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# Contract selection for collaborative innovation in the new energy vehicle supply chain under the dual credit policy: Cost sharing and benefit sharing

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A B S T R A C T

The dual point policy is an important policy in the field of China's new energy vehicle industry, various factors such as point trading prices and technological innovation costs were included in the profit game model to explore the effects of cost contract model and revenue contract model on the optimal profit of new energy vehicle supply entities after collaborative decision-making. Research has found that the dual credit policy for China's new energy industry has a promoting effect on collaborative innovation among entities in the new energy vehicle supply chain; Compared with decentralized decision-making situations, the integration of cost sharing contracts or revenue sharing contracts can more effectively stimulate the innovation vitality of new energy battery suppliers and enhance their technological innovation level; Under the cost sharing contract and the benefit sharing contract, the optimal profit after collaborative decision-making between new energy vehicle manufacturers and new energy battery suppliers is greater than the optimal profit during decentralized decision-making, while the optimal profit of new energy vehicle supply chain entities under the benefit sharing contract is slightly higher than the optimal profit of new energy vehicle supply chain entities under the cost sharing contract.



## 1. Introduction

The report of the 20th National Congress of China emphasizes the emerging strategic position of the new energy vehicle industry, and the 14th Five Year Plan also points out that the new energy vehicle industry is an important strategic measure to increase the green, low-carbon, and high-end development of the automotive industry. In the past decade or so, China has introduced multiple special policies to address the development of the new energy vehicle industry, and the implementation and reform of the dual point policy have greatly improved the Chinese new energy vehicle market. However, the innovation bottleneck of new energy vehicle batteries has always been a key issue that restricts the rapid renewal of new energy vehicles. Therefore, studying how the main enterprises in the new energy vehicle supply chain collaborate to achieve technological innovation under the dual point policy is of great significance (Xiaoshan et al., 2021).

For many years, domestic and foreign experts and scholars have conducted comprehensive investigations and research on the collaborative innovation issues of the main enterprises in the new energy vehicle supply chain, with a particular focus on the impact of policies on the new energy vehicle supply chain. Under the government's reward and punishment mechanism, a profit function for automobile manufacturers and an evolutionary game model between the government and automobile manufacturers were constructed (Wang et al., 2023). Study the impact of different types of industrial policies on technological innovation in enterprises (Military Power, 2023). Analyzed the impact of multiple government promotion strategies on innovation preferences of new energy vehicle enterprises (Yongqing & Shufeng, 2023). Some scholars use a dual difference

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model to test the impact and mechanism of government strategies on technological innovation in new energy vehicle enterprises (Liu et al., 2023). Studied how policy transition affects new energy vehicle production decisions (Jing et al., 2022). Some scholars have focused their research on the dual point policy, studying the mechanism of collaborative innovation among the main enterprises in the entire new energy vehicle supply chain. Research has been conducted on whether the dual point policy can promote substantive innovation (Stan & Star, 2023). The impact and benefits of the dual point policy on the competitiveness of automobile manufacturing enterprises (Zhou & Qiu, 2023). From the perspective of various new energy industry policies proposed by the government, the impact on new energy vehicle technology innovation, low-carbon, and other aspects was analyzed (Joo et al., 2018; Bigerna et al., 2019; Huang et al., 2013; Shao et al., 2017).

Considering the rational characteristics of the main enterprises in the new energy vehicle supply chain, some scholars discussed the impact of supply chain contracts on their collaboration. For example, Coordination decision-making among entities in the new energy vehicle supply chain based on consensus decision-making (Lin, 2022). We studied the coordination effects of three different new energy vehicle supply chain contracts (Lu et al., 2021). Research on collaborative innovation decision optimization of the circular supply chain for new energy vehicles (Xie et al., 2020).

Previous scholars' research has provided useful reference for this article's study of contract selection for cooperative innovation under the dual point policy. However, previous scholars' research mainly focused on how policies affect production decisions. Unlike previous studies, this study focuses more on the decision-making mechanism of two-point policies for collaborative innovation among entities in the new energy vehicle supply chain, simultaneously considering the roles of two types of cost contracts and revenue contracts, analyze their mechanisms for collaborative innovation decision-making among entities in the new energy vehicle industry chain. This article constructs a profit game model between new energy battery suppliers and new energy vehicle manufacturers, obtains the optimal factor solution and optimal profit of the model through calculation, discusses, and compares the impact of key factors on member decisions, and conducts actual data case analysis.

## 2. Basic Assumptions of the Model

The "dual point" policy means that if enterprise sells a new energy car that meets the standard range, energy density, and electricity consumption, the new energy vehicle manufacturing enterprise will receive corresponding points. Positive point new energy vehicle enterprises can transfer points to negative point enterprises to obtain corresponding point profits. To improve the level of technological innovation, new energy vehicle manufacturing enterprises must continuously carry out technological innovation in order to obtain positive points. However, not all enterprises can make independent innovation in the field of core components of new energy vehicles as BYD Auto Automobile. Therefore, they must demand corresponding collaborative innovation from suppliers of their core components. Based on this, this article studies the collaborative innovation decision-making mechanism between the main enterprises in the new energy vehicle supply chain under China's new energy point creation policy.

This study considers a supply chain system composed of a single new energy vehicle manufacturer and a core component supplier. Due to the important role of new energy batteries in the range and power consumption of new energy vehicles, this article assumes that the core component supplier is a new energy battery supplier. This article mainly studies the contract selection problem of collaborative innovation between new energy vehicle manufacturers and new energy vehicle battery suppliers. Under the promotion of the "dual point" policy in the new energy field, automobile manufacturers will propose cost sharing contracts and revenue sharing contracts to energy battery suppliers to improve the technological level of new energy batteries and obtain positive points, thereby promoting technological innovation of battery suppliers.

The game order must be that the new energy vehicle manufacturer first provides a cost sharing contract or a benefit sharing contract to the battery supplier; Battery suppliers determine the level of technological innovation and selling price of batteries based on the cost sharing contract or revenue sharing contract they provide; Finally, new energy vehicle manufacturers make wholesale quantity and sales price decisions based on the selling price of battery suppliers.

The basic assumptions of this study are as follows:

H1: Production cost. New energy battery suppliers and new energy vehicle manufacturers will both pay corresponding costs when producing new energy batteries and whole vehicles, such as battery costs, final assembly costs, wages, etc. Use $C_g$ to represent the basic cost of producing new energy batteries for new energy battery suppliers; Use $C_z$ to represent the total production costs paid by new energy vehicle manufacturers, excluding battery costs.

H2: Innovation cost. New energy battery suppliers need to pay a certain amount of research and development costs when conducting technological innovation. The technological innovation of new energy battery suppliers mainly aims to increase the ratio of battery life to battery energy, to increase the mileage of new energy vehicles. Therefore, this article uses range to represent the technological innovation level of new energy battery suppliers. Use $H$ to represent the range of new energy vehicles, i.e. the degree of technological innovation; Use $C(H)$ to represent the technological innovation cost of new energy battery suppliers. To accurately measure the cost of innovation, a cost model was introduced (Ghosh et al., 2012) to construct a technology innovation cost function for new energy battery suppliers, which is: $C(H)=\frac{1}{2}kH^2$, where $k$ represents the innovation cost coefficient.

H3: Product price. Use $w$ to represent the selling price of a new energy battery supplier selling one battery; Use $p$ to represent the price at which car seller sells a car. Regulation $w \geq C_g + C(H)$; $p \geq C_z + w$.

H4: Market size. The market has the greatest potential demand for any product, and $a$ represents the potential demand for new energy vehicles in the market; If $b$ represents the elasticity coefficient of demand price, then the demand function of the new energy vehicle market is: $Q=a-bp$.

H5: Points Policy. The "double point" policy defines the calculation method for new energy vehicle points is: $Y = 0.0034H + 0.2$. For the convenience of research, this article simplifies the calculation method of the dual integration policy as follows: $Y = tH$, where $t$ is the integration coefficient. So, the point income earned by new energy vehicle manufacturers for each new energy vehicle sold is: $R = p_0 tH$, where $p_0$ is the market new energy point transaction price.

## 3. Model Analysis and Solution

When new energy battery suppliers and new energy vehicle manufacturers make decisions, there are often two decision-making modes, that is, joint decision-making and decentralized decision-making among collaborative innovation entities. Centralized decision-making: Centralized decision-making refers to the cooperation between new energy battery suppliers and new energy vehicle manufacturers to make decisions on the level of technological innovation and price level.
Decentralized decision-making: It means that new energy battery suppliers and new energy vehicle manufacturers make decisions based on their respective Profit maximization principles.

### *3.1 Centralized Decision Model*

In the case of centralized decision-making, new energy battery suppliers and new energy vehicle manufacturers will make decisions to maximize the overall Profit maximization of the entire supply chain system. According to the assumed conditions, the profit function of the entire new energy vehicle supply chain system in this situation is:

$$\prod(H \quad p) = (p - C_g - C_z + p_0 tH)(a - bp) - \frac{1}{2}kH^2 . \tag{1}$$

Based on the overall profit function $\prod(H \quad p)$ of the new energy vehicle supply chain system, solve the first and second derivative functions of product price $p$ and innovation level $H$, which are:

$$\frac{\partial \prod(H \quad p)}{\partial p} = a + b(C_g + C_z - p_0 tH) - 2bp$$

$$\frac{\partial^2 \prod(H \quad p)}{\partial p^2} = -2b < 0$$

$$\frac{\partial \prod(H \quad p)}{\partial H} = p_0 t(a - bp) - kH$$

$$\frac{\partial^2 \prod(H \quad p)}{\partial H^2} = -k < 0$$

Because $\frac{\partial^2 \prod(H \quad p)}{\partial p^2} < 0$ and $\frac{\partial^2 \prod(H \quad p)}{\partial H^2} < 0$, the overall profit function $\prod(p \quad H)$ of the new energy vehicle supply chain system is a Concave function about product price $p$ and innovation level $H$, and the maximum value is taken when the first derivative is zero. Therefore, for $\frac{\partial \prod(H \quad p)}{\partial p} = 0$ and $\frac{\partial \prod(H \quad p)}{\partial H} = 0$, the optimal product price $p^*$ and the optimal innovation level $H^*$ of the new energy vehicle supply chain system under this scenario can be obtained, respectively:

$$p^* = \frac{k(a + b(C_g + C_z)) - ab(p_0 t)^2}{2bk - (bp_0 t)^2} \qquad H^* = \frac{b(a\text{-}b(C_g + C_z))p_0 t}{2bk - (bp_0 t)^2} .$$

Based on the obtained optimal product price $p^*$ and the optimal innovation level $H^*$, by introducing Eq. (1), the optimal profit of the entire new energy vehicle supply chain system can be obtained as:

$$\Pi^{*}(H \quad p)=\frac{k(a-b(C_g+C_z))^2}{4bk-2(bp_0t)^2}.$$

*3.2 Decentralized Decision-making Model*

New energy battery suppliers and new energy vehicle manufacturers, as Rational agent, will pursue their own Profit maximization. According to the assumed conditions, the profit functions of new energy battery suppliers and new energy vehicle manufacturers in this situation are:

$$\Pi_g(H \quad w)=(w-C_g)(a-bp)-\frac{1}{2}kH^2 \tag{2}$$

$$\Pi_z(H \quad p)=(p-w-C_z+p_0tH)(a-bp) \tag{3}$$

The game order between new energy battery suppliers and new energy vehicle manufacturers under decentralized decision-making is as follows: first, the new energy battery supplier determines the degree of technological innovation and selling price, then the new energy vehicle manufacturer determines the wholesale quantity and sales price, and finally determines the optimal decision solution.

This article uses the reverse induction method to solve the optimal strategy combination, and the calculation process is as follows.

Firstly, based on the profit function $\Pi_z(H \quad p)$ of new energy vehicle manufacturers, solve their first-order and second-order derivative functions regarding product price $p$, which are:

$$\frac{\partial \Pi_z(H \quad p)}{\partial p}=a+b(w+C_z-p_0tH)-2bp$$

$$\frac{\partial^2 \Pi_z(H \quad p)}{\partial p^2}=-2b<0$$

Because of $\frac{\partial^2 \Pi(H \quad p)}{\partial p^2}<0$, the profit function $\Pi_z(H \quad p)$ is a concave function respect to product price, and the maximum value is taken when the first derivative is zero. Therefore, by setting $\frac{\partial \Pi(H \quad p)}{\partial p}=0$, the optimal product price $p^*$ for a new energy vehicle manufacturer in this situation can be obtained as:

$$p^*=\frac{a+b(w+C_z-p_0tH)}{2b} \tag{4}$$

Replacing Eq. (4) into Eq. (2), it can be concluded that the profit function of new energy battery suppliers is:

$$\Pi_g(H \quad w)=(w-C_g)(\frac{a-b(w+C_z-p_0tH)}{2})-\frac{1}{2}kH^2 \tag{5}$$

However, according to Eq. (5), the profit function $\Pi_g(H \quad w)$ of new energy battery suppliers can be solved by solving their first-order and second-order derivative functions regarding product selling price $w$ and innovation level $H$, which are:

$$\frac{\partial \Pi(H \quad w)}{\partial w}=\frac{a-b(C_z-p_0tH)+bC_g-2bw}{2}$$

$$\frac{\partial^2 \Pi(H \quad w)}{\partial w^2}=-b<0$$

$$\frac{\partial \Pi(H \quad w)}{\partial H}=\frac{bp_0t(w-C_g)}{2}-kH$$

$$\frac{\partial^2 \Pi(H \quad w)}{\partial H^2}=-k<0$$

Because of $\frac{\partial^2 \Pi(H \quad w)}{\partial w^2}<0$ and $\frac{\partial^2 \Pi(H \quad w)}{\partial H^2}<0$, the profit function $\Pi_g(H \quad w)$ of new energy battery suppliers is a concave function about the selling price $w$ of products and the innovation level $H$, and the maximum value is taken when the first derivative is zero. Therefore, for $\frac{\partial \prod(H \quad w)}{\partial w}=0$ and $\frac{\partial \prod(H \quad w)}{\partial H}=0$, the optimal selling price $w^*$ and the optimal innovation level $H^*$ of new energy battery suppliers in this situation can be obtained, respectively:

$$w^*=\frac{2k(a-bC_z+bC_g)-(bp_0t)^2C_g}{4bk-(bp_0t)^2} \qquad H^*=\frac{(a-bC_z-bC_g)bp_0t}{4bk-(bp_0t)^2}.$$

By incorporating the optimal selling price $w^*$ and the optimal innovation level $H^*$ into Eq. (4), the optimal product price $p^*$ for a new energy vehicle manufacturer can be obtained as:

$$p^*=\frac{k(3a+bC_z+bC_g)-ab(p_0t)^2}{4bk-(bp_0t)^2}$$

Based on the obtained optimal selling price $w^*$ and innovation level $H^*$ of new energy battery suppliers, as well as the optimal product price $p^*$ of vehicle manufacturers, the optimal profits of battery suppliers and new energy vehicle manufacturers can be obtained by introducing Eq. (2) and Eq. (3), which are:

$$\prod{}^*_g(H \quad w)=\frac{k(a-bC_z-bC_g)^2}{2\left[4bk-(bp_0t)^2\right]}$$

$$\prod{}^*_z(H \quad p)=\frac{bk^2(a-bC_z-bC_g)^2}{\left[4bk-(bp_0t)^2\right]^2}$$

Then, the overall optimal profit of the whole new energy vehicle supply chain system under Decentralized decision-making is:

$$\prod{}^*(H \quad p)=\frac{k(a-bC_z-bC_g)^2(6bk-(bp_0t)^2)}{2\left[4bk-(bp_0t)^2\right]^2}$$

Property 1: According to the innovation level $H^*$ and optimal product price $p^*$, the optimal transfer price for new energy vehicles increases with the increase in battery creation costs and other costs; The optimal innovation level decreases with the reduction of new energy battery costs and other costs, and increases with the increase of new energy point trading prices.

Nature 2: In the case of discrete decision-making between new energy vehicle manufacturers and suppliers, it can be seen from the optimal product selling price $w^*$ that the selling price of new energy batteries increases with the increase of production costs of new energy battery suppliers.

Nature 3: When compared to the collaborative centralized decision-making between new energy vehicle manufacturers and new energy battery suppliers, the level of technological innovation and total profit of new energy battery suppliers in a decentralized decision-making state are lower, but the product sales price is indeed higher.

According to the above properties, it can be found that there is a bilateral effect in the case of Decentralized decision-making, that is, new energy battery suppliers and automobile manufacturers unilaterally pursue their own interests to maximize, resulting in the supply chain benefits under Decentralized decision-making and lower than the overall benefits of the supply chain under centralized decision-making.

## 4. Supply Chain Collaborative Innovation Contract

Due to the existence of double marginal effect, new energy battery suppliers ignore the improvement of battery innovation level to obtain high profits and low innovation costs. Efforts will be made to address the technological updates and progress of new energy vehicles, energy density, and electricity consumption, new energy vehicle manufacturers can share or partially benefit from innovation costs to compensate for the innovation costs of battery suppliers, which may effectively promote the improvement of the innovation level of new energy batteries. Therefore, this article introduces cost sharing contracts and revenue sharing contracts in the profit game model to study the impact of these two types of contracts on decentralized decision-making in the new energy vehicle supply chain.

*4.1 Cost Sharing Contract*

Cost sharing contract is a pre contract in which new energy vehicle manufacturers share the corresponding technological innovation costs with new energy battery suppliers to reduce the innovation risks of battery suppliers. This article assumes that the proportion of technological innovation costs borne by new energy vehicle manufacturers is $\theta$, and the proportion of technological innovation costs borne by new energy battery suppliers is $1-\theta$. Therefore, in this case, the profit functions of new energy battery suppliers and new energy vehicle manufacturers are:

$$\Pi_g(H \quad w)=(w-C_g)(a-bp)-\frac{1}{2}(1-\theta)kH^2 \tag{6}$$

$$\Pi_z(H \quad p)=(p-w-C_z+p_0tH)(a-bp)-\frac{1}{2}\theta kH^2 \tag{7}$$

In the case of decentralized decision-making considering cost sharing contracts, the game order between new energy battery suppliers and new energy vehicle manufacturers is as follows: firstly, the new energy vehicle manufacturer specifies the sharing contract and proportion of technological innovation costs, secondly, the new energy battery supplier determines the degree of technological innovation and selling price, then the new energy vehicle manufacturer determines the wholesale quantity and sales price, and finally determines the optimal decision solution.

This article still uses the reverse induction method to solve the optimal strategy combination, and the calculation process can be seen in Appendix 1.

In the case of Decentralized decision-making considering the cost sharing contract, the optimal selling price $w^*$ and the optimal innovation level $H^*$ of the new energy battery supplier are:

$$w^*=\frac{2k(1-\theta)(a-bC_z+bC_g)-(bp_0t)^2C_g}{4bk(1-\theta)-(bp_0t)^2} \qquad H^*=\frac{(a-bC_z-bC_g)bp_0t}{4bk(1-\theta)-(bp_0t)^2}.$$

The optimal product price $p^*$ for new energy vehicle manufacturers is:

$$p^*=\frac{k(1-\theta)(3a+bC_z+bC_g)-ab(p_0t)^2}{4bk(1-\theta)-(bp_0t)^2}$$

The optimal profits for new energy battery suppliers and new energy vehicle manufacturers are:

$$\Pi^*_g(H \quad w)=\frac{k(1-\theta)(a-bC_z-bC_g)^2}{2\left[4bk(1-\theta)-(bp_0t)^2\right]}$$

$$\Pi^*_z(H \quad p)=\frac{(2b(k(1-\theta))^2-\theta k(bp_0t)^2)(a-bC_z-bC_g)^2}{2\left[4bk(1-\theta)-(bp_0t)^2\right]^2}$$

Then, considering the Decentralized decision-making of cost sharing contract, the total optimal profit sum of the whole new energy vehicle supply chain system is:

$$\Pi^*(H \quad p)=\frac{(6b(k(1-\theta))^2-k(bp_0t)^2)(a-bC_z-bC_g)^2}{2\left[4bk(1-\theta)-(bp_0t)^2\right]^2}$$

Property 4: According to the optimal innovation level $H^*$ and optimal product price $p^*$, the optimal sales price of new energy vehicles increases with the increase of new energy battery costs and other costs; The optimal innovation level decreases with the reduction of new energy battery costs and other costs, and increases with the increase of new energy point trading prices.

Property 5: By calculating the first derivative function of the cost allocation proportion for the optimal profit $\Pi^*_z(H \quad p)$ of the new energy vehicle manufacturer under the Decentralized decision-making of the cost allocation contract, and making it zero, the optimal cost allocation proportion that maximizes the profit of the new energy vehicle manufacturer can be obtained as $\theta^*=\frac{(bp_0t)^2}{8bk}$.

*4.2 Revenue Sharing Contract*

Revenue sharing contract is a type of time contract in which new energy vehicle manufacturers share the profits from car sales to new energy battery suppliers in a certain proportion. This article assumes that the revenue sharing ratio between new energy vehicle manufacturers and new energy battery suppliers is $\beta$, that is, new energy vehicle manufacturers share the revenue of $\beta$ ratio with new energy battery suppliers. Therefore, in this case, the profit functions of new energy battery suppliers and new energy vehicle manufacturers are:

$$\prod_g(H \quad w) = (w + \beta p - C_g)(a - bp) - \frac{1}{2}kH^2 \tag{8}$$

$$\prod_z(H \quad p) = ((1-\beta)p - w - C_z + p_0 tH)(a - bp) \tag{9}$$

In the case of decentralized decision-making considering revenue sharing contracts, the game order between new energy battery suppliers and new energy vehicle manufacturers is as follows: first, the new energy vehicle manufacturer specifies the revenue sharing contract and proportion, second, the new energy battery supplier determines the degree of technological innovation and selling price, then the new energy vehicle manufacturer determines the wholesale quantity and sales price, and finally determines the optimal decision solution.

This article still uses the reverse induction method to solve the optimal strategy combination, and the calculation process can be seen in Appendix 2.

In the case of Decentralized decision-making considering the revenue sharing contract, the optimal selling price $w^*$ and the optimal innovation level $H^*$ of the new energy battery supplier are:

$$w^* = \frac{2k(1-\beta)(a(1-\beta) - bC_z + bC_g) + (a\beta - bC_g)b(p_0 t)^2}{2bk(2-\beta) - (bp_0 t)^2} \qquad H^* = \frac{(a - bC_z - bC_g)bp_0 t}{2bk(2-\beta) - (bp_0 t)^2} \text{。}$$

The optimal product price $p^*$ for new energy vehicle manufacturers is:

$$p^* = \frac{(a(3-2\beta) + bC_z + bC_g)k - ab(p_0 t)^2}{2bk(2-\beta) - (bp_0 t)^2}$$

The optimal profits for new energy battery suppliers and new energy vehicle manufacturers are:

$$\prod{}^*_g(H \quad w) = \frac{k(a - bC_g - bC_z)^2}{2(2bk(2-\beta) - (bp_0 t)^2)}$$

$$\prod{}^*_z(H \quad p) = \frac{bk^2(1-\beta)(a - bC_g - bC_z)^2}{2(2bk(2-\beta) - (bp_0 t)^2)}$$

Then, considering the Decentralized decision-making of revenue sharing contract, the total optimal profit sum of the whole new energy vehicle supply chain system is:

$$\prod{}^*(H \quad p) = \frac{(bk^2(1-\beta) + k)(a - bC_g - bC_z)^2}{2(2bk(2-\beta) - (bp_0 t)^2)}$$

Property 6: by calculating the first derivative function of the cost sharing proportion of the new energy vehicle manufacturer's optimal profit $\prod{}^*_z(H \quad p)$ under the Decentralized decision-making of the revenue sharing contract and making it zero, the optimal revenue sharing proportion that maximizes the profit of the new energy vehicle manufacturer can be obtained as $\beta^* = \frac{(bp_0 t)^2}{2bk}$.

## 5. Discussion and Comparison of Main Parameters

Based on the optimal product selling price $w^*$, optimal innovation level $H^*$, optimal product price $p^*$, optimal cost sharing ratio $\theta^*$, and optimal revenue sharing ratio $\beta^*$ obtained from the previous text, they are integrated into the profit function of new energy battery suppliers, new energy vehicle manufacturers, and the entire new energy vehicle supply chain system, and summarized to form the decision results of the new energy vehicle supply chain system under different scenarios. As shown in Table 1. According to Table 1, it can be found that the following propositions are consistent with the previous properties:

Proposition 1: From $\frac{\partial w^*}{\partial p_0} > 0$ and $\frac{\partial w^*}{\partial C_z} < 0$, it can be seen that the optimal selling price is an increasing function of the integral transaction price and a decreasing function of the manufacturing cost of new energy vehicles.

Proposition 2: From $\frac{\partial p^*}{\partial p_0} < 0$, $\frac{\partial p^*}{\partial C_g} > 0$, and $\frac{\partial p^*}{\partial C_z} > 0$, it can be seen that the optimal product transaction price is a decreasing function of the integral transaction price, and an increasing function of the manufacturing costs of new energy batteries and new energy vehicles.

Proposition 1 and Proposition 2 both indicate the significant impact of the dual credit policy on the supply chain system of the new energy industry. The increase in credit transaction prices has increased the additional income of new energy vehicle manufacturers. Therefore, new energy vehicle manufacturers are willing to grant partial profits to new energy battery suppliers and new energy vehicle buyers. Under the influence of the dual point policy, the selling prices of new energy battery suppliers increase with the increase of point trading prices, and new energy battery suppliers can also enjoy the additional profits brought by the dual point policy; At the same time, due to the additional income generated by new energy vehicle manufacturers, they are willing to lower the sales prices of their products to promote the development of the new energy vehicle supply chain and sales chain.

**Table 1**
Optimal Parameter Values and Profit Results under Different Scenarios

| Parameter | Decentralized decision-making | Cost sharing contract | Revenue sharing contract |
|---|---|---|---|
| $w^*$ | $\frac{2k(a-bC_z+bC_g)-(bp_0t)^2C_g}{4bk-(bp_0t)^2}$ | $\frac{2k(1-\theta)(a-bC_z+bC_g)-(bp_0t)^2C_g}{4bk(1-\theta)-(bp_0t)^2}$ | $\frac{2k(1-\beta)(a(1-\beta)-bC_z+bC_g)+(a\beta-bC_g)b(p_0t)^2}{2bk(2-\beta)-(bp_0t)^2}$ |
| $H^*$ | $\frac{(a-bC_z-bC_g)bp_0t}{4bk-(bp_0t)^2}$ | $\frac{(a-bC_z-bC_g)bp_0t}{4bk(1-\theta)-(bp_0t)^2}$ | $\frac{(a-bC_z-bC_g)bp_0t}{2bk(2-\beta)-(bp_0t)^2}$ |
| $p^*$ | $\frac{k(3a+bC_z+bC_g)-ab(p_0t)^2}{4bk-(bp_0t)^2}$ | $\frac{k(1-\theta)(3a+bC_z+bC_g)-ab(p_0t)^2}{4bk(1-\theta)-(bp_0t)^2}$ | $\frac{(a(3-2\beta)+bC_z+bC_g)k-ab(p_0t)^2}{2bk(2-\beta)-(bp_0t)^2}$ |
| $\prod^*_g(H \quad w)$ | $\frac{k(a-bC_z-bC_g)^2}{2\left[4bk-(bp_0t)^2\right]}$ | $\frac{k(1-\theta)(a-bC_z-bC_g)^2}{2\left[4bk(1-\theta)-(bp_0t)^2\right]}$ | $\frac{k(a-bC_g-bC_z)^2}{2(2bk(2-\beta)-(bp_0t)^2)}$ |
| $\prod^*_z(H \quad p)$ | $\frac{bk^2(a-bC_z-bC_g)^2}{\left[4bk-(bp_0t)^2\right]^2}$ | $\frac{(2b(k(1-\theta))^2-\theta k(bp_0t)^2)(a-bC_z-bC_g)^2}{2\left[4bk(1-\theta)-(bp_0t)^2\right]^2}$ | $\frac{bk^2(1-\beta)(a-bC_g-bC_z)^2}{2(2bk(2-\beta)-(bp_0t)^2)}$ |
| $\prod^*(H \quad p)$ | $\frac{k(a-bC_z-bC_g)^2(6bk-(bp_0t)^2)}{2\left[4bk-(bp_0t)^2\right]^2}$ | $\frac{(6b(k(1-\theta))^2-k(bp_0t)^2)(a-bC_z-bC_g)^2}{2\left[4bk(1-\theta)-(bp_0t)^2\right]^2}$ | $\frac{(bk^2(1-\beta)+k)(a-bC_g-bC_z)^2}{2(2bk(2-\beta)-(bp_0t)^2)}$ |

Note: $\theta=\frac{(bp_0t)^2}{8bk}$ **;** $\beta=\frac{(bp_0t)^2}{2bk}$

Proposition 3: From $\frac{\partial H^*}{\partial p_0} > 0$, $\frac{\partial H^*}{\partial C_g} < 0$, and $\frac{\partial H^*}{\partial C_z} < 0$, it can be seen that the optimal innovation level is an increasing function of the integral transaction price, and a decreasing function of the manufacturing costs of new energy batteries and new energy vehicles.

Proposition 3 indicates that the optimal innovation level is influenced by the integral transaction price. As the integral transaction price increases, the optimal innovation level of new energy battery suppliers gradually increases. Under the influence of the dual point policy, the increase in point trading prices has led new energy vehicle manufacturers to find ways to improve the innovation level of technical factors such as range in order to obtain points, which has prompted upstream new energy battery suppliers to improve their technological innovation level. This point trading price will drive innovation demand and improve the level of technological innovation.

Proposition 4: From $\frac{\partial \prod^*}{\partial p_0} > 0$, $\frac{\partial \prod^*}{\partial C_g} < 0$, and $\frac{\partial \prod^*}{\partial C_z} < 0$, it can be seen that the optimal profit for new energy battery suppliers, new energy vehicle manufacturers, and the entire new energy vehicle supply chain system is an increasing function of the integral transaction price, and a decreasing function of the manufacturing costs of new energy batteries and new energy vehicles.

Proposition 5: $\frac{\partial \theta^*}{\partial p_0} > 0$ and $\frac{\partial \beta^*}{\partial p_0} > 0$ indicate that the cost sharing coefficient and profit-sharing coefficient that new energy vehicle manufacturers are willing to bear are an increasing function of the integral transaction price. With the increase of point trading prices, new energy vehicle manufacturers can obtain more point profits, making them more willing to bear innovation costs or share profits with new energy battery suppliers. Therefore, the increase in point trading prices has driven the proportion of cost sharing and revenue sharing among new energy vehicle manufacturers.

## 6. Empirical Research

Based on the research reports sorted out by China Automobile Association and China Commercial Industry Research Institute in 2022 and relevant data in other internal reports, the cost data and market integral transaction price data of BYD Auto Auto from 2020 to 2022 can be obtained through analysis and sorting. The cost data of new energy batteries is set as 1/3 of the manufacturing cost of new energy vehicles. The detailed data table is shown in Table 2.

**Table 2**
Cost Data and Market data of BYD New Energy Vehicles in 2020-2022

| Parameter | 2020 | 2021 | 2022 |
|---|---|---|---|
| Cost of new energy batteries | 34260 | 38640 | 43020 |
| Manufacturing cost of new energy vehicles | 114200 | 128800 | 143400 |
| Market sales volume | 1367000 | 3521000 | 6887000 |
| Point transaction price | 1000 | 2088 | 1128 |

Note: K=500；b=5；t=0.0034

This article studies the new energy vehicle market. Due to the large demand range of the new energy vehicle market, this article specifies a price demand elasticity coefficient of 5; Assuming a cost coefficient of 500 for technological innovation; The integration coefficient is set to 0.0034 based on the latest policy in 2023. Based on this, the optimal parameter values and profit values for different scenarios in this article can be calculated. The results are shown in Table 3.

**Table 3**
Optimal Parameter Values and Optimal Profit Values under Different Scenarios

| Parameter | Time | $w^*$ | $H^*$ | $p^*$ | $\prod^*_g(H \quad w)$ | $\prod^*_z(H \quad p)$ | $\prod^*(H \quad p)$ |
|---|---|---|---|---|---|---|---|
| Decentralized decision-making | 2020 | 98589.11 | 1093.59 | 241235.44 | 10046598959.94 | 5172793203.55 | 15219392163.50 |
| | 2021 | 345709.74 | 10899.75 | 550665.13 | 206028444888.94 | 117864784774.35 | 323893229663.29 |
| | 2022 | 661243.24 | 11855.05 | 1068288.38 | 920364395558.15 | 477749970783.12 | 1398114366341.26 |
| Cost sharing contract | 2020 | 98617.19 | 1110.11 | 241221.40 | 10050984586.83 | 5172858461.83 | 15223843048.65 |
| | 2021 | 348715.14 | 11746.43 | 549162.43 | 208044912578.86 | 118010132078.86 | 326055044657.71 |
| | 2022 | 661685.61 | 12085.74 | 1068067.19 | 921022966610.34 | 477762541485.34 | 1398785508095.67 |
| Revenue sharing contract | 2020 | 89313.45 | 1127.14 | 240248.86 | 10354757217.15 | 4422577353.23 | 14777334570.39 |
| | 2021 | 248184.03 | 12735.74 | 524803.23 | 240732519771.67 | 95067623342.45 | 335800143114.12 |
| | 2022 | 591881.05 | 12325.59 | 1056019.46 | 956894503654.79 | 466557487711.73 | 1423451991366.52 |

It can be seen from Table 3 that when new energy vehicle manufacturers choose to share innovation costs with new energy battery suppliers, or share profits, the technological innovation level of new energy battery suppliers is significantly higher than that of Decentralized decision-making. This indicates that both cost sharing contracts and revenue sharing contracts can effectively promote the technological innovation of new energy battery suppliers.

Secondly, under the cost sharing contract and revenue sharing contract, the optimal profit of both new energy vehicle manufacturers and new energy battery suppliers is higher than that under the Decentralized decision-making situation. Although new energy vehicle manufacturers partially benefit battery suppliers, the bonus points brought by the technological innovation of battery suppliers also feed back to the new energy vehicle manufacturers, enabling both parties to achieve win-win cooperation.

Finally, by comparing the optimal profits of battery suppliers and new energy vehicle manufacturers under cost sharing contracts and revenue sharing contracts, it can be found that the optimal profits under revenue sharing contracts are slightly higher than those under cost sharing contracts. This indicates that the risk of new energy vehicle suppliers is malignant and they tend to choose post contract to reduce unknown risks brought by pre contract.

## 7. Conclusion

This article studies the contract selection of collaborative innovation in the supply chain of new energy vehicles under the background of the "double integral" policy. By establishing profit models between new energy battery suppliers and new energy vehicle manufacturers in different situations, the optimal parameter solution and profit function in the model are obtained using differential game method. Research findings:

(1) The dual credit policy for China's new energy industry has a promoting effect on collaborative innovation among entities in the new energy vehicle supply chain. The increase in point trading prices not only increases the bonus points for new energy

vehicle manufacturers, but also promotes new energy vehicle manufacturers to benefit battery suppliers and car users, which is conducive to promoting technological innovation for new energy battery suppliers and promoting the healthy development of the new energy vehicle market. Therefore, the government should continue to promote the implementation and reform of the dual credit policy, protect the innovation dividends of the new energy supply chain, and implement a credit transaction guarantee system.

(2) Compared with decentralized decision-making situations, the integration of cost sharing contracts or revenue sharing contracts can more effectively stimulate the innovation vitality of new energy battery suppliers and enhance their technological innovation level. Cost sharing contracts or revenue sharing contracts enable new energy battery suppliers to share innovation costs or dividends with new energy vehicle manufacturers, reducing the innovation risks of new energy battery suppliers.

(3) Under both contract conditions, the optimal profit after collaborative innovation between new energy vehicle manufacturers and new energy battery suppliers is higher than the optimal profit under decentralized decision-making, and it can be clearly found that the optimal profit under revenue sharing contracts is much higher than the optimal profit when new energy vehicle manufacturers choose cost sharing contracts.

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**Appendix 1: Calculation Process of Supply Chain Collaborative Innovation Model under Cost Sharing Contract**

Firstly, based on the profit function $\prod_z(H \quad p)$ of new energy vehicle manufacturers, solve their first-order and second-order derivative functions regarding product price $p$, which are:

$$\frac{\partial \prod_z(H \quad p)}{\partial p} = a + b(w + C_z - p_0 tH) - 2bp$$

$$\frac{\partial^2 \prod_z(H \quad p)}{\partial p^2} = -2b < 0$$

Because of $\frac{\partial^2 \prod(H \quad p)}{\partial p^2} < 0$, the profit function $\prod_z(H \quad p)$ of the new energy vehicle manufacturer is a Concave function about the product price, and the maximum value is taken when the first derivative is zero.

Therefore, by setting $\frac{\partial \prod(H \quad p)}{\partial p} = 0$, the optimal product price $p^*$ for a new energy vehicle manufacturer in this situation can be obtained as:

$$p^* = \frac{a + b(w + C_z - p_0 tH)}{2b} \tag{10}$$

By replacing Eq. (10) into Eq. (6), the profit function of new energy battery suppliers is:

$$\prod_g(H \quad w) = (w - C_g)\left(\frac{a - b(w + C_z - p_0 tH)}{2}\right) - \frac{1}{2}(1-\theta)kH^2 \tag{11}$$

However, according to Eq. (11), the profit function $\prod_g(H \quad w)$ of new energy battery suppliers can be solved by solving their first-order and second-order derivative functions regarding product selling price $w$ and innovation level $H$, which are:

$$\frac{\partial \prod(H \quad w)}{\partial w} = \frac{a - b(C_z - p_0 tH) + bC_g - 2bw}{2}$$

$$\frac{\partial^2 \prod(H \quad w)}{\partial w^2} = -b < 0$$

$$\frac{\partial \prod(H \quad w)}{\partial H} = \frac{bp_0 t(w - C_g)}{2} - (1-\theta)kH$$

$$\frac{\partial^2 \prod(H \quad w)}{\partial H^2} = -(1-\theta)k < 0$$

Because of $\frac{\partial^2 \prod(H \quad w)}{\partial w^2} < 0$ and $\frac{\partial^2 \prod(H \quad w)}{\partial H^2} < 0$, the profit function $\prod_g(H \quad w)$ of new energy battery suppliers is a Concave function about the selling price $w$ of products and the innovation level $H$, and the maximum value is taken when the first derivative is zero. Therefore, for $\frac{\partial \prod(H \quad w)}{\partial w} = 0$ and $\frac{\partial \prod(H \quad w)}{\partial H} = 0$, the optimal selling price $w^*$ and the optimal innovation level $H^*$ of new energy battery suppliers in this situation can be obtained, respectively:

$$w^* = \frac{2k(1-\theta)(a - bC_z + bC_g) - (bp_0 t)^2 C_g}{4bk(1-\theta) - (bp_0 t)^2} \qquad H^* = \frac{(a - bC_z - bC_g)bp_0 t}{4bk(1-\theta) - (bp_0 t)^2}.$$

By incorporating the optimal selling price $w^*$ and the optimal innovation level $H^*$ into equation (10), the optimal product price $p^*$ for a new energy vehicle manufacturer can be obtained as:

$$p^* = \frac{k(1-\theta)(3a + bC_z + bC_g) - ab(p_0 t)^2}{4bk(1-\theta) - (bp_0 t)^2}$$

Based on the optimal selling price $w^*$ and innovation level $H^*$ of the new energy battery supplier, as well as the optimal product price $p^*$ of the new energy vehicle manufacturer, and by introducing equations (6) and (7), the optimal profits of the new energy battery supplier and the new energy vehicle manufacturer can be obtained, which are:

$$\prod_g(H \quad w) = \frac{k(1-\theta)(a-bC_z-bC_g)^2}{2\left[4bk(1-\theta)-(bp_0t)^2\right]}$$

$$\prod_z(H \quad p) = \frac{(2b(k(1-\theta))^2-\theta k(bp_0t)^2)(a-bC_z-bC_g)^2}{2\left[4bk(1-\theta)-(bp_0t)^2\right]^2}$$

Then, the overall optimal profit of the whole new energy vehicle supply chain system under Decentralized decision-making is:

$$\prod^*(H \quad p) = \frac{(6b(k(1-\theta))^2-k(bp_0t)^2)(a-bC_z-bC_g)^2}{2\left[4bk(1-\theta)-(bp_0t)^2\right]^2}$$

**Appendix 2: Calculation Process of Supply Chain Collaborative Innovation Model under Revenue Sharing Contract**

Therefore, in this case, the profit functions of new energy battery suppliers and new energy vehicle manufacturers are:

$$\prod_g(H \quad w) = (w+\beta p - C_g)(a-bp) - \frac{1}{2}kH^2 \tag{8}$$

$$\prod_z(H \quad p) = ((1-\beta)p - w - C_z + p_0tH)(a-bp) \tag{9}$$

Firstly, based on the profit function $\prod_z(H \quad p)$ of new energy vehicle manufacturers, solve their first-order and second-order derivative functions regarding product price $p$, which are:

$$\frac{\partial \prod_z(H \quad p)}{\partial p} = a(1-\beta) + b(w+C_z-p_0tH) - 2b(1-\beta)p$$

$$\frac{\partial^2 \prod_z(H \quad p)}{\partial p^2} = -2b(1-\beta) < 0$$

Because of $\frac{\partial^2 \prod(H \quad p)}{\partial p^2} < 0$, the profit function $\prod_z(H \quad p)$ of the new energy vehicle manufacturer is a concave function about the product price, and the maximum value is taken when the first derivative is zero. Therefore, by setting $\frac{\partial \prod(H \quad p)}{\partial p} = 0$, the optimal product price $p^*$ for a new energy vehicle manufacturer in this situation can be obtained as:

$$p^* = \frac{a(1-\beta) + b(w+C_z-p_0tH)}{2b(1-\beta)} \tag{12}$$

Replacing Eq. (12) into Eq. (8), the profit function of new energy battery suppliers is:

$$\prod_g(H \quad w) = (w+\beta\frac{a(1-\beta)+b(w+C_z-p_0tH)}{2b(1-\beta)} - C_g)(\frac{a(1-\beta)-b(w+C_z-p_0tH)}{2(1-\beta)}) - \frac{1}{2}kH^2 \tag{13}$$

However, according to Eq. (13), the profit function $\prod_g(H \quad w)$ of new energy battery suppliers can be solved by solving their first-order and second-order derivative functions regarding product selling price $w$ and innovation level $H$, which are:

$$\frac{\partial \prod(H \quad w)}{\partial w} = \frac{a(1-\beta) - b(C_z-p_0tH) + (1-\beta)bC_g - b(2-\beta)w}{2(1-\beta)^2}$$

$$\frac{\partial^2 \prod(H \quad w)}{\partial w^2} = \frac{-b(2-\beta)}{2(1-\beta)^2} < 0$$

$$\frac{\partial \prod(H \quad w)}{\partial H} = \frac{bp_0t((w-C_g)(1-\beta)+b\beta(w+C_z))}{2b(1-\beta)^2} - \frac{b^2\beta(p_0t)^2}{2b(1-\beta)^2}H - kH$$

$$\frac{\partial^2 \prod(H \quad w)}{\partial H^2} = -\frac{b^2\beta(p_0t)^2}{2b(1-\beta)^2} - k < 0$$

Because of $\frac{\partial^2 \prod(H \quad w)}{\partial w^2} < 0$ and $\frac{\partial^2 \prod(H \quad w)}{\partial H^2} < 0$, the profit function $\prod_g(H \quad w)$ of new energy battery suppliers is a concave function about the selling price $w$ of products and the innovation level $H$, and the maximum value is taken when the first derivative is zero. Therefore, for $\frac{\partial \prod(H \quad w)}{\partial w}=0$ and $\frac{\partial \prod(H \quad w)}{\partial H}=0$, the optimal selling price $w^*$ and the optimal innovation level $H^*$ of new energy battery suppliers in this situation can be obtained, respectively:

$$w^*=\frac{2k(1-\beta)(a(1-\beta)-bC_z+bC_g)+(a\beta-bC_g)b(p_0t)^2}{2bk(2-\beta)-(bp_0t)^2} \qquad H^*=\frac{(a-bC_z-bC_g)bp_0t}{2bk(2-\beta)-(bp_0t)^2}\text{。}$$

By incorporating the optimal selling price $w^*$ and the optimal innovation level $H^*$ into equation (12), the optimal product price $p^*$ for a new energy vehicle manufacturer can be obtained as:

$$p^*=\frac{(a(3-2\beta)+bC_z+bC_g)k-ab(p_0t)^2}{2bk(2-\beta)-(bp_0t)^2}$$

Based on the optimal selling price $w^*$ and innovation level $H^*$ of the new energy battery supplier, as well as the optimal product price $p^*$ of the new energy vehicle manufacturer, and by introducing Eq. (8) and Eq. (9), the optimal profits of the new energy battery supplier and the new energy vehicle manufacturer can be obtained, which are:

$$\prod_g(H \quad w)=\frac{k(a-bC_g-bC_z)^2}{2(2bk(2-\beta)-(bp_0t)^2)}$$

$$\prod_z(H \quad p)=\frac{bk^2(1-\beta)(a-bC_g-bC_z)^2}{2(2bk(2-\beta)-(bp_0t)^2)}$$

Then, the overall optimal profit of the whole new energy vehicle supply chain system under Decentralized decision-making is:

$$\prod^*(H \quad p)=\frac{(bk^2(1-\beta)+k)(a-bC_g-bC_z)^2}{2(2bk(2-\beta)-(bp_0t)^2)}$$