - k_1 C_R - k_1 C_M)^2}{16k_1} \quad (52)$$

The maximum profit of third-party recyclers can be expressed as:

$$\Pi_T^T = \frac{\left(\Delta k_2 + k_2 P_T^G + r_2 D_2 - k_2 C_T\right)^2}{16k_2} \tag{53}$$

The manufacturer's maximum profit can be expressed as:

$$\Pi_M^T = \frac{(\alpha D_1 + r_1 e - k_1 C_R - k_1 C_M)^2}{8k_1} + \frac{\left(\Delta k_2 + k_2 P_T^G + r_2 D_2 - k_2 C_T\right)^2}{8k_2} \tag{54}$$

The total profit of the entire closed-loop supply chain can be expressed as:

$$\Pi_T = \frac{3\,(\alpha D_1 + r_1 e - k_1 C_R - k_1 C_M)^2}{16k_1} + \frac{3\left(\Delta k_2 + k_2 P_T^G + r_2 D_2 - k_2 C_T\right)^2}{16k_2} \tag{55}$$

## 3.5 Government-Subsidized Manufacturer Model (Model M)

According to the subsidy policy for new energy vehicles, after a new energy vehicle is registered, the manufacturer can obtain a certain municipal subsidy. This article sets the unit subsidy obtained by the manufacturer from the government as $P_M^G$, and assumes that manufacturers will comply with laws and regulations, operate in good faith, and not engage in illegal behavior such as fraudulent claims for compensation. On the other hand, if the manufacturer participates in the recycling of the used car, it can also receive the government unit recycling subsidy $P_M^{G'}$ (differentiated from the unit subsidy for sale $P_M^G$). Therefore, when the government subsidizes new energy vehicle manufacturers, the profits of the latter will change. The manufacturer's income has three parts: the wholesale income from the retailer, the cost of recycling and remanufacturing, and the government's additional two subsidies pertaining to the procurement production cost $C_M$ and the cost of recycling. Hence, the manufacturer's profit can be expressed as:

$$\Pi_M^M = \left(P_R^M + P_M^G - C_M\right) Q_1 + \left(? + P_M^G - P_M^T\right) Q_2 \tag{56}$$

The profits of retailers and the profits of third-party recyclers can be expressed as:

$$\Pi_R^M = \left(P_C^R - P_R^M - C_R\right) Q_1 \tag{57}$$

$$\Pi_T^M = \left(P_M^T - P_T^C - C_T\right) Q_2 \tag{58}$$

The total profit of the entire closed-loop supply chain member can be expressed as:

$$\Pi_M = (P_C^R + P_M^G - C_M - C_R)Q_1 + (\Delta + P_M^G - P_T^C - C_T)Q_2 \tag{59}$$

In the closed-loop supply chain of new energy vehicles, the government provides cash subsidies to manufacturers. Manufacturers are in a dominant position, while retailers and third-party recyclers are in a follow-up position. The game model is a complete information dynamic game, which can use the inverse induction method to solve. The objective function and constraints are as follows:

$$\max_{P_R^M,\,P_M^T} \Pi_M^M \quad s.t.\begin{cases} P_C^R \in \max \Pi_R^M \\ P_T^C \in \max \Pi_T^M \end{cases} \tag{60}$$

First, the retailer's profit function $\Pi_R^M$ performs a first-order derivation of the sales price $P_C^R$, namely:

$$\frac{\partial \Pi_R^M}{\partial P_C^R} = \alpha D_1 - k_1 P_C^R + r_1 e - k_1\left(P_C^R - P_R^M - C_R\right) = 0 \tag{61}$$

The relationship between the wholesale price $P_R^M$ and the sales price $P_C^R$ is:

$$P_C^R = \frac{k_1 P_R^M + k_1 C_R + r_1 e + \alpha D_1}{2k_1} \tag{62}$$

Bringing the result of $P_C^R$ into the manufacturer's profit function $\Pi_M^M$ and derive the $P_R^M$ to get the optimal solution:

$$P_R^M = \frac{\alpha D_1 - k_1 P_M^G + r_1 e + k_1 C_M - k_1 C_R}{2k_1} \tag{63}$$

$$P_C^R = \frac{3\alpha D_1 + 3r_1 e - k_1 P_M^G + k_1 C_M + k_1 C_R}{4k_1} \tag{64}$$

Similarly, the third-party recycler's profit function $\Pi_T^M$ is used to make a first-order derivative of the recovery price $P_T^C$, namely:

$$\frac{\partial \Pi_T^M}{\partial P_T^C} = -\left(r_2 D_2 + k_2 P_T^C\right) + k_2\left(P_M^T - P_T^C - C_T\right) = 0 \tag{65}$$

The relationship between the recovered price $P_T^C$ and $P_M^T$ is:

$$P_T^C = \frac{k_2 P_M^T - k_2 C_T - r_2 D_2}{2k_2} \tag{66}$$

Incorporating the result of $P_T^C$ into the manufacturer's profit function $\Pi_M^N$ and derive the $P_M^T$ to get the optimal solution:

$$P_M^T = \frac{\Delta k_2 + k_2 P_M^{G'} + k_2 C_T - r_2 D_2}{2k_2} \tag{67}$$

$$P_T^C = \frac{\Delta k_2 + k_2 P_M^{G'} - k_2 C_T - 3r_2 D_2}{4k_2} \tag{68}$$

The optimal solution $P_C^R$, $P_R^M$, $P_M^T$, $P_T^C$ above comprises the optimal selling price, the wholesale price, the price recovered from the consumer, and the pricing that is recycled to the manufacturer. Incorporating them into the profit function $\Pi_R^N$, $\Pi_T^N$, $\Pi_M^N$, $\Pi_N$, the result is as follows:

The maximum profit of the retailer is:

$$\Pi_R^M = \frac{\left(\alpha D_1 + r_1 e + k_1 P_M^G - k_1 C_R - k_1 C_M\right)^2}{16k_1} \tag{69}$$

The maximum profit of third-party recyclers is:

$$\Pi_T^M = \frac{\left(\Delta k_2 + k_2 P_M^{G'} + r_2 D_2 - k_2 C_T\right)^2}{16 k_2} \tag{70}$$

The manufacturer's maximum profit is:

$$\Pi_M^M = \frac{\left(\alpha D_1 + k_1 P_M^G + r_1 e - k_1 C_R - k_1 C_M\right)^2}{8 k_1} + \frac{\left(\Delta k_2 + k_2 P_M^{G'} + r_2 D_2 - k_2 C_T\right)^2}{8 k_2} \tag{71}$$

The total profit of the entire closed-loop supply chain is:

$$\Pi_M = \frac{3\left(\alpha D_1 + r_1 e + k_1 P_M^G - k_1 C_R - k_1 C_M\right)^2}{16 k_1} + \frac{3\left(\Delta k_2 + k_2 P_M^{G'} + r_2 D_2 - k_2 C_T\right)^2}{16 k_2} \tag{72}$$

## 3.6 Government-Subsidized Retailer Model (Model R)

At present, the government's subsidies for new energy vehicles are focused on consumer terminals, aiming to boost market demand and allowing more consumers to choose new energy vehicles. However, the importance of retailers in promoting new energy vehicles cannot be ignored: on the one hand, retailers promote the development of new energy vehicles through advertising and store sales; on the other hand, they promote the production and technological innovation of upstream manufacturers. Therefore, the government can appropriately subsidize the retailer's income. The unit subsidy here is called $P_R^G$. In this way, the retailer's profits include a certain subsidy income in addition to the difference between sales revenue and wholesale cost and operating costs. Therefore, the retailer's profits can be expressed as:

$$\Pi_R^R = \left(P_C^R + P_R^G - P_R^M - C_R\right) Q_1 \tag{73}$$

Third-party recyclers reclaim products from the consumer at the price of $P_T^C$ and then sell these to the manufacturer at the price of $P_M^T$, which includes certain operating costs $C_T$. Hence, the profits of a third-party recycler can be expressed as:

$$\Pi_T^R = \left(P_M^T - P_T^C - C_T\right) Q_2 \tag{74}$$

The manufacturer's income has two parts: the wholesale income from the retailer, and the cost of recycling and remanufacturing. The expenses include the cost of purchasing $C_M$ and the cost of recycling. Hence, the manufacturer's profits can be expressed as:

$$\Pi_M^R = \left(P_R^M - C_M\right) Q_1 + \left(\Delta - P_M^T\right) Q_2 \tag{75}$$

Therefore, under the condition of government-subsidized retailers, the total profits of the entire closed-loop supply chain members can be expressed as:

$$\Pi_R = \Pi_R^N + \Pi_T^N + \Pi_M^N \tag{76}$$

$$\Pi_R = (P_C^R + P_R^G - C_M - C_R) Q_1 + (\Delta - P_T^C - C_T) Q_2 \tag{77}$$

In the closed-loop supply chain of new energy vehicles, the government subsidizes retailers, the manufacturers are still in a dominant position, and retailers and third-party recyclers are in a follow-up position. The game model is a complete information dynamic game, which can use the inverse induction method to solve the problem. The objective function and constraints are as follows:

$$\max_{P_R^M, P_M^T} \Pi_M^R \quad s.t. \begin{cases} P_C^R \in \max \Pi_R^R \\ P_T^C \in \max \Pi_T^R \end{cases} \tag{78}$$

First, the retailer's profit function $\Pi_R^R$ performs a first-order derivation of the sales price $P_C^R$, namely:

$$\frac{\partial \Pi_R^R}{\partial P_C^R} = \alpha D_1 - k_1 P_C^R + r_1 e - k_1 \left(P_C^R + P_R^G - P_R^M - C_R\right) = 0 \tag{79}$$

The relationship between the wholesale price $P_R^M$ and the sales price $P_C^R$ can be expressed as:

$$P_C^R = \frac{k_1 P_R^M + k_1 C_R + r_1 e + \alpha D_1 - k_1 P_R^G}{2 k_1} \tag{80}$$

Incorporating the result of $P_C^R$ into the manufacturer's profit function $\Pi_M^R$ and derive the $P_R^M$ to get the optimal solution:

$$P_R^M = \frac{\alpha D_1 + r_1 e + k_1 C_M - k_1 C_R + k_1 P_R^G}{2 k_1} \tag{81}$$

$$P_C^R = \frac{3\alpha D_1 + 3 r_1 e + k_1 C_M + k_1 C_R - k_1 P_R^G}{4 k_1} \tag{82}$$

Similarly, the third-party recycler's profit function $\Pi_T^N$ is used to make a first-order derivative of the recovery price $P_T^C$, namely:

$$\frac{\partial \Pi_T^N}{\partial P_T^C} = -\left(r_2 D_2 + k_2 P_T^C\right) + k_2 \left(P_M^T - P_T^C - C_T\right) = 0 \tag{83}$$

The relationship between the recovered price $P_T^C$ and $P_M^T$ can be expressed as:

$$P_T^C = \frac{k_2 P_M^T - k_2 C_T - r_2 D_2}{2 k_2} \tag{84}$$

Bringing the result of $P_T^C$ into the manufacturer's profit function $\Pi_M^N$ and derive the $P_M^T$ to obtain the optimal solution:

$$P_M^T = \frac{\Delta k_2 + k_2 C_T - r_2 D_2}{2 k_2} \tag{85}$$

$$P_T^C = \frac{\Delta k_2 - k_2 C_T - 3 r_2 D_2}{4 k_2} \tag{86}$$

The optimal solution, $P_C^R$, $P_R^M$, $P_M^T$, $P_T^C$ above, comprises the optimal selling price, the wholesale price, the price recovered

**Table 2** Sales Channel Optimal Pricing Table.

| Model | Third party recycling price $P_T^C$ | Third party recycling price $P_M^T$ |
|---|---|---|
| N | $\frac{\Delta k_2 - k_2 C_T - 3r_2 D_2}{4k_2}$ | $\frac{\Delta k_2 + k_2 C_T - r_2 D_2}{2k_2}$ |
| C | $\frac{\Delta k_2 - k_2 C_T - 3r_2 D_2}{4k_2}$ | $\frac{\Delta k_2 + k_2 C_T - r_2 D_2}{2k_2}$ |
| T | $\frac{\Delta k_2 + k_2 P_T^G - k_2 C_T - 3r_2 D_2}{4k_2}$ | $\frac{\Delta k_2 + k_2 C_T - r_2 D_2 - k_2 P_T^G}{2k_2}$ |
| M | $\frac{\Delta k_2 + k_2 P_M^{G'} - k_2 C_T - 3r_2 D_2}{4k_2}$ | $\frac{\Delta k_2 + k_2 P_M^{G'} + k_2 C_T - r_2 D_2}{2k_2}$ |
| R | $\frac{\Delta k_2 - k_2 C_T - 3r_2 D_2}{4k_2}$ | $\frac{\Delta k_2 + k_2 C_T - r_2 D_2}{2k_2}$ |

from the consumer, and the pricing of products recycled to the manufacturer. Bringing them into the profit function $\Pi_R^N$, $\Pi_T^N$, $\Pi_M^N$, $\Pi_N$, the result is as follows:

The maximum profit of the retailer can be expressed as:

$$\Pi_R^R = \frac{\left(\alpha D_1 + r_1 e + k_1 P_R^G - k_1 C_R - k_1 C_M\right)^2}{16k_1} \tag{87}$$

The maximum profits of third-party recyclers can be expressed as:

$$\Pi_T^R = \frac{(\Delta k_2 + r_2 D_2 - k_2 C_T)^2}{16k_2} \tag{88}$$

The manufacturer's maximum profits can be expressed as:

$$\Pi_M^R = \frac{\left(\alpha D_1 + r_1 e + k_1 P_R^G - k_1 C_R - k_1 C_M\right)^2}{8k_1} + \frac{(\Delta k_2 + r_2 D_2 - k_2 C_T)^2}{8k_2} \tag{89}$$

The total profits of the entire closed-loop supply chain can be expressed as:

$$\Pi_R = \frac{3\left(\alpha D_1 + r_1 e + k_1 P_R^G - k_1 C_R - k_1 C_M\right)^2}{16k_1} + \frac{3(\Delta k_2 + r_2 D_2 - k_2 C_T)^2}{16k_2} \tag{90}$$

## 4. COMPARISON OF VARIOUS MODEL INDICATORS

By comparing wholesale prices and sales prices under different subsidy models, third parties recover prices from consumers, and recycle pricing strategies such as manufacturer prices, retailer profits, third-party recycler profits, manufacturer profits, and total profits; we can analyze and compare the impact of pricing decisions on different government subsidies, and obtain useful conclusions through the analysis and comparison of models.

### 4.1 Comparison of Sales Channel Pricing

Table 2 shows the positive sales channels of new energy vehicles, including the wholesale price $P_R^M$ and sales price $P_C^R$ of retailers. For wholesale prices $P_R^M$, the following conclusions are obtained:

**Conclusion 1** If the government government's unit subsidy for the retailer is more than that for the consumer, namely, $P_C^G < P_R^G$:

$$P_R^M(M) < P_R^M(N) = P_R^M(T) < P_R^M(C) < P_R^M(R) \quad (M < N = T < C < R);$$

Conversely, if the government's unit subsidy for the consumer is more than that for the retailer, namely, $P_R^G < P_C^G$:

$$P_R^M(M) < P_R^M(N) = P_R^M(T) < P_R^M(R) < P_R^M(C) \quad (M < N = T < R < C)$$

**Proof.** *The results of the table above are calculated:* $P_R^M(N) = P_R^M(T)$ $P_R^M(N) - P_R^M(M) = P_M^G/2 > 0$, $P_R^M(R) - P_R^M(N) = P_R^G/2 > 0$, $P_R^M(C) - P_R^M(N) = P_C^G/2 > 0$, $P_R^M(C) - P_R^M(R) = \left(P_C^G - P_R^G\right)/2$ *Certified.*

Conclusion 1 Shows that in the manufacturer-led decision-making model, government-subsidized manufacturers will set the lowest wholesale price of new energy vehicles. Government subsidized third-party manufacturers have the same wholesale price as no government subsidies, while the subsidizing of retailers and consumers will raise wholesale prices. When the government gives a greater subsidy to the retailer's unit than to the consumer's unit, the subsidized retailer's wholesale price will be higher, and if the subsidy is more, the wholesale price will be higher when the consumer is subsidized.

For the sales price $P_C^R$, the following conclusions are made:

**Conclusion 2** If government's unit subsidy for the manufacturer is more than that for the retailer, namely, $P_M^G > P_R^G$, then:

$$P_M^G > P_R^G P_C^R(M) < P_C^R(R) < P_C^R(N) = P_C^R(T) < P_C^R(C) \quad (M < R < N = T < C)$$

Conversely, if the government's unit subsidy for retailer is more than that for the manufacturer, namely, $P_R^G > P_M^G$, then:

$$P_C^R(R) < P_C^R(M) < P_C^R(N) = P_C^R(T) < P_C^R(C) \quad (R < M < N = T < C)$$

**Proof.** *Calculated from the results of the table above:*

$$P_C^R(N) = P_C^R(T) \; P_C^R(N) - P_C^R(M) = P_M^G/4 > 0,$$
$$P_C^R(N) - P_C^R(R) = P_R^G/4 > 0,$$
$$P_C^R(C) - P_C^R(N) = 3P_C^G/4 > 0,$$
$$P_C^R(R) - P_C^R(M) = \left(P_M^G - P_R^G\right)/4$$

*Certified.*

**Table 3** Optimal Pricing Table for Recycling Channels.

| Model | Wholesale prices $P_R^M$ | Selling price $P_C^R$ |
|---|---|---|
| N | $\frac{\alpha D_1+r_1e+k_1C_M-k_1C_R}{2k_1}$ | $\frac{3\alpha D_1+3r_1e+k_1C_M+k_1C_R}{4k_1}$ |
| C | $\frac{\alpha D_1+k_1P_C^G+r_1e+k_1C_M-k_1C_R}{2k_1}$ | $\frac{3\alpha D_1+3r_1e+3k_1P_G^C+k_1C_M+k_1C_R}{4k_1}$ |
| T | $\frac{\alpha D_1+r_1e+k_1C_M-k_1C_R}{2k_1}$ | $\frac{3\alpha D_1+3r_1e+k_1C_M+k_1C_R}{4k_1}$ |
| M | $\frac{\alpha D_1-k_1P_M^G+r_1e+k_1C_M-k_1C_R}{2k_1}$ | $\frac{3\alpha D_1+3r_1e-k_1P_M^G+k_1C_M+k_1C_R}{4k_1}$ |
| R | $\frac{\alpha D_1+r_1e+k_1C_M-k_1C_R+k_1P_R^G}{2k_1}$ | $\frac{3\alpha D_1+3r_1e+k_1C_M+k_1C_R-k_1P_R^G}{4k_1}$ |

**Table 4** Optimal Profitability of Different Model Retailers.

| Model | Retailer profit representation |
|---|---|
| N | $\Pi_R^N=\frac{(\alpha D_1+r_1e-k_1C_R-k_1C_M)^2}{16k_1}$ |
| C | $\Pi_R^C=\frac{\left(\alpha D_1+k_1P_C^G+r_1e-k_1C_R-k_1C_M\right)^2}{16k_1}$ |
| T | $\Pi_R^T=\frac{(\alpha D_1+r_1e-k_1C_R-k_1C_M)^2}{16k_1}$ |
| M | $\Pi_R^M=\frac{\left(\alpha D_1+r_1e+k_1P_M^G-k_1C_R-k_1C_M\right)^2}{16k_1}$ |
| R | $\Pi_R^R=\frac{\left(\alpha D_1+r_1e+k_1P_R^G-k_1C_R-k_1C_M\right)^2}{16k_1}$ |

We know that when the government subsidizes the manufacturer, the manufacturing costs of the manufacturer decrease, indirectly decreasing the wholesale price, while the government subsidizes the third party will not affect the wholesale price and the sales price; when consumers are subsidized, they benefit and the sales of new energy vehicles will increase, indirectly raising the price of products. This proves our conclusion.

## 4.2 Comparison of Pricing of Recycling Channels

In the manufacturer-led decision-making model, there is a reverse recycling channel in the new energy closed-loop supply chain. First, the third-party recycler recovers the price $P_T^C$ from the consumer, and then sells to the manufacturer for re-manufacturing at the price of $P_M^T$. According to the results shown in the table above, it is not difficult to obtain the following conclusions:

**Conclusion 3** For third-party recycling prices $P_T^C$, if government's unit subsidy for the manufacturer for recycling is more than that for the third-party recycler, namely, $P_M^{G'} > P_T^G$, then:

$$P_T^C(N)=P_T^C(R)=P_T^C(C)<P_T^C(T)<P_T^C(M)$$
$$(R=N=C<T<M);$$

Conversely, if the government's unit subsidy for the third-party recycler for recovery is more than that for the manufacturer, namely, $P_T^G > P_M^{G''}$, then:

$$P_T^C(N)=P_T^C(R)=P_T^C(C)<P_T^C(M)<P_T^C(T)$$
$$(N=R=C<M<T).$$

**Proof.** *Calculated from the results of the table above:*

$$P_T^C(N)=P_T^C(C)=P_T^C(R),\ P_T^C(M)-P_T^C(N)=\frac{P_M^{G'}}{4}>0,$$

$$P_T^C(T)-P_T^C(N)=\frac{P_T^G}{4}>0,\quad P_T^C(T)-P_T^C(M)=\frac{P_T^G-P_M^{G'}}{4}$$

*Certified.*

**Conclusion 4** Third-party recyclers to recycle the waste to the manufacturer for remanufacturing, recycling prices $P_M^T$ will have:

$$P_T^C(T)<P_T^C(N)=P_T^C(R)=P_T^C(C)<P_T^C(M)$$
$$(T<N=R=C<M)$$

**Proof.** *Calculated from the results of the table above:*

$$P_T^C(N)=P_T^C(C)=P_T^C(R),\ P_T^C(M)-P_T^C(N)=\frac{P_M^{G'}}{4}>0,$$

$$P_T^C(T)-P_T^C(N)=\frac{P_T^G}{4}>0,\quad P_T^C(T)-P_T^C(M)=\frac{P_T^G-P_M^{G'}}{4}$$

*Certified.*

Government subsidies for consumer retailers will not affect the pricing of recycling channels. The government subsidizes third-party recyclers, and third-party recyclers will be more willing to recycle products at higher prices. Third-party recyclers can also sell to manufacturers for remanufacturing at a higher price, when the government also applies corresponding unit recovery subsidies to manufacturers.

## 4.3 Comparison of Retailer's Profit Optimal Equilibrium Solution

**Conclusion 5** The profit optimal equilibrium solution size of Model C, M and Retailers are related to the government unit subsidy $P_R^G$, $P_C^G$, $P_M^G$. If the subsidy is higher, and the retailer's profit will be greater, and both of them will be greater than subsidized third-party recyclers.

**Table 5** Third Party Recycler's Optimal Income Statement under Different Models.

| Model | Third-party recycler profit representation |
|---|---|
| N | $\Pi_T^N = \frac{(\Delta k_2 + r_2 D_2 - k_2 C_T)^2}{16k_2}$ |
| C | $\Pi_T^C = \frac{(\Delta k_2 + r_2 D_2 - k_2 C_T)^2}{16k_2}$ |
| T | $\Pi_T^T = \frac{\left(\Delta k_2 + k_2 P_T^G + r_2 D_2 - k_2 C_T\right)^2}{16k_2}$ |
| M | $\Pi_T^M = \frac{\left(\Delta k_2 + k_2 P_M^{G'} + r_2 D_2 - k_2 C_T\right)^2}{16k_2}$ |
| R | $\Pi_T^R = \frac{(\Delta k_2 + r_2 D_2 - k_2 C_T)^2}{16k_2}$ |

**Proof.** *Calculated from the results of the table above:*

$$\Pi_R^N(N) = \Pi_R^T(T), \Pi_R^N(N) - \Pi_R^N(C) < 0,$$
$$\Pi_R^N(N) - \Pi_R^M(M) < 0, \Pi_R^N(N) - \Pi_R^R(R) < 0$$

$$\Pi_R^C(C) - \Pi_R^R(R) = \frac{\left(\alpha D_1 + k_1 P_C^G + r_1 e - k_1 C_R - k_1 C_M\right)^2 - \left(\alpha D_1 + r_1 e + k_1 P_R^G - k_1 C_R - k_1 C_M\right)^2}{16k_1}$$

$$\Pi_R^M(M) - \Pi_R^N(R) = \frac{\left(\alpha D_1 + k_1 P_M^G + r_1 e - k_1 C_R - k_1 C_M\right)^2 - \left(\alpha D_1 + r_1 e + k_1 P_R^G - k_1 C_R - k_1 C_M\right)^2}{16k_1}$$

$$\Pi_R^C(C) - \Pi_R^M(M) = \frac{\left(\alpha D_1 + k_1 P_C^G + r_1 e - k_1 C_R - k_1 C_M\right)^2 - \left(\alpha D_1 + r_1 e + k_1 P_M^G - k_1 C_R - k_1 C_M\right)^2}{16k_1}$$

*So the size of $\Pi_R^C(C)$, $\Pi_R^R(R)$ and $\Pi_R^M(M)$ depends on the size comparison among $P_C^G$, $P_R^G$. and $P_M^G$.*
*Certified.*

Government's subsidies for retailers will increase retailers' profits, while government-subsidized manufacturers will lower wholesale prices, which will indirectly increase retailers' profits.

## 4.4 Comparison of the Best Equilibrium Solution for Third-Party Recyclers

**Conclusion 6** For third-party recycler profits, if government's unit subsidy for the manufacturer is more than that for the third-party recycler, namely, $P_M^{G'} > P_T^G$, then:

$$\Pi_T^R(R) = \Pi_T^N(N) = \Pi_T^C(C) < \Pi_T^T(T) < \Pi_T^M(M)$$
$$(R = N = C < T < M)$$

Conversely, if government's unit subsidy for the third-party recycler is more than that for the manufacturer, namely, $P_T^G > P_M^{G'}$, then:

$$\Pi_T^R(R) = \Pi_T^N(N) = \Pi_T^C(C) < \Pi_T^T(T) < \Pi_T^M(M)$$
$$(R = N = C < M < T)$$

**Proof.** *Calculated from the above table:* $\Pi_T^R(R) = \Pi_T^N(N) = \Pi_T^C(C)$, $\Pi_T^N(N) - \Pi_T^T(T) < 0$, $\Pi_T^N(N) - \Pi_T^M(M) < 0$ *and*

$$\Pi_T^T(T) - \Pi_T^M(M) = \frac{\left(\Delta k_2 + k_2 P_T^G + r_2 D_2 - k_2 C_T\right)^2 - \left(\Delta k_2 + k_2 P_M^{G'} + r_2 D_2 - k_2 C_T\right)^2}{16k_2}$$

*Hence, the size of $\Pi_T^T(T)$, $\Pi_T^M(M)$ depends on the size of $P_T^G$, $P_M^{G'}$.*
*Certified.*

## 4.5 Comparison of Manufacturer's Optimal Profit Equilibrium Solution and Total Profit Optimal Equilibrium Solution

**Conclusion 7** In any of the subsidy models in this paper, the manufacturer's profit is always two-thirds of the total profit. This can be seen in Table 6 and Table 7 which show the division of profits. where the profits are divided.

Under the condition that the government subsidizes any item, in the manufacturer-driven decision-making model, the manufacturer is in a favorable position for the game, two-thirds of the entire profits of the supply chain goes to the manufacturer, with the rest going to the retailer and the seller The size changes slightly, and the sum is only one-third of the remaining profits

# 5. NUMERICAL EXAMPLES

This section uses numerical examples to verify the conclusions of the above models and to make relevant comparisons, mainly including the following aspects of research content:

① In the different subsidy model, we study the impact of government subsidies on closed-loop supply chain pricing and profits, and explore the impact of different subsidies on the supply chain under horizontal conditions.

② Under the same subsidy model, we study the impact of government subsidies on the closed-loop supply chain, including the impact of government on the pricing of supply chain members, the impact on profits, and the proportion of profits.

③ Dynamic research on sales price, third-party recycling price and total profit in different subsidy models.

Given realistic scenario of new energy vehicles, in order to facilitate mathematical calculations, the following parameters are used:

**Table 6** Manufacturer's Optimal Income Statement under Different Models.

| Model | Manufacturer profit representation |
|---|---|
| N | $\Pi_M^N = \frac{(\alpha D_1+r_1e-k_1C_R-k_1C_M)^2}{8k_1} + \frac{(\Delta k_2+r_2D_2-k_2C_T)^2}{8k_2}$ |
| C | $\Pi_M^C = \frac{\left(\alpha D_1+k_1P_C^G+r_1e-k_1C_R-k_1C_M\right)^2}{8k_1} + \frac{(\Delta k_2+r_2D_2-k_2C_T)^2}{8k_2}$ |
| T | $\Pi_M^T = \frac{(\alpha D_1+r_1e-k_1C_R-k_1C_M)^2}{8k_1} + \frac{\left(\Delta k_2+k_2P_T^G+r_2D_2-k_2C_T\right)^2}{8k_2}$ |
| M | $\Pi_M^M = \frac{\left(\alpha D_1+k_1P_M^G+r_1e-k_1C_R-k_1C_M\right)^2}{8k_1} + \frac{\left(\Delta k_2+k_2P_M^{G'}+r_2D_2-k_2C_T\right)^2}{8k_2}$ |
| R | $\Pi_M^R = \frac{\left(\alpha D_1+r_1e+k_1P_R^G-k_1C_R-k_1C_M\right)^2}{8k_1} + \frac{(\Delta k_2+r_2D_2-k_2C_T)^2}{8k_2}$ |

**Table 7** Total Profit Statement of Supply Chain under Different Models.

| Model | Total profit |
|---|---|
| N | $\Pi_N = \frac{3(\alpha D_1+r_1e-k_1C_R-k_1C_M)^2}{16k_1} + \frac{3(\Delta k_2+r_2D_2-k_2C_T)^2}{16k_2}$ |
| C | $\Pi_C = \frac{3\left(\alpha D_1+k_1P_C^G+r_1e-k_1C_R-k_1C_M\right)^2}{16k_1} + \frac{3(\Delta k_2+r_2D_2-k_2C_T)^2}{16k_2}$ |
| T | $\Pi_T = \frac{3(\alpha D_1+r_1e-k_1C_R-k_1C_M)^2}{16k_1} + \frac{3\left(\Delta k_2+k_2P_T^G+r_2D_2-k_2C_T\right)^2}{16k_2}$ |
| M | $\Pi_M = \frac{3\left(\alpha D_1+r_1e+k_1P_M^G-k_1C_R-k_1C_M\right)^2}{16k_1} + \frac{3\left(\Delta k_2+k_2P_M^{G'}+r_2D_2-k_2C_T\right)^2}{16k_2}$ |
| R | $\Pi_R = \frac{3\left(\alpha D_1+r_1e+k_1P_R^G-k_1C_R-k_1C_M\right)^2}{16k_1} + \frac{3(\Delta k_2+r_2D_2-k_2C_T)^2}{16k_2}$ |

**Table 8** Optimal Pricing and Optimal Income Statement for Each Model.

| | N | C | T | M | R | Model comparison |
|---|---|---|---|---|---|---|
| $P_R^M$/ten thousand | 16.13 | 18.13 | 16.13 | 15.13 | 16.63 | $M < N = T < R < C$ |
| $P_C^R$/ten thousand | 21.19 | 24.19 | 21.19 | 20.69 | 20.94 | $M < R < N = T < C$ |
| $P_T^C$/ten thousand | 0.50 | 0.50 | 0.55 | 0.60 | 0.50 | $N = C = R < T < M$ |
| $P_M^T$/ten thousand | 1.58 | 1.58 | 1.48 | 1.78 | 1.58 | $T < N = C = R < M$ |
| $\Pi_M$ /billion | 136.18 | 209.2 | 136.7 | 171.76 | 152.94 | $N < T < R < M < C$ |
| $\Pi_R$ /billion | 66.01 | 102.52 | 66.01 | 83.27 | 74.39 | $N = T < R < M < C$ |
| $\Pi_T$ /billion | 2.08 | 2.08 | 2.34 | 2.61 | 2.08 | $N = C = R < T < M$ |

$$\alpha = 0.02,\ D_1 = 5000,\ D_2 = 10,\ r_1 = 0.1,\ r_2 = 0.1,$$
$$k_1 = 4,\ k_2 = 3,\ C_M = 8$$
$$C_R = 1,\ C_r = 0.25,\ e = 10,\ \Delta = 3.25,\ P_C^G = 4,\ P_R^G = 1,$$
$$P_M^G = 2,\ P_T^G = 0.2,\ P_C^{G'}.$$

According to the above assumptions, the corresponding values of the optimal pricing and profit in each decision model are obtained as follows:

As can be seen from Table 8, the government's subsidy for consumers increases the wholesale price of products, while that for manufacturers reduces the wholesale price of products; the subsidizing of consumers also indirectly increases the price of new energy vehicles, but the subsidizing of manufacturers and retailers will lower the price of new energy vehicles.

In terms of recycling channels, the government's subsidy for third-party recyclers and manufacturers will drive up the price at which consumers choose to recycle their waste products so that consumers will get more benefits, and will be more willing to choose to recycle their waste. If the government subsidizes third-party recyclers, and recyclers will be more willing to sell a manufacturer at a lower price for remanufacturing. If the government subsidizes the manufacturers' recycling behavior, it will make this price higher, and the difference earned by third-party recyclers will be even greater;

Government subsidies for consumers, retailers, and manufacturers have increased the profits of retailers. When the government subsidizes more consumers, retailers will receive the greatest profits; if the government subsidizes the recycling third-party recyclers and manufacturers, it will increase the profits of third-party recyclers; because manufacturers are involved in both sales and recycling, in the decision-making model, manufacturers are dominant, so the government's subsidy for closed-loop supply chain members will increase the profits of manufacturers.

## 5.1 Research on Pricing and Profit Impact Under Different Subsidy Models

In the manufacturer-led closed-loop supply chain decision-making model, in order to further explore the influence of different types of government subsidies on supply chain pricing and profit, based on the mathematical model established in the previous section, this paper combines numerical examples for dynamic simulation using MATLAB R2014a to explore the impact of different government subsidies on pricing and profits in the closed-loop supply chain.

As can be seen from Figure 2, when the government subsidizes the manufacturer, the manufacturer benefits and will be more

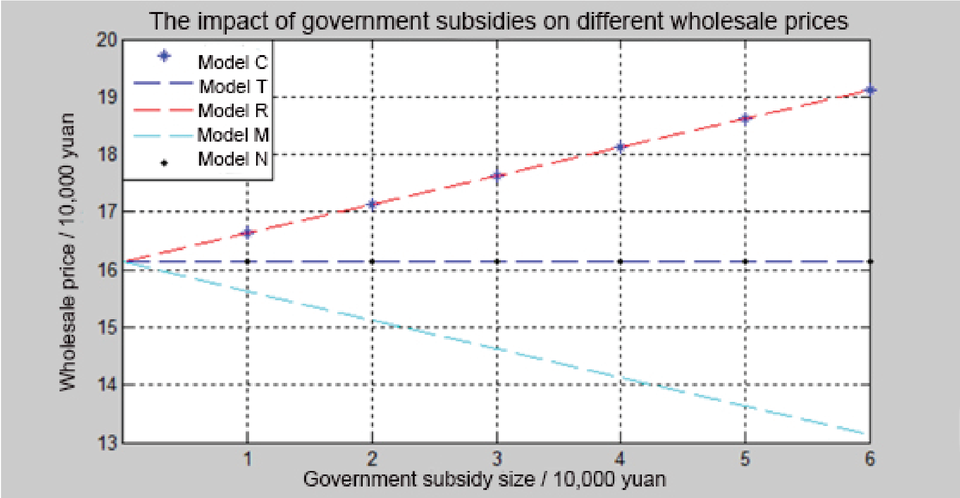


**Figure 2** The impact of different government subsidies on wholesale prices

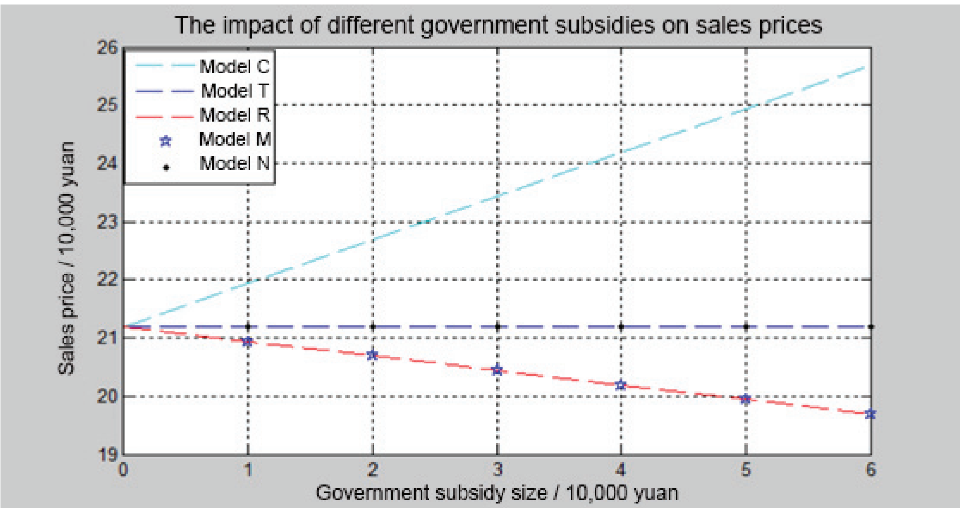


**Figure 3** The impact of different government subsidies on sales prices

willing to sell at a lower wholesale price, that is, the wholesale price in Model M is the lowest Subsidies to both retailers and consumers will increase the wholesale price, and the growth of these two types of models will be the same. If the government subsidizes consumers more than retailers, the wholesale price in Model C will be higher. If the government subsidizes retailers more than consumers, the wholesale price in Model R will be higher. Since third-party recyclers do not participate in product sales activities, Model T will not affect the level of the wholesale price.

As shown in Figure 3, in different subsidy models, government subsidies also have an impact on the sales price of new energy vehicles. In Model C, the government subsidizes consumers, bringing benefits to consumers. Because the manufacturer is in a dominant position, it will drive the increase in sales price The government subsidies for manufacturers M and retailers R will reduce the sales price, but the reduction is more moderate than the increase in the subsidy model C; since third-party recyclers do not participate in product sales activities, government subsidies for third-party recycler model T will not affect the sales prices.

As can be seen from Figure 4, in order to protect the environment and save energy, when the government subsidizes manufacturers and third-party recyclers, consumers can handle used cars at higher recycling prices; if the government gives third-party recyclers a higher subsidy than the manufacturers' recycling subsidy, the recovery price in Model T will be higher. If the government subsidies for the manufacturer are higher than the recycling subsidies for the third-party recyclers, the recycling price in Model M will be higher; since it does not participate in the recycling process, Model R will not affect the recycling price.

As can be seen from Figure 5, third-party recyclers hand over products recycled from consumers to manufacturers for recycling and remanufacturing; manufacturers under Model T can be recovered at a lower price; and manufacturers under Model M are more willing to recycle at a higher price. However, the increase in the price of recycling is more moderate than the decline in the price of subsidized third-party recyclers; and the subsidized retailer model R and the subsidized consumer model C will not affect the manufacturers' recycling price level.

As can be seen from Figure 6, the government subsidies are different, and the impact on retailers' profits is different. The government's subsidies for the sales channel members-manufacturers, and suppliers and consumers will drive retailers'

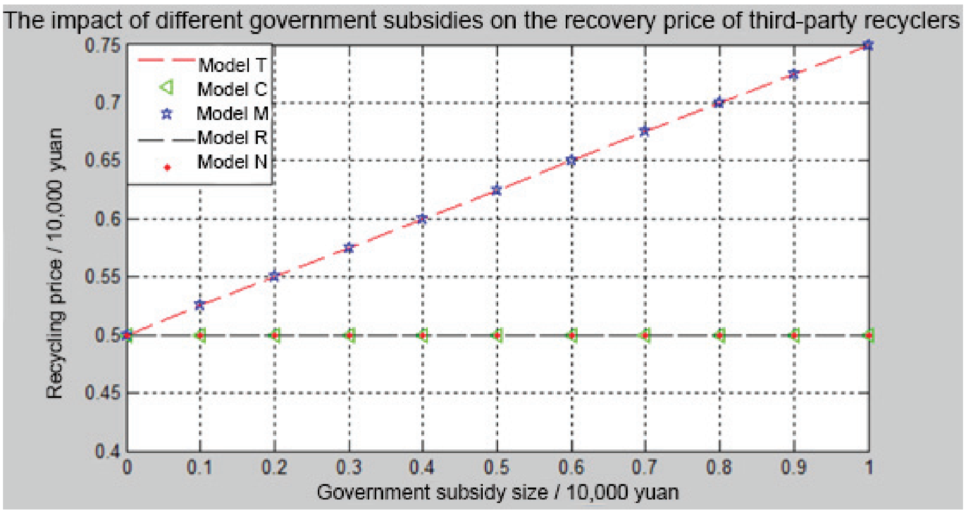


**Figure 4** The impact of different government subsidies on the recovery price of third-party recyclers

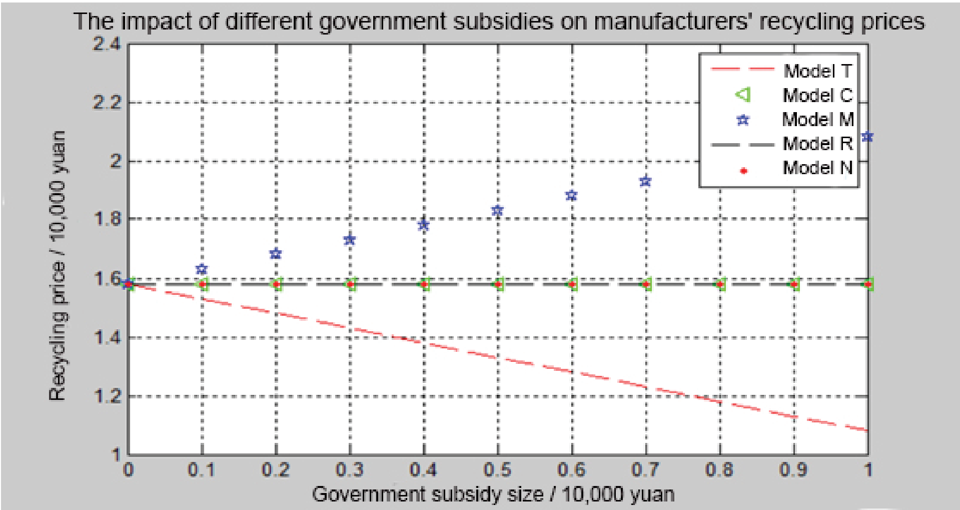


**Figure 5** The impact of different government subsidies on manufacturers' recycling prices

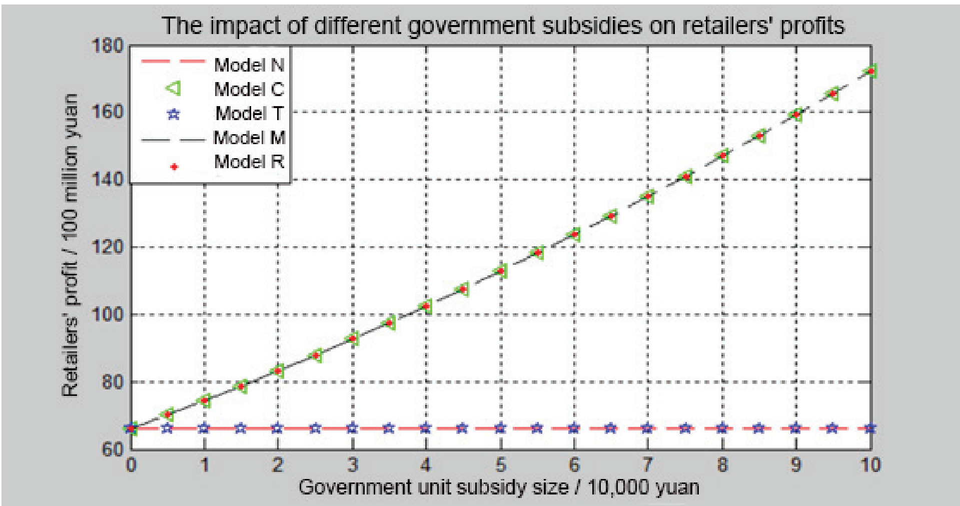


**Figure 6** The impact of different government subsidies on retailers' profits

profits. However, the subsidizing of third-party recyclers will not affect retailers' profit levels.

As can be seen from Figure 7, the government subsidies are different, and the impact on the profits of third-party recyclers is also different. In order to encourage the conservation of resources in order to protect the environment, the government subsidizes the recycling activities of third-party recyclers and manufacturers, which will increase the profit of third-party

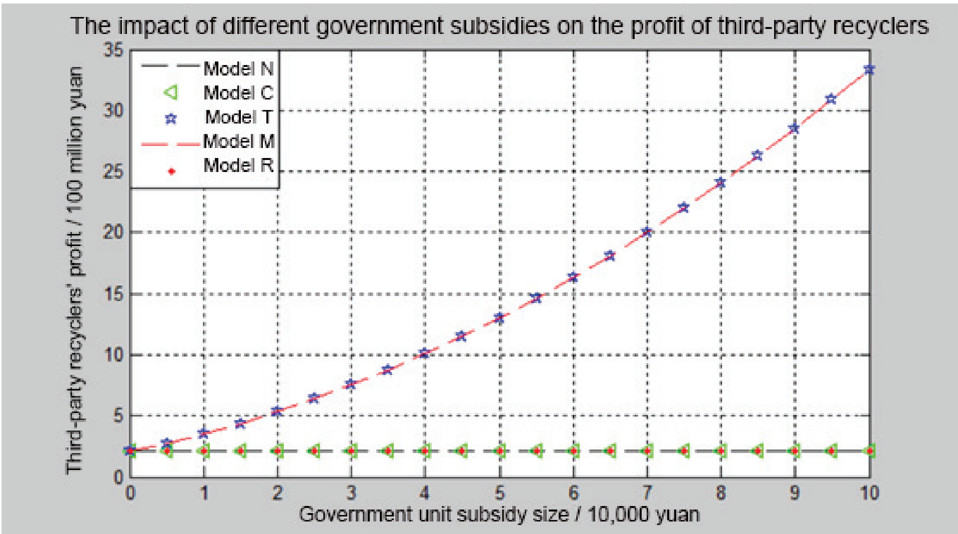


**Figure 7** The impact of different government subsidies on the profit of third-party recyclers

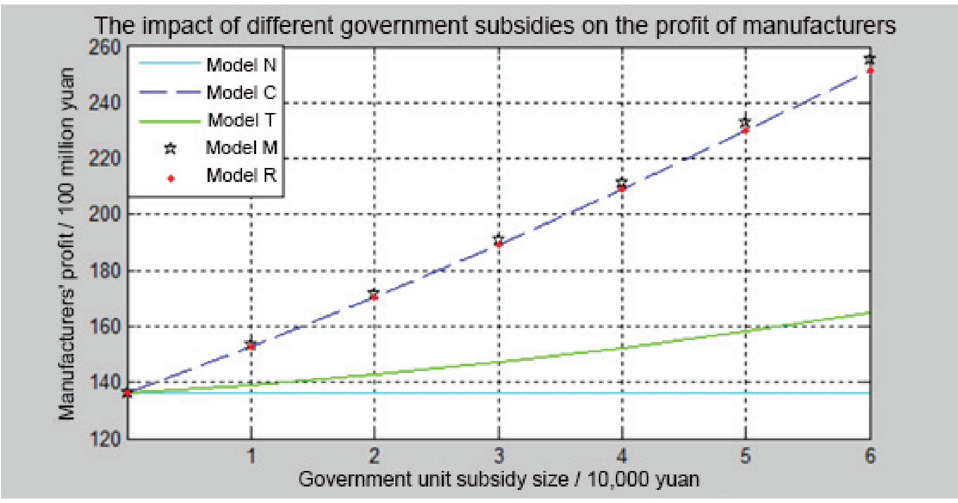


**Figure 8** The impact of different government subsidies on manufacturers' profits

recyclers in the supply chain; however, subsidies given to consumers or retailers will not affect the profit level of third-party recyclers.

In order to demonstrate its practical significance, this paper distinguishes the government's manufacturing subsidy $P_M^G$ and the unit recycling subsidy $P_M^{G'}$. In order to facilitate simulation, here we assume $P_M^{G'} G$ .

As can be seen from Figure 8, manufacturers are in a dominant position, and in any model with subsidies, manufacturers' profits will increase, and those of manufacturers, retailers, and consumers in subsidized sales channels will increase even more, while the profits of subsidized third-party recyclers will be more moderate.

## 5.2 Closed-Loop Supply Chain Pricing and Profit Research Under Model C

This section explores the impact of government subsidies for the pricing and profits of supply chain members, including the government's impact on pricing, profits and the proportion of profits.

As can be seen from Figure 9, in regard to supply chain member pricing, when the government subsidizes consumers, manufacturers and retailers will increase the wholesale price and retail price in order to obtain more profits, and the wholesale price will increase faster than retailer's price; while the subsidizing of consumers have no effect on the recycling price of used products

As can be seen from Figures 10 and 11, when the government subsidizes consumers, market demand will increase as will the profits of manufacturers and retailers. However, because manufacturers are in a leading position, their profits will increase slightly. Third-party recyclers are the only members of the recycling channel who do not participate in sales activities. Government subsidies to consumers will not affect the profit value of third-party recyclers; manufacturers obtain two-thirds of the total profits received by the entire supply chain, and with the government's increase in consumer subsidies, third-party recyclers' profits have fallen slightly, while retailers' profits have risen slightly.

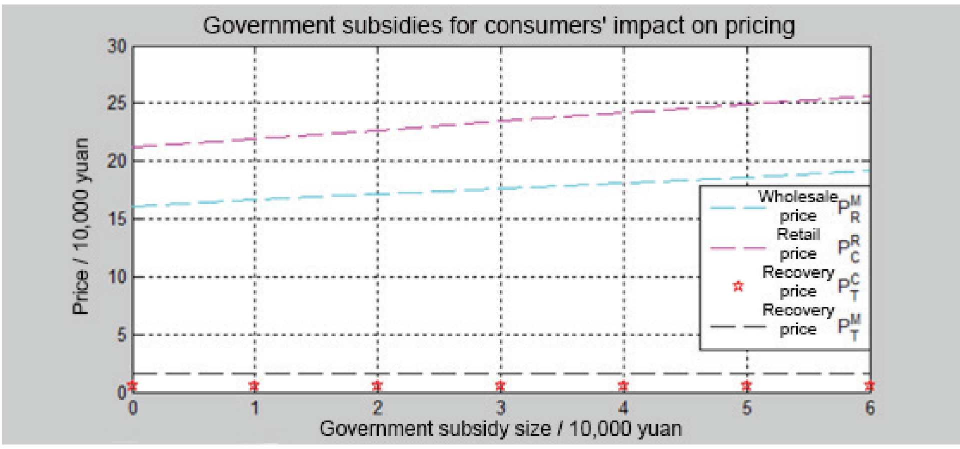


**Figure 9** Impact of government subsidized consumers on supply chain pricing

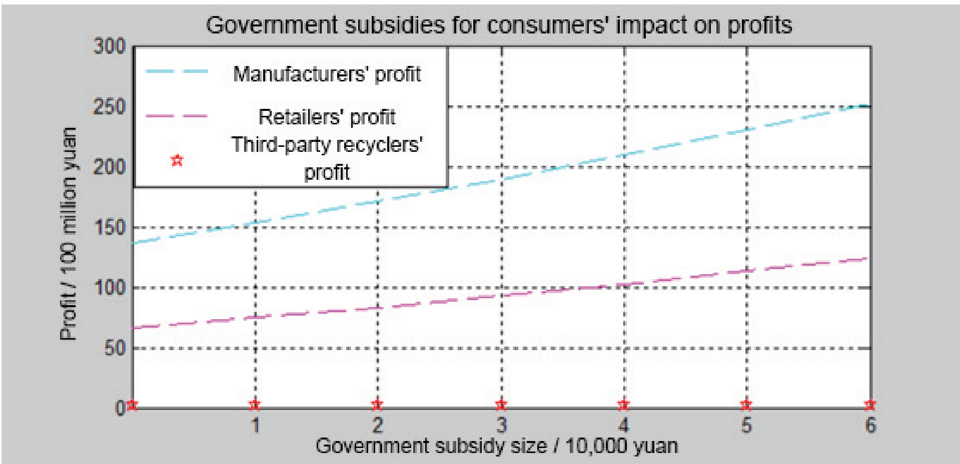


**Figure 10** Government subsidies for consumers' impact on profits

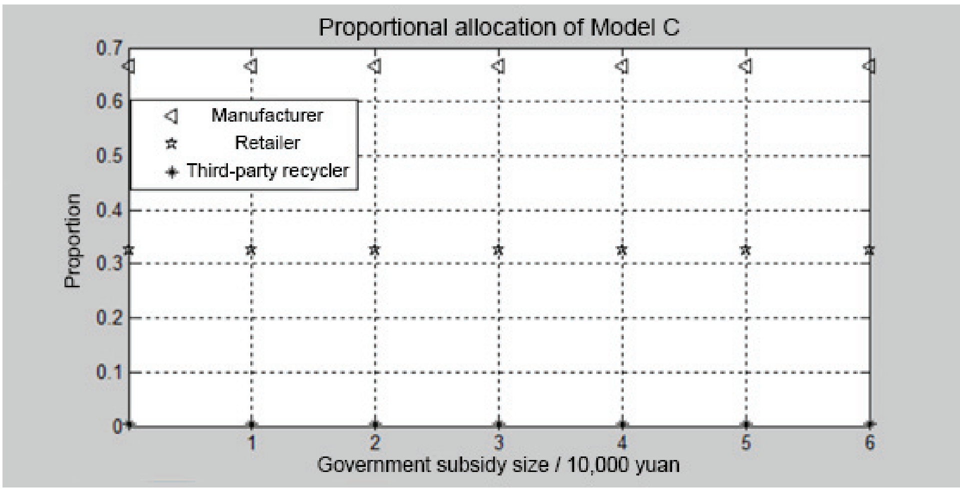


**Figure 11** Proportional allocation of Model C

## 5.3 Closed-Loop Supply Chain Pricing and Profit Research Under Model T

This section explores the impact of government subsidies on third-party recyclers on the pricing and profits of supply chain members, including the government's impact on pricing, profits and the proportion of profits.

As can be seen from Figure 12, when the government subsidizes third-party recyclers, it will increase the price that third-party recyclers recycle from consumers. Consumers receive more benefits, which will indirectly encourage the recovery of waste products; when the government subsidizes third-party recyclers, third-party recyclers will be more willing to sell to manufacturers for remanufacturing at lower prices,

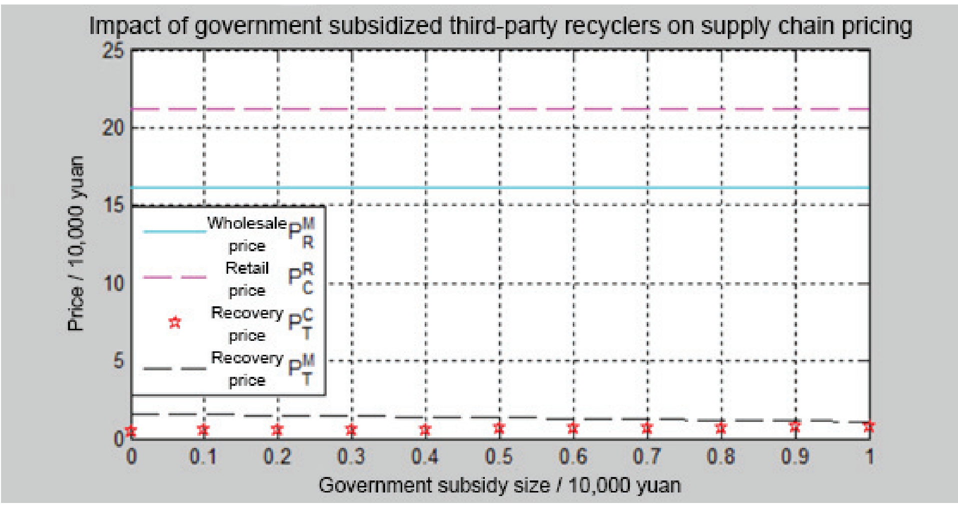


**Figure 12** Impact of government subsidized third-party recyclers on supply chain pricing

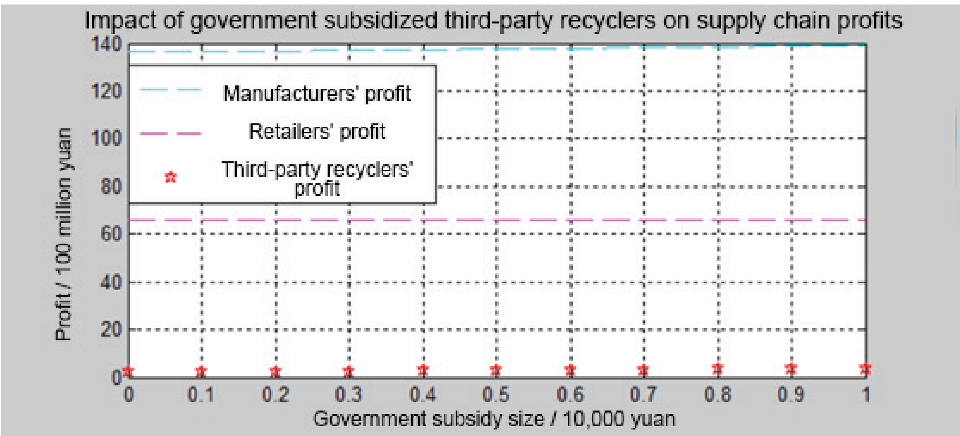


**Figure 13** Impact of government-subsidized third-party recyclers on supply chain profits

and the subsidizing of manufacturers will have no effect on the wholesale price and sales price of the products.

As the subsidy proceeds, third-party recyclers will be willing to recycle units from consumers at higher prices and then sell them to manufacturers for recycling at a lower price. Because third-party recyclers are also profitable, they must satisfy $P_M^T > P_T^C + C_T$.

Bringing in the value, $1.58 - 1/2P_T^G > 0.50 + 1/4P_T^G + 0.25$, then $P_R^G < 0.63$ is calculated.

This means that when the government subsidizes third-party recyclers, the subsidy cannot be greater than 6.3 thousand yuan; otherwise the third-party recyclers will not be profitable in the manufacturer-driven decision-making model.

As can be seen from Figures 13 and 14, when third-party recyclers are subsidized, the profits of third-party recyclers will increase. Because of the decreased costs of recycling and remanufacturing the profits of manufacturers will increase, while the retailers' profits remain unchanged because the retailer does not participate in the recycling process of the new energy vehicle. When third-party recyclers are subsidized, the retailers' profits will be lower than those of subsidized consumers, the ratio of third-party recyclers will become higher, and which will increase slightly with the increase of subsidies.

## 5.4 Closed-Loop Supply Chain Pricing and Profit Research Under Model R

This section explores the impact of government subsidized retailers on the pricing and profits of supply chain members, including the government's impact on pricing, profits and the amount of profit for each member of the supply chain.

As can be seen from Figure 15, when the government subsidizes the retailers' sales activities, consumers can buy new energy vehicles at a lower price, and manufacturers raise the wholesale price in order to increase their profits. Third-party recyclers do not participate in sales activities, so their recycling prices remain unchanged. Of course, the amount of the government subsidy for retailers is a critical factor; that is, the retailer's sales price per unit product must be greater than the sum of the wholesale price and the operating cost, namely, $P_C^R > P_R^M + C_R$.

Bringing in the value, $21.19 - 1/4P_R^G > 16.13 + 1/2P_R^G + 1$, then $P_R^G < 5.4$ is calculated.

This means that when the government subsidizes retailers, the subsidy cannot exceed 5.4 million yuan. If it is larger than this, the retailer will not benefit.

As shown in Figures 16 and 17, under Model R, the profits of manufacturers and retailers increase, manufacturers will

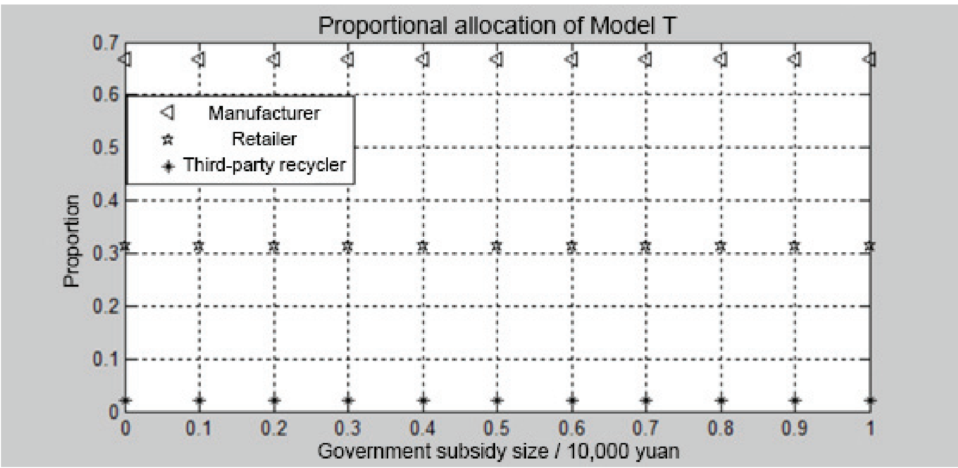


**Figure 14** Proportional allocation of Model T

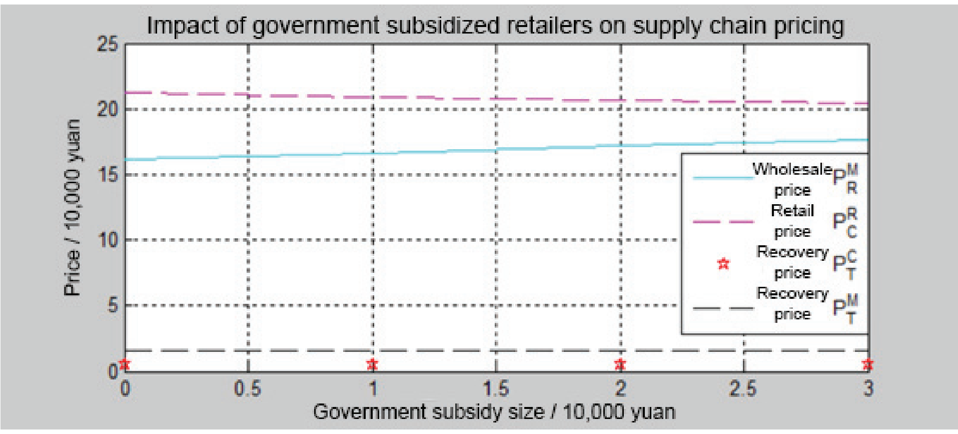


**Figure 15** Impact of government-subsidized retailers on supply chain pricing

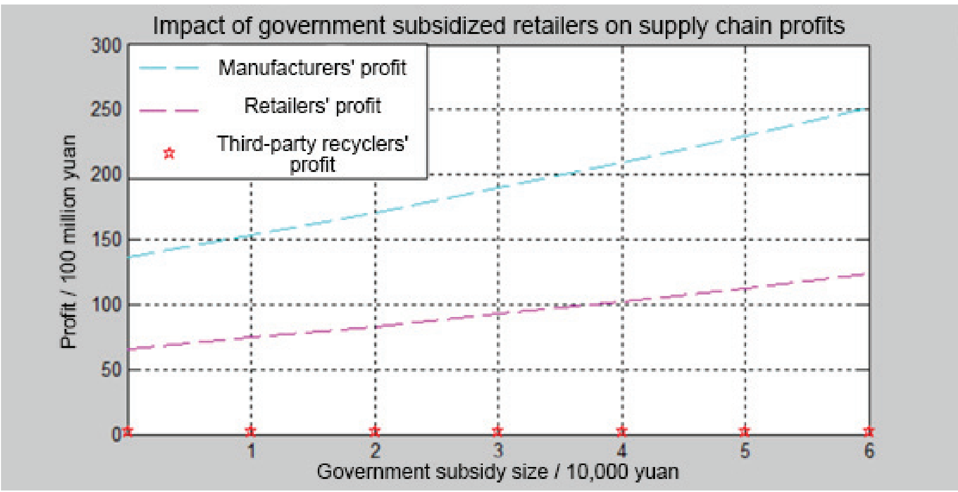


**Figure 16** Impact of government-subsidized retailers on supply chain profits

sell to retailers at higher wholesale prices, and manufacturers' profits will increase even more. Because third-party recyclers do not participate in sales activities, they do not profit from subsidies given to retailers In terms of profit ratios, the manufacturer has taken two-thirds of the profits, the retailer's profit is more than 30%, and the subsidy has increased slightly.

## 5.5 Closed-Loop Supply Chain Pricing and Profit Research Under Model M

In the previous section, in order to distinguish the government's sales subsidies and recycling subsidies to manufacturers, $P_M^G$ and $P_M^{G'}$ respectively expressed subsidies for each unit sold by

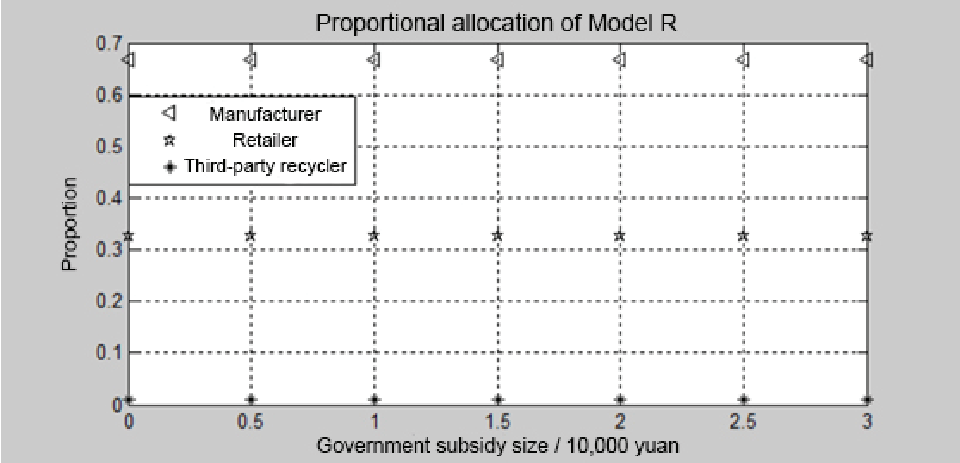


**Figure 17** Proportional allocation of Model R

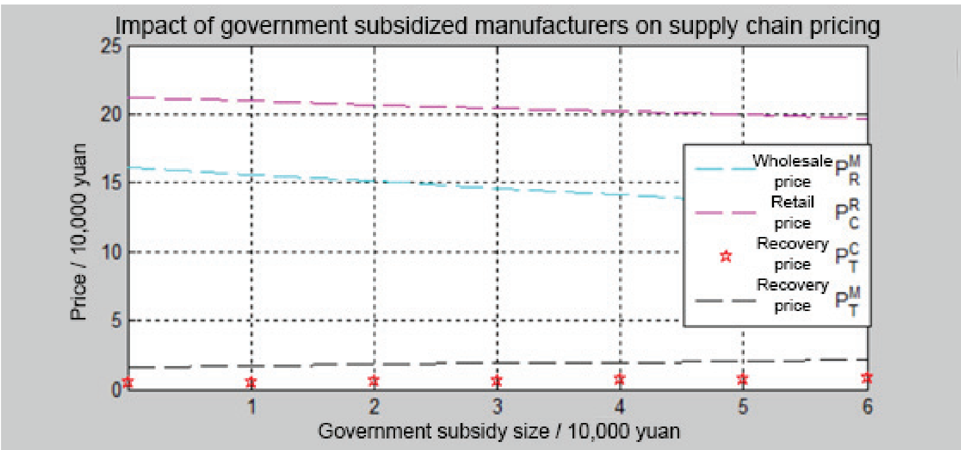


**Figure 18** Impact of government subsidized manufacturers on supply chain pricing

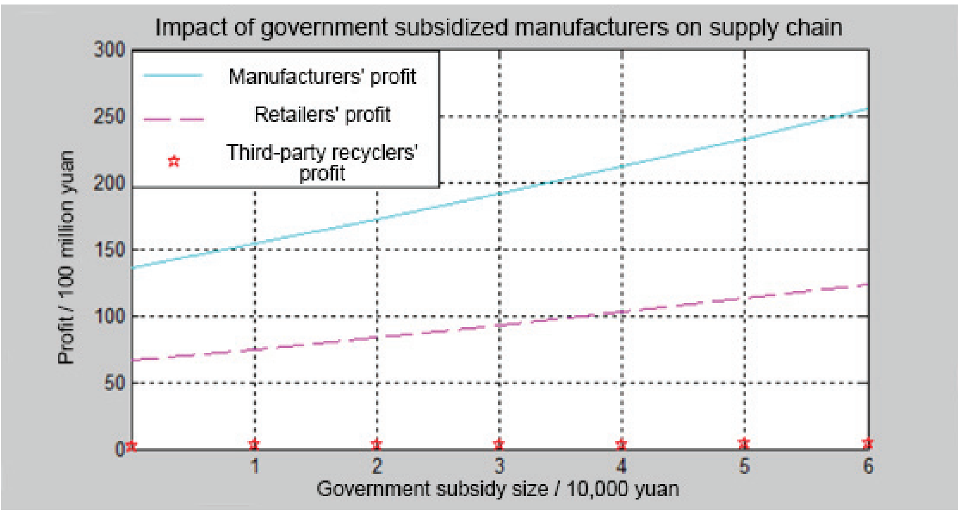


**Figure 19** Impact of government-subsidized manufacturers on supply chain profits

the manufacturer to the retailer and a recycling subsidy for each used car. In order to facilitate the graphical simulation of this part, it is assumed $P_M^{G'} = 1/5P_M^G$ here to calculate.

As can be seen from Figure 18, when the sales channel government subsidizes the manufacturer, the wholesale and the retail price of the product will decrease, while the wholesale price will decrease significantly; in the recycling channel when the government subsidizes the manufacturer, the third-party's and the manufacturer's recycling price will increase, while the manufacturer's recycling price will increase significantly.

In terms of profit, as can be seen from Figures 19 and 20, that when government subsidies increase, manufacturers' and

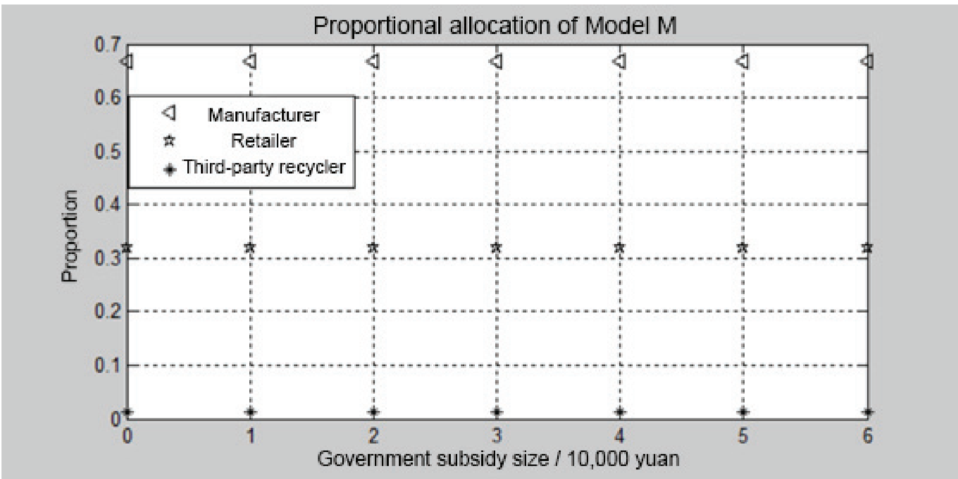


**Figure 20** Proportional allocation of Model M

retailers' profits will increase, while manufacturers' profits will increase more rapidly; in terms of ratio, manufacturing still accounts for 2/3 of the profits, and retailers account for nearly 1/3 of the profits, third-party recyclers have only a small portion of profits, and the ratio of subsidies will increase slightly.

## 6. CONCLUSION

In the context of government subsidies for new energy vehicles, this paper studies the impact of different government subsidies on the supply chain. Combining with game theory and the reality of new energy vehicles, a government subsidized consumer model (Model C), a government subsidy manufacturer model (Model M), a government subsidized third party recycler model (Model T), and government subsidized retailers (Model R) were established. Combining with the anarchic subsidy model (Model N), a comparative study is carried out to obtain the optimal pricing, profits and total profits of the supply chain members under different subsidy models. The findings are as follows:

① In different subsidy models, the wholesale price of Model M is the lowest in the sales channel, while Model R and C will increase the wholesale price. The growth of the two models is the same, Model T does not affect the wholesale price level; Model C will drive the increase in sales price, Model M and R will reduce the sales price of the product, but the reduction is more moderate than the increase of the subsidy in Model C.

In terms of recycling channels, both Model T and M will reduce the recycling price of third-party recyclers, and the two models experience the same decline Under Model T, manufacturers can recycle at a lower price; under Model M, manufacturers are more willing to recycle at a higher price, but the growth rate of the Model M recovery price is flat compared with the decline of Model T.

Models C, R, and M all drive the retailer's profit level, while Model T does not affect it; Model T and M will drive the increase of third-party recyclers' profits, while Model C and R will not affect their profit level.

In any subsidy model, the profits of the manufacturer will increase, and those of the manufacturers, retailers and consumers in the subsidized sales channel will increase more, while the subsidies of third-party recyclers will be more moderate.

② In the same subsidy model, the impact of government subsidies on closed-loop supply chain pricing and profits was examined. In Model C, with the increase of government subsidies, the growth rate of the wholesale price of the product is greater than that of the sales price, and manufacturer's profit growth is slightly higher, the profits of third-party recyclers are slightly lower, and the proportion of retailers' profits is also slightly higher; the increase in government subsidies in Model T will increase the price that third-party recyclers recover from consumers, while the manufacturer's recycling price will decrease.

In terms of the proportion, when subsidizing third-party recyclers, the proportion of retailers' profits will be lower than those of subsidized consumers, the ratio of third-party recyclers will become higher, and will grow slightly as subsidies increase; in Model R, with the increase of government subsidies, consumers can buy new energy vehicles at a lower price, while in order to earn higher profits, manufacturers raise the wholesale prices thereby earning two-thirds of profits; the retailer's profit is greater than 30%, and there is a slight increase with the increase in subsidies; in Model M, with the increase of government subsidies, the wholesale price and retail price of the products will decrease, and the wholesale price will decrease greatly. As the government subsidies increase, the profits of the manufacturers and the retailers will increase, and manufacturers' profits will increase more rapidly

In terms of ratio, manufacturers still account for two-thirds of the profits, and retailers account for nearly one-third of the profits. Third-party recyclers have only a small portion of profits, and with the increase in subsidies, the ratio is slightly lower.

## ACKNOWLEDGEMENTS

This work was supported by the Project of Humanities and Social Sciences of Education Ministry (No.14YJCZH218), Natural

Science Fostering Fund (1F-19-303-001), The National Natural Science Fund (71801150) and Shanghai Sports Social Science Research Foundation (TYSKYJ201915)

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