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Research on collaborative innovation decision making of new energy vehicle industry chain considering carbon quota sharing contract

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C H R O N I C L E

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A B S T R A C T

This article constructs a collaborative innovation decision-making model for the new energy vehicle industry chain under decentralized and carbon quota sharing contracts, and obtains the optimal parameter values and profit values of the new energy vehicle industry entities under two different scenarios. Taking BYD's new energy vehicle industry as a case study, the beneficial effect of carbon sharing contracts on the collaborative decision-making of the new energy vehicle industry system is empirically analyzed. Research has found that although carbon sharing contracts may weaken the willingness of new energy vehicle battery suppliers to innovate in carbon reduction, they will effectively improve their innovation in the range of new energy vehicles. The market price of new energy vehicle manufacturers under carbon sharing contracts decreases with the increase of the carbon sharing coefficient. Carbon sharing contracts can significantly increase the profits of the main players in the new energy vehicle industry system, and are directly proportional to the carbon sharing coefficient of the contract.

1. Introduction

At present, the carbon emissions in China's transportation sector account for about 10% of the country's total carbon emissions. China is actively promoting the development of the new energy vehicle market. Although new energy vehicles have lower carbon emissions than traditional fuel vehicles, there are still high carbon emitting enterprises in the new energy vehicle industry system, such as new energy vehicle battery production nodes. Therefore, based on the construction of carbon emissions and carbon trading market system, this article has certain practical significance in studying the impact of carbon trading system on the collaborative decision-making of new energy vehicle industry system entities.

In recent years, many experts and scholars at home and abroad have conducted research on collaborative innovation in the new energy vehicle industry. Scholars' research on the synergy of the new energy vehicle industry mainly focuses on various perspectives and the impact of various factors. The perspectives for studying collaborative innovation in the new energy vehicle industry include those based on dynamic networks (Li & Li, 2025), ecological innovation systems (Liu et al., 2023), technology and cooperation networks (Suo & Li, 2023), and collaborative network evolution (Wang et al., 2024; Yuan et al., 2023) and the perspective of industry collaboration (Quan et al., 2024). Some scholars have shifted their research perspective to the dual credit policy and studied its impact on collaborative innovation in the new energy vehicle supply chain (Shi & Ming, 2023; Zhou & Qiu, 2023). There is also a policy perspective based on new energy vehicles (Joo et al., 2018). Bigerna et al. (2019); Huang et al. (2013) and Shao et al. (2017) analyzed its impact on technological innovation and low-carbon aspects of new energy vehicles.

Scholars have analyzed the impact of various contract forms on collaborative innovation in the new energy vehicle industry, with a focus on cost sharing contracts, revenue sharing contracts, and so on. The impact of revenue sharing contracts on supply chain collaborative decision-making was studied (Han et al., 2021; Shafiq & Luong, 2021; Bangjun et al., 2021; Cui et al.,

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2021). Research on supply chain coordination strategy based on cost sharing contract (Zhu et al., 2021; Kumar et al., 2021; Peng & Luo, 2015). In the field of new energy vehicle industry, scholars have studied incentive contracts for the synergy of the new energy vehicle industry (Liu et al., 2022). Our team has previously conducted research on cost sharing and revenue sharing contracts for collaborative innovation in the new energy vehicle industry (Jun et al., 2024). Based on the bounded rationality of the main body of the new energy vehicle industry system, some scholars have used differential game theory to study collaborative innovation decision-making problems (Tao et al., 2023).

Previous scholars' research has provided useful references for this article to study the collaborative innovation decision-making of the new energy vehicle industry chain through carbon quota sharing contracts. However, previous scholars' research mainly focused on the impact of cost sharing contracts and revenue sharing contracts on the collaborative decision-making of the new energy vehicle industry. Unlike previous research, this article studies the corresponding carbon trading system of the Party Central Committee, considering the collaborative innovation decision-making role of carbon quota sharing contracts on member entities in the new energy vehicle supply chain. Therefore, based on carbon quota sharing contracts, 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 value of the model, and empirically analyzes the impact of carbon quota sharing contracts on innovation decisions of new energy vehicle supply chain entities.

Basic assumptions of the model

In the ecosystem of China's new energy vehicle industry chain, the production cost of new energy vehicle batteries almost determines the production cost and sales price of new energy vehicle manufacturers. Therefore, reducing the production and manufacturing costs of new energy vehicle batteries is the key to improving the ecology of China's new energy vehicle industry chain and promoting the healthy development of the industry. However, currently, in addition to considering production costs, the cost of new energy vehicle batteries also needs to take into account the cost of carbon emissions. Our team has previously studied cost sharing contracts and revenue sharing contracts between new energy vehicle manufacturers and new energy vehicle battery suppliers. Now this article will study the innovation coordination of the new energy vehicle industry chain from the perspective of carbon quota sharing. As is well known, new energy vehicle battery suppliers are high carbon emitting enterprises, and their carbon quotas are not enough to meet their carbon emissions, so they need to purchase additional carbon quotas; New energy vehicle manufacturers have lower carbon emissions during the entire vehicle production and assembly process, and conflicting carbon quotas are available for trading. Carbon quota "refers to the total amount of greenhouse gases emitted into the atmosphere by enterprises during a certain period of time, as approved by the competent government department; Carbon trading "refers to one party to a contract receiving greenhouse gas emissions reductions by paying the other party, and the buyer can use the purchased emissions reductions to mitigate the greenhouse effect and achieve their emission reduction goals. In October 2011, the National Development and Reform Commission of China issued a notice on the pilot work of carbon emission trading.

Based on this, this article considers incorporating carbon quota sharing contracts into the new energy vehicle industry chain, and constructing a new energy vehicle industry ecosystem consisting of a single new energy battery supplier and a single new energy vehicle manufacturer. Propose the following basic assumptions:

Assumption 1: Production cost. New energy vehicle manufacturers and new energy battery suppliers need to pay corresponding costs when producing new energy vehicles and new energy vehicle batteries, such as raw material costs, labor costs, etc. This article C_g represents the production cost of new energy vehicle battery suppliers; Use C_z to represent the production cost of new energy vehicle manufacturers.

Assumption 2: Technological innovation. New energy vehicle battery suppliers who want to reduce production and carbon emission costs must carry out technological innovation. At the same time, the positive demand of new energy vehicle manufacturers for carbon credits will inevitably drive new energy battery suppliers to innovate. This article uses T_e to represent the carbon emissions reduced by the technological innovation of new energy vehicle battery suppliers; Use H to represent the mileage increase due to technological innovation of new energy vehicle battery suppliers. Technological innovation requires corresponding costs. Based on the cost model studied （Zhang et al., 2015), this article constructs the cost function of technological innovation for new energy vehicle battery suppliers as follows: $C(T_e)=\frac{1}{2}k_1T_e^2$, $C(H)=\frac{1}{2}k_2H^2$, where k_1 represents the innovation cost coefficient of reduced carbon emissions, and k_2 represents the innovation cost coefficient of increased mileage.

Assumption 3: Carbon quotas and carbon trading. The carbon quota of the new energy vehicle industry system refers to the legal carbon emissions owned by Chinese new energy vehicle manufacturers and new energy vehicle battery suppliers. When producing new energy vehicle batteries, a large amount of carbon emissions will be generated, so the self owned carbon quotas and technological innovations of new energy vehicle battery suppliers often cannot meet carbon emissions and require the purchase of carbon credits; New energy vehicle manufacturers, due to their low carbon emissions during the production process, can earn carbon credits for every new energy vehicle they produce and sell, which can be used for sales benefits. This article uses $T - T_e$ to represent the carbon quota that a new energy vehicle battery supplier needs to purchase to produce a set of automotive batteries; Use G to represent the carbon credits that a new energy vehicle manufacturer can earn from producing and selling a new energy vehicle. According to the "Parallel Management Measures for Average Fuel Consumption and New Energy Vehicle Credits of Passenger Vehicle Enterprises" issued by three ministries and commissions, as well as the degree of innovation, the calculation method for carbon credits in the production and sales of new energy vehicles is: $G = 0.0034(R + H) + 0.2$. Among them, R is the driving range of electric vehicles.

Assumption 4: Carbon cost and carbon benefit. According to hypothesis 2, both new energy vehicle battery suppliers and new energy vehicle manufacturers will participate in carbon trading. New energy vehicle battery suppliers need to purchase due to insufficient carbon credits, while new energy vehicle manufacturers need to sell due to sufficient carbon credits. According to the carbon credit calculation method, new energy vehicle battery suppliers need to purchase a set of new energy vehicle battery systems at a cost of $e(T - T_e)$ for excess carbon; The carbon credits earned from the production and sale of a new energy vehicle by a new energy vehicle manufacturer are $(0.0034(R + H) + 0.2)e$. To simplify the model, this article defines the carbon credit income of each new energy vehicle as $t(R + H)e$. Where e is the response coefficient of carbon credits to kilometers, and A is the carbon trading price.

Assumption 5: Price. New energy vehicle battery suppliers and new energy vehicle manufacturers each produce a corresponding price. This article uses w to represent the wholesale price of a battery sold by a new energy vehicle battery supplier; Use p to represent the price at which a new energy vehicle manufacturer sells a new energy vehicle.

Assumption 6: Market size. The market has the greatest potential demand for any product. Use a to represent the potential demand in the new energy vehicle market; If b represents the demand price elasticity coefficient, then the demand function of the new energy vehicle market is: $Q=a - bp$.

2. Model Analysis and Solution

2.1 Decentralized Decision Model

According to the assumed conditions, the profit functions of new energy vehicle battery suppliers and new energy vehicle manufacturers in decentralized decision-making can be obtained as follows:

$$\prod_g = (w - C_g - e(T - T_e))(a - bp) - \frac{1}{2}k_1 T_e^2 - \frac{1}{2}k_2 H^2 \quad (1)$$

$$\prod_z = (p - w - C_z + te(R + H))(a - bp) \quad (2)$$

In decentralized decision-making, as new energy vehicle battery suppliers are upstream enterprises in the new energy vehicle industry ecosystem, they have priority pricing power, while new energy vehicle manufacturers can only price based on the pricing of new energy vehicle battery suppliers. Therefore, the order of decentralized decision-making is that upstream new energy vehicle battery suppliers first determine the price of new energy vehicle batteries, and then the new energy vehicle manufacturers determine the selling price of the vehicles. This article uses reverse induction method to solve the optimal strategy combination, and the calculation process is as follows.

Firstly, based on the profit function $\prod_z$ of the new energy vehicle manufacturer, the first-order and second-order derivative functions of the new energy vehicle price p are solved as follows:

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

$$\frac{\partial^2 \prod_z}{\partial p^2} = -2b < 0$$

Due to $\frac{\partial^2 \prod}{\partial p^2} < 0$, the profit function $\prod_z$ of new energy vehicle manufacturers is a convex function with respect to the sales price of new energy vehicles, and takes its maximum value when the first-order derivative is zero.

Therefore, let $\frac{\partial \prod_z}{\partial p}=0$ obtain the optimal car sales price p^* for the new energy vehicle manufacturer at this time, which is:

$$p^*=\frac{a+b(w+C_z-te(R+H))}{2b} \tag{3}$$

By substituting the optimal sales price p^* of the new energy vehicle manufacturer into Eq. (1), the profit function of the photovoltaic system supplier at this time can be obtained as:

$$\prod_g=(w-C_g-e(T-T_e))(\frac{a-b(w+C_z-te(R+H))}{2})-\frac{1}{2}k_1T_e^2-\frac{1}{2}k_2H^2 \tag{4}$$

However, according to equation (4), the profit function $\prod_g$ of the new energy vehicle battery supplier can be solved for its first-order and second-order derivative functions regarding the price w of the new energy vehicle battery, which are:

$$\frac{\partial \prod_g}{\partial w}=\frac{a+b(C_g+e(T-T_e))-b(C_z-te(R+H))}{2}-bw$$

$$\frac{\partial^2 \prod_g}{\partial w^2}=-b<0$$

Due to $\frac{\partial^2 \prod_g}{\partial w^2}<0$, the profit function $\prod_g$ of the new energy vehicle battery supplier is a convex function with respect to the price w of the new energy vehicle battery, and takes its maximum value when the first-order derivative is zero. Therefore, assuming $\frac{\partial \prod_g}{\partial w}=0$, the optimal new energy battery price w^* for new energy vehicle battery suppliers under decentralized decision-making can be obtained as follows:

$$w^*=\frac{a+b(C_g+e(T-T_e))-b(C_z-te(R+H))}{2b}$$

By substituting the optimal new energy battery price w^* of the new energy vehicle battery supplier into equation (3), the optimal car sales price p^* of the new energy vehicle manufacturer can be obtained as follows:

$$p^*=\frac{3a+b(C_g+e(T-T_e))+b(C_z-te(R+H))}{4b}$$

Based on the optimal new energy battery price w^* obtained from the new energy vehicle battery supplier and the optimal vehicle sales price p^* obtained from the new energy vehicle manufacturer, by substituting Eq. (1) and Eq. (2), the optimal profits of the new energy vehicle battery supplier and the new energy vehicle manufacturer can be obtained, which are:

$$\prod{}^{\bullet}_g=\frac{[a-b(C_g+e(T-T_e))-b(C_z-te(R+H))]^2}{8b}-\frac{1}{2}k_1T_e^2-\frac{1}{2}k_2H^2$$

$$\prod{}^{\bullet}_z=\frac{[a-b(C_g+e(T-T_e))-b(C_z-te(R+H))]^2}{16b}$$

Based on the optimal profit function $\prod{}^{\bullet}_g$ of the new energy vehicle battery supplier obtained, solve the first-order and second-order derivative functions of the carbon reduction T_e and new mileage H achieved by the new energy vehicle battery supplier due to technological innovation, which are:

$$\frac{\partial \prod{}^{\bullet}_g(T_e,H)}{\partial T_e}=\frac{2be[a-b(C_g+e(T-T_e))-b(C_z-te(R+H))]}{8b}-k_1T_e$$

$$\frac{\partial^2 \prod{}^{\bullet}_g(T_e,H)}{\partial^2 T_e}=\frac{be^2}{4}-k_1$$

$$\frac{\partial \prod{}^{\bullet}_g(T_e,H)}{\partial H}=\frac{2bte[a-b(C_g+e(T-T_e))-b(C_z-te(R+H))]}{8b}-k_2H$$

$$\frac{\partial^2 \prod{}^{\bullet}_g(T_e,H)}{\partial^2 H}=\frac{bt^2e^2}{4}-k_2$$

Let $\frac{\partial \prod^{\bullet}{}_{g}(T_e,H)}{\partial T_e}=0$ and $\frac{\partial \prod^{\bullet}{}_{g}(T_e,H)}{\partial H}=0$ respectively obtain the optimal carbon reduction $T^{\bullet}{}_{e}$ and optimal new mileage $H^{\bullet}$ achieved by the new energy vehicle battery supplier due to technological innovation at this time:

$$T^{\bullet}{}_{e}=\frac{k_2e[a-b(C_g+eT)-b(C_z-teR)]}{4k_1k_2-k_1bt^2e^2-k_2e^2b}$$
$$H^{\bullet}=\frac{k_1te[a-b(C_g+eT)-b(C_z-teR)]}{4k_1k_2-k_1bt^2e^2-k_2e^2b}$$

Based on the optimal carbon emission reduction $T^{\bullet}{}_{e}$ and the optimal new mileage $H^{\bullet}$ obtained, which are then incorporated into the optimal new energy battery price w^{*}, the optimal car sales price p^{*}, and the optimal profits of new energy vehicle battery suppliers and manufacturers, we can obtain:

$$w^{*}=\frac{b(C_g+eT)(2k_1k_2-k_1bt^2e^2)+(a-b(C_z-teR))(2k_1k_2-k_2be^2)}{b(4k_1k_2-k_1bt^2e^2-k_2e^2b)}$$
$$p^{*}=\frac{a(3k_1k_2-k_1bt^2e^2-k_2be^2)+bk_1k_2((C_g+eT)+(C_z-teR))}{b(4k_1k_2-k_1bt^2e^2-k_2e^2b)}$$
$$\prod{}^{*}{}_{g}=\frac{k_1k_2[a-b(C_g+eT)-b(C_z-teR)]^2}{2b(4k_1k_2-k_1bt^2e^2-k_2e^2b)}$$
$$\prod{}^{*}{}_{z}=\frac{k^2{}_1k^2{}_2[a-b(C_g+eT)-b(C_z-teR)]^2}{b(4k_1k_2-k_1bt^2e^2-k_2e^2b)^2}$$

So, the overall optimal profit of the entire new energy vehicle industry ecosystem under decentralized decision-making is:

$$\prod{}^{*}=\frac{k_1k_2(6k_1k_2-k_1bt^2e^2-k_2e^2b)[a-b(C_g+eT)-b(C_z-teR)]^2}{2b(4k_1k_2-k_1bt^2e^2-k_2e^2b)^2}$$

Property 1: The optimal carbon emission reduction $T^{\bullet}{}_{e}$ and optimal new mileage $H^{\bullet}$ achieved by new energy vehicle battery suppliers due to technological innovation indicate that the low-carbon technological innovation of new energy vehicle battery suppliers is limited by their own cost factors. The higher the cost, the more restricted the technological innovation; Secondly, the optimal carbon emission reduction is the reduction function of the emission reduction response coefficient. The optimal innovation level of new energy vehicle battery suppliers is influenced by carbon emission factors. The more carbon emissions, the higher the carbon emission cost, and the lower the innovation level; The optimal new mileage is the decreasing function of the mileage innovation cost coefficient.

Property 2: According to the optimal battery price w^{*} of the new energy vehicle battery supplier, the optimal new energy battery price increases with the increase of its own cost; Simultaneously affected by the carbon price, it increases with the rise of carbon price.

2.2 Carbon quota sharing contract model

In the case of decentralized decision-making, due to the existence of double marginal effects, new energy vehicle battery suppliers neglect the improvement of new energy battery innovation level and investment in carbon reduction research and development in order to obtain high profits and low innovation costs. In order to achieve the national "dual carbon" goal, realize the long-term plan of carbon peak and carbon neutrality, and meet people's low-carbon consumption preferences, the country is promoting the upgrading and transition of China's new energy vehicle industry ecosystem from the traditional fuel vehicle era to the new energy vehicle era. As the core component supplier, the new energy vehicle battery supplier plays an important role, and the range and carbon reduction of the new energy vehicle lifecycle are related to it. Therefore, in order to achieve goals such as technological innovation and carbon reduction, the ecosystem of the new energy vehicle industry should work together to solve problems. In previous studies, our team has investigated the impact of contract forms such as innovation cost sharing and revenue sharing contracts on the ecosystem of the new energy vehicle industry. This article will not elaborate further here. Only considering the impact of carbon quota sharing contracts on the decision-making of the new energy vehicle industry ecosystem based on carbon quota trading. Although carbon quota sharing contracts, cost sharing contracts, and revenue sharing contracts are all benefit contracts, they are different from pre - or post contracts. Carbon quota sharing is more similar to industrial integration carbon emission methods. As is well known, in the ecosystem of the new energy vehicle industry, the production of new energy vehicle batteries is a high carbon process. Faced with high carbon emission costs, the increase in carbon emission costs invisibly weakens the cost share of enterprises for technological innovation. The carbon credits that a new energy vehicle manufacturer can earn from selling a new energy vehicle are closely related to the range of the new energy vehicle. If the new energy vehicle industry system is integrated for emissions, that is, new energy vehicle manufacturers are willing to share some carbon quotas with new energy vehicle battery suppliers in order to encourage innovation in new energy vehicle battery suppliers and achieve innovation in new energy vehicle battery manufacturing range, this will make new energy vehicle battery suppliers no longer consider carbon emission costs, thereby increasing funding for technological innovation.

Under the carbon quota sharing contract decision, this article assumes that new energy vehicle manufacturers will share a portion of their carbon emission quotas with new energy vehicle battery suppliers, with a sharing ratio of θ. So the proportion of carbon emissions borne by new energy vehicle manufacturers for new energy vehicle battery suppliers is θ, and the proportion of carbon emissions borne by new energy vehicle battery suppliers is $1-\theta$. Therefore, in this situation, the profit functions of new energy vehicle battery suppliers and new energy vehicle manufacturers are as follows:

$$\prod_g = (w - C_g - e(1-\theta)(T-T_e))(a-bp) - \frac{1}{2}k_1 T_e^2 - \frac{1}{2}k_2 H^2 \tag{5}$$

$$\prod_z = (p - w - C_z + e(t(R+H) - \theta(T-T_e)))(a-bp) \tag{6}$$

The reverse induction method is still used to solve the optimal strategy combination, and the calculation process is as follows.

Firstly, based on the profit function $\prod_z$ of the new energy vehicle manufacturer, the first-order and second-order derivative functions of the new energy vehicle price p are solved as follows:

$$\frac{\partial \prod_z}{\partial p} = a + b(w + C_z - e(t(R+H) + \theta(T-T_e))) - 2bp$$

$$\frac{\partial^2 \prod_z}{\partial p^2} = -2b < 0$$

Due to $\frac{\partial^2 \prod}{\partial p^2} < 0$, the profit function $\prod_z$ of new energy vehicle manufacturers is a convex function with respect to the sales price of new energy vehicles, and takes its maximum value when the first-order derivative is zero. Therefore, let $\frac{\partial \prod_z}{\partial p} = 0$ obtain the optimal car sales price p^* for the new energy vehicle manufacturer at this time, which is:

$$p^* = \frac{a + b(w + C_z - e(t(R+H) + \theta(T-T_e)))}{2b} \tag{7}$$

By substituting the optimal sales price p^* of the new energy vehicle manufacturer into equation (5), the profit function of the photovoltaic system supplier at this time can be obtained as:

$$\prod_g = (w - C_g - e(1-\theta)(T-T_e))\left(\frac{a - b(w + C_z - e(t(R+H) + \theta(T-T_e)))}{2}\right) - \frac{1}{2}k_1 T_e^2 - \frac{1}{2}k_2 H^2$$

However, according to the profit function $\prod_g$ of the new energy vehicle battery supplier in the above equation, the first-order and second-order derivative functions of the new energy vehicle battery price w can be solved as follows:

$$\frac{\partial \prod_g}{\partial w} = \frac{a + b(C_g + e(1-\theta)(T-T_e)) - b(C_z - e(t(R+H) + \theta(T-T_e)))}{2} - bw$$

$$\frac{\partial^2 \prod_g}{\partial w^2} = -b < 0$$

Due to $\frac{\partial^2 \prod_g}{\partial w^2} < 0$, the profit function $\prod_g$ of the new energy vehicle battery supplier is a convex function with respect to the price w of the new energy vehicle battery, and takes its maximum value when the first-order derivative is zero.

Therefore, assuming $\frac{\partial \prod_g}{\partial w} = 0$, the optimal new energy battery price w^* for new energy vehicle battery suppliers under decentralized decision-making can be obtained as follows:

$$w^* = \frac{a + b(C_g + e(1-\theta)(T - T_e)) - b(C_z - e(t(R+H) + \theta(T - T_e)))}{2b}$$

By substituting the optimal new energy battery price w^* of the new energy vehicle battery supplier into Eq. (7), the optimal car sales price p^* of the new energy vehicle manufacturer can be obtained as follows:

$$p^* = \frac{3a + b(C_g + e(1-\theta)(T - T_e)) + b(C_z - e(t(R+H) + \theta(T - T_e)))}{4b}$$

Based on the optimal new energy battery price w^* obtained from the new energy vehicle battery supplier and the optimal vehicle sales price p^* obtained from the new energy vehicle manufacturer, by substituting Eq. (5) and Eq. (6), the optimal profits of the new energy vehicle battery supplier and the new energy vehicle manufacturer can be obtained, which are:

$$\prod{}^{\bullet}_g = \frac{[a - b(C_g + e(1-\theta)(T - T_e)) - b(C_z - e(t(R+H) + \theta(T - T_e)))]^2}{8b} - \frac{1}{2}k_1 T_e^2 - \frac{1}{2}k_2 H^2$$

$$\prod{}^{\bullet}_z = \frac{[a - b(C_g + e(1-\theta)(T - T_e)) - b(C_z - e(t(R+H) + \theta(T - T_e)))]^2}{16b}$$

Based on the optimal profit function $\prod^{\bullet}_g$ of the new energy vehicle battery supplier obtained, solve the first-order and second-order derivative functions of the carbon reduction T_e and new mileage H achieved by the new energy vehicle battery supplier due to technological innovation, which are:

$$\frac{\partial \prod^{\bullet}_g(T_e, H)}{\partial T_e} = \frac{2be(1-2\theta)[a - b(C_g + e(1-\theta)(T - T_e)) - b(C_z - e(t(R+H) + \theta(T - T_e)))]}{8b} - k_1 T_e$$

$$\frac{\partial^2 \prod^{\bullet}_g(T_e, H)}{\partial^2 T_e} = \frac{be^2(1-2\theta)^2}{4} - k_1$$

$$\frac{\partial \prod^{\bullet}_g(T_e, H)}{\partial H} = \frac{2bte[a - b(C_g + e(1-\theta)(T - T_e)) - b(C_z - e(t(R+H) + \theta(T - T_e)))]}{8b} - k_2 H$$

$$\frac{\partial^2 \prod^{\bullet}_g(T_e, H)}{\partial^2 H} = \frac{bt^2e^2}{4} - k_2$$

Let $\frac{\partial \prod^{\bullet}_g(T_e, H)}{\partial T_e} = 0$ and $\frac{\partial \prod^{\bullet}_g(T_e, H)}{\partial H} = 0$ respectively obtain the optimal carbon reduction $T^{\bullet *}_e$ and optimal new mileage $H^{\bullet *}$ achieved by the new energy vehicle battery supplier due to technological innovation at this time:

$$T^{\bullet *}_e = \frac{k_2 e(1-2\theta)[a - b(C_g + e(1-2\theta)T) - b(C_z - etR)]}{4k_1k_2 - k_1bt^2e^2 - k_2e^2b(1-2\theta)^2}$$

$$H^{\bullet *} = \frac{k_1 te[a - b(C_g + e(1-2\theta)T) - b(C_z - etR)]}{4k_1k_2 - k_1bt^2e^2 - k_2e^2b(1-2\theta)^2}$$

Based on the optimal carbon emission reduction $T^{\bullet *}_e$ and the optimal new mileage $H^{\bullet *}$ obtained, they are incorporated into the optimal new energy battery price w^*, the optimal car sales price p^*, and the optimal profits of new energy vehicle battery suppliers and manufacturers. The following can be obtained:

$$w{*}{*} = \frac{b(C_g + eT)(2k_1k_2 - k_1bt^2e^2) + (a - b(C_z - teR))(2k_1k_2 - k_2be^2(1-2\theta)^2) + k_1bt^2e^2be\theta T}{b(4k_1k_2 - k_1bt^2e^2 - k_2e^2b(1-2\theta)^2)}$$

$$p**=\frac{a(3k_1k_2-k_1bt^2e^2-k_2be^2(1-2\theta)^2)+bk_1k_2((C_g+e(1-2\theta)T)+(C_z-teR))}{b(4k_1k_2-k_1bt^2e^2-k_2e^2b(1-2\theta)^2)}$$

$$\prod**_g=\frac{k_1k_2[a-b(C_g+e(1-2\theta)T)-b(C_z-teR)]^2}{2b(4k_1k_2-k_1bt^2e^2-k_2e^2b(1-2\theta)^2)}$$

$$\prod**_z=\frac{k^2{}_1k^2{}_2[a-b(C_g+e(1-2\theta)T)-b(C_z-teR)]^2}{b(4k_1k_2-k_1bt^2e^2-k_2e^2b(1-2\theta)^2)^2}$$

So, considering the overall optimal profit of the entire new energy vehicle industry ecosystem under the carbon sharing contract decision, it is:

$$\prod^{**}=\frac{k_1k_2(6k_1k_2-k_1bt^2e^2-k_2e^2b(1-2\theta)^2)[a-b(C_g+e(1-2\theta)T)-b(C_z-teR)]^2}{2b(4k_1k_2-k_1bt^2e^2-k_2e^2b(1-2\theta)^2)^2}$$

Property 3: The optimal carbon reduction $T^{**}{}_e$ and optimal new mileage H^{**} achieved by new energy vehicle battery suppliers due to technological innovation indicate that the technological innovation of new energy vehicle battery suppliers is influenced by the carbon sharing contract coefficient. As the carbon sharing contract coefficient increases, the innovation of new energy vehicle suppliers in carbon reduction gradually decreases, while the innovation in vehicle mileage gradually increases.

Property 4: It can be inferred from the optimal battery sales price w^{**} of the new energy vehicle battery supplier and the optimal new energy vehicle sales price p^{**} of the new energy vehicle manufacturer that the battery price of the new energy vehicle battery supplier is not affected by the carbon sharing contract coefficient. However, the selling price of new energy vehicle manufacturers decreases as the carbon sharing contract coefficient increases.

2.3 Equilibrium result analysis

New energy vehicle battery suppliers and new energy vehicle manufacturers, as rational economic agents, will only choose carbon sharing contracts when the profits after implementing carbon sharing contracts are greater than those in decentralized decision-making situations. Therefore, this article assumes that $\prod**_g$ is greater than $\prod*_g$, and $\prod**_z$ is greater than $\prod*_z$. It can be inferred from this that:

$$\frac{[a-b(C_g+e(1-2\theta)T)-b(C_z-teR)]^2}{(4k_1k_2-k_1bt^2e^2-k_2e^2b(1-2\theta)^2)}>\frac{[a-b(C_g+eT)-b(C_z-teR)]^2}{(4k_1k_2-k_1bt^2e^2-k_2e^2b)}$$

The range of values for the carbon emission ratio of new energy vehicle battery suppliers borne by new energy vehicle manufacturers can be obtained as follows:

$$\theta>\frac{k_2[a-b(C_g+eT)-b(C_z-teR)]^2-T[a-b(C_g+eT)-b(C_z-teR)](4k_1k_2-k_1bt^2e^2-k_2e^2b)}{k_2[a-b(C_g+eT)-b(C_z-teR)]^2+b^2eT^2(4k_1k_2-k_1bt^2e^2-k_2e^2b)}$$

Based on the optimal new energy battery price w^*, optimal new mileage H^*, optimal new energy vehicle sales price p^*, and optimal carbon reduction amount $T^{**}{}_e$ obtained in 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 to summarize and form the decision results of the new energy vehicle supply chain system under different situations. As shown in Table 1. According to Table 1, the following proposition can be found to be consistent with the previous properties:

Proposition 1: It can be inferred from $\frac{\partial w^*}{\partial e}>0$ and $\frac{\partial w^*}{\partial C_g}>0$ that the optimal wholesale price is an increasing function of the integral transaction price and the cost of new energy vehicle batteries.

Proposition 2: It can be inferred from $\frac{\partial p^*}{\partial e}<0$, $\frac{\partial p^*}{\partial C_g}>0$, and $\frac{\partial p^*}{\partial C_z}>0$ 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.

Table 1
Optimal parameter values and profit results under different scenarios

parameter	Decentralized decision-making	Decision on Carbon Quota Sharing Contract
$T^{\bullet}_e$	$\frac{k_2 e[a-b(C_g+eT)-b(C_z-teR)]}{4k_1k_2-k_1bt^2e^2-k_2e^2b}$	$\frac{k_2 e(1-2\theta)[a-b(C_g+e(1-2\theta)T)-b(C_z-etR)]}{4k_1k_2-k_1bt^2e^2-k_2e^2b(1-2\theta)^2}$
$H^{\bullet}$	$\frac{k_1 te[a-b(C_g+eT)-b(C_z-teR)]}{4k_1k_2-k_1bt^2e^2-k_2e^2b}$	$\frac{k_1 te[a-b(C_g+e(1-2\theta)T)-b(C_z-etR)]}{4k_1k_2-k_1bt^2e^2-k_2e^2b(1-2\theta)^2}$
$w*$	$\frac{b(C_g+eT)(2k_1k_2-k_1bt^2e^2)+(a-b(C_z-teR))(2k_1k_2-k_2be^2)}{b(4k_1k_2-k_1bt^2e^2-k_2e^2b)}$	$\frac{b(C_g+eT)(2k_1k_2-k_1bt^2e^2)+(a-b(C_z-teR))(2k_1k_2-k_2be^2(1-2\theta)^2)+k_1bt^2e^2be\theta T}{b(4k_1k_2-k_1bt^2e^2-k_2e^2b(1-2\theta)^2)}$
$p*$	$\frac{a(3k_1k_2-k_1bt^2e^2-k_2be^2)+bk_1k_2((C_g+eT)+(C_z-teR))}{b(4k_1k_2-k_1bt^2e^2-k_2e^2b)}$	$\frac{a(3k_1k_2-k_1bt^2e^2-k_2be^2(1-2\theta)^2)+bk_1k_2((C_g+e(1-2\theta)T)+(C_z-teR))}{b(4k_1k_2-k_1bt^2e^2-k_2e^2b(1-2\theta)^2)}$
$\Pi*_g$	$\frac{k_1k_2[a-b(C_g+eT)-b(C_z-teR)]^2}{2b(4k_1k_2-k_1bt^2e^2-k_2e^2b)}$	$\frac{k_1k_2[a-b(C_g+e(1-2\theta)T)-b(C_z-teR)]^2}{2b(4k_1k_2-k_1bt^2e^2-k_2e^2b(1-2\theta)^2)}$
$\Pi*_z$	$\frac{k^2{}_1k^2{}_2[a-b(C_g+eT)-b(C_z-teR)]^2}{b(4k_1k_2-k_1bt^2e^2-k_2e^2b)^2}$	$\frac{k^2{}_1k^2{}_2[a-b(C_g+e(1-2\theta)T)-b(C_z-teR)]^2}{b(4k_1k_2-k_1bt^2e^2-k_2e^2b(1-2\theta)^2)^2}$
Π^*	$\frac{k_1k_2(6k_1k_2-k_1bt^2e^2-k_2e^2b)[a-b(C_g+eT)-b(C_z-teR)]^2}{2b(4k_1k_2-k_1bt^2e^2-k_2e^2b)^2}$	$\frac{k_1k_2(6k_1k_2-k_1bt^2e^2-k_2e^2b(1-2\theta)^2)[a-b(C_g+e(1-2\theta)T)-b(C_z-teR)]^2}{2b(4k_1k_2-k_1bt^2e^2-k_2e^2b(1-2\theta)^2)^2}$

3. Empirical Analysis

By analyzing and organizing relevant data from BYD's annual financial reports and other internal reports in recent years, we have obtained cost data and market point trading price data for BYD Auto from 2020 to 2024. Taking BYD Han as an example, new energy vehicles are equipped with approximately 75KW lithium batteries to calculate the cost of new energy vehicle batteries. The cost data of new energy batteries is set as 40% of the manufacturing cost of new energy vehicles. The detailed data table is shown in Table 2. (2024 data is forecast data)

Table 2

Cost and Market Data of BYD New Energy Vehicles from 2020 to 2024

parameter	2020	2021	2022	2023	2024
Cost of lithium batteries（Yuan/kw）	650	788	1200	691	400
Cost of new energy batteries（Yuan）	48750	59100	90000	51825	30000
Manufacturing cost of new energy vehicles (Yuan)	121875	147750	225000	129562.5	75000
Market sales volume（Liang）	179054	593745	1868500	3020000	3757300
Points trading price (Yuan)	1000	2088	1128	3000	3000

Note: k_1 =100； k_2 =100； b =5； t =0.0034； T =2000000； R =500

This article studies the ecosystem of the new energy vehicle industry chain. As the new energy vehicle industry is greatly affected by market price fluctuations, this article assumes a price demand elasticity coefficient of 5; The innovation cost coefficient for carbon emissions is set to 100, and the innovation cost coefficient for increased mileage is set to 100; The integral coefficient is set to 0.0034 based on the latest policy in 2023. In addition, although the carbon emissions of new energy vehicle battery manufacturers vary each year, this article sets the annual carbon emissions of battery manufacturers as a fixed value of 2 million tons for simple calculation, and sets the normal mileage of new energy vehicles at 500 kilometers. Based on this, the optimal parameter values and profit values for different scenarios in this article can be calculated.

3.1 Collaborative decision-making results of new energy vehicle industry entities under different circumstances

Firstly, calculate the optimal parameter values and profit values for the decision-making of new energy vehicle battery suppliers and new energy vehicle manufacturers under decentralized decision-making. The calculation results are shown in Table 3.

Table 3

Optimal parameter values and profit values under decentralized decision-making scenarios

parameter	year				
	2020	2021	2022	2023	2024e
$T^{\bullet}_e$	2.79E-02	8.33E-01	1.81E+00	8.56E+00	1.10E+01
H^*	2.37E-02	7.08E-01	1.54E+01	7.27E+01	9.32E+01
w^*	8.62E+04	3.49E+05	1.11E+06	1.87E+06	2.34E+06
p^*	2.15E+05	6.17E+05	1.84E+06	2.88E+06	3.55E+06
Π^*_g	1.22E+08	2.48E+10	4.00E+11	1.26E+12	2.07E+12
Π^*_z	6.10E+07	1.24E+10	2.00E+11	6.36E+11	1.04E+12
Π^*	1.83E+08	3.72E+10	6.01E+11	1.90E+12	3.12E+12

From Table 3, it can be seen that in the case of decentralized decision-making between new energy vehicle battery suppliers and new energy vehicle manufacturers, as the carbon emissions reduction and new mileage of new energy vehicle battery production by new energy vehicle battery suppliers increase, the wholesale selling price of new energy vehicle batteries gradually increases, and the selling price of new energy vehicle manufacturers also increases year by year.

In collaborative decision-making, new energy vehicle manufacturers choose to share their carbon quotas with new energy vehicle battery suppliers to incentivize innovation in carbon reduction and mileage. Therefore, considering the benefit decision-making between new energy vehicle battery suppliers and new energy vehicle manufacturers under the carbon sharing contract model, it is assumed that the carbon quota sharing coefficient between new energy vehicle manufacturers and new energy battery suppliers is 0.3, which means that new energy vehicle manufacturers bear 30% of the carbon emissions of new energy vehicle battery suppliers. The calculation results are shown in Table 4. From Table 4, it can be seen that under the carbon contract decision-making scenario, the prices of new energy vehicle batteries and new energy vehicles still increase with the innovation of carbon emission reduction and mileage, just like in the decentralized scenario. The optimal profits for new energy vehicle battery suppliers and new energy vehicle manufacturers have also increased.

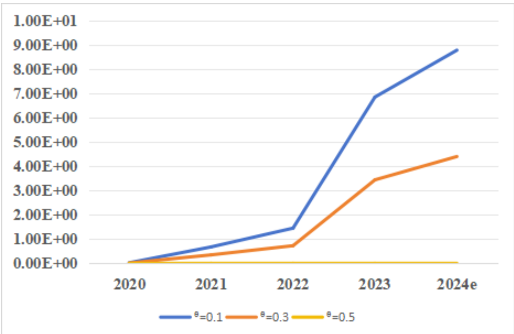
Table 4
Optimal Parameter Values and Profit Values under Carbon Sharing Contract Decision Scenarios

parameter	year				
	2020	2021	2022	2023	2024e
$T^{\bullet}_e$	1.50E-02	3.49E-01	7.27E-01	3.44E+00	4.40E+00
H^*	3.19E-02	7.42E-01	1.54E+01	7.30E+01	3.74E+01
w^*	8.62E+04	3.49E+05	1.11E+06	1.88E+06	2.35E+06
p^*	2.12E+05	6.12E+05	1.83E+06	2.88E+06	3.55E+06
Π^*_g	2.20E+08	2.73E+10	4.06E+11	1.28E+12	2.09E+12
Π^*_z	1.10E+08	1.36E+10	2.03E+11	6.41E+11	1.05E+12
Π^*	3.30E+08	4.09E+10	6.08E+11	1.92E+12	3.14E+12

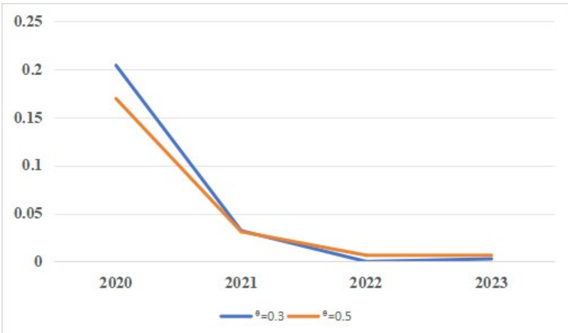
By comparing the data in Table 3 and Table 4, it can be found that the optimal parameter values and profit values of the new energy vehicle industry entities are different under the decentralized situation and the carbon sharing contract situation. It is obvious that the data of each entity in the new energy vehicle industry is better under the carbon sharing contract situation. By comparison, it can be found that when new energy vehicle manufacturers share a 30% carbon quota with new energy vehicle battery suppliers, the innovation drive for carbon reduction of new energy vehicle battery suppliers is significantly insufficient, while the innovation in new energy vehicle mileage is significantly improved. Secondly, the selling prices of batteries from new energy vehicle suppliers have not changed significantly, while the prices of cars from new energy vehicle manufacturers have shown a downward trend. However, overall, both new energy vehicle battery suppliers and new energy vehicle manufacturers have higher optimal profits than decentralized decision-making.

3.2 Sensitivity analysis of carbon contract sharing coefficient

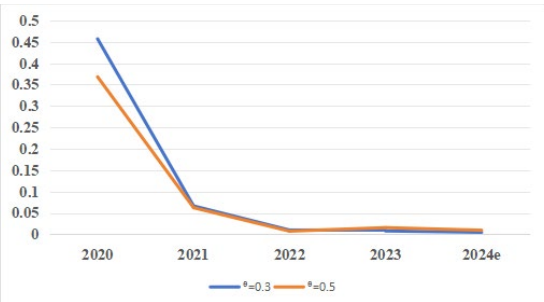
According to Table 3 and Table 4, it has been found that under the carbon sharing contract, new energy vehicle industry entities can obtain more profits. This section conducts sensitivity analysis on the carbon sharing contract coefficient, and the analysis results are shown in Table 5. From Table 5, it can be observed that as the carbon contract sharing coefficient increases, the willingness of new energy vehicle battery suppliers to innovate in carbon reduction decreases, while innovation in new energy vehicle mileage gradually increases. The sales prices of new energy vehicle manufacturers are gradually decreasing, but the optimal profits for new energy vehicle battery suppliers and manufacturers are gradually increasing. The optimal total profit of the entire new energy vehicle industry system is gradually increasing.



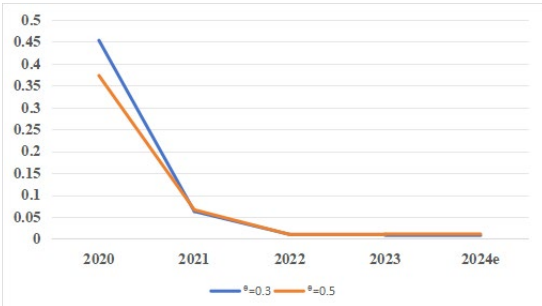
(a) Innovation situation of carbon



(b) Innovative growth rate of mileage emission reduction



(c) Profit growth rate of new energy vehicle battery suppliers



(d) Profit growth rate of new energy vehicle manufacturers

Fig. 1. Trends of various parameter values under carbon sharing contracts

Table 5
Sensitivity analysis results of carbon sharing contract coefficients

θ	parameter	Year				
		2020	2021	2022	2023	2024e
0.1	$T^{\bullet}_{e}$	2.49E-02	6.77E-01	1.45E+00	6.85E+00	8.78E+00
	H^{*}	2.65E-02	7.19E-01	1.54E+01	7.28E+01	7.46E+01
	w^{*}	8.62E+04	3.49E+05	1.11E+06	1.87E+06	2.35E+06
	p^{*}	2.14E+05	6.16E+05	1.83E+06	2.88E+06	3.55E+06
	Π^{*}_{g}	1.51E+08	2.56E+10	4.02E+11	1.27E+12	2.08E+12
	Π^{*}_{z}	7.57E+07	1.28E+10	2.01E+11	6.36E+11	1.04E+12
	Π^{*}	2.27E+08	3.84E+10	6.03E+11	1.90E+12	3.12E+12
0.3	$T^{\bullet}_{e}$	1.50E-02	3.49E-01	7.27E-01	3.44E+00	4.40E+00
	H^{*}	3.19E-02	7.42E-01	1.54E+01	7.30E+01	3.74E+01
	w^{*}	8.62E+04	3.49E+05	1.11E+06	1.88E+06	2.35E+06
	p^{*}	2.12E+05	6.12E+05	1.83E+06	2.88E+06	3.55E+06
	Π^{*}_{g}	2.20E+08	2.73E+10	4.06E+11	1.28E+12	2.09E+12
	Π^{*}_{z}	1.10E+08	1.36E+10	2.03E+11	6.41E+11	1.05E+12
	Π^{*}	3.30E+08	4.09E+10	6.08E+11	1.92E+12	3.14E+12
0.5	$T^{\bullet}_{e}$	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	H^{*}	3.73E-02	7.65E-01	1.55E+01	7.34E+01	0.00E+00
	w^{*}	8.62E+04	3.49E+05	1.11E+06	1.88E+06	2.36E+06
	p^{*}	2.10E+05	6.07E+05	1.83E+06	2.88E+06	3.55E+06
	Π^{*}_{g}	3.01E+08	2.90E+10	4.09E+11	1.30E+12	2.11E+12
	Π^{*}_{z}	1.51E+08	1.45E+10	2.05E+11	6.48E+11	1.06E+12
	Π^{*}	4.52E+08	4.36E+10	6.14E+11	1.94E+12	3.17E+12

Fig. 1(a) and Fig. 1(b) show the trend of carbon reduction and mileage innovation of new energy vehicle battery suppliers under carbon contracts as a function of the carbon contract sharing coefficient; Fig. 1(c) and Fig. 1(d) show the optimal profit growth trends of new energy vehicle battery suppliers and new energy vehicle manufacturers. From Fig. 1(a), it can be seen that as the carbon contract sharing coefficient gradually increases, there is a significant difference in carbon emissions reduction among new energy vehicle battery suppliers, which decreases with the increase of the sharing coefficient. From the graph of mileage growth rate of new energy vehicles (b), it can be seen that the mileage growth rate is greater than zero and proportional to the carbon contract sharing coefficient, but the growth rate decreases year by year. From Fig. 1(c) and Fig. 1(d), it can be observed that the optimal profit growth rate for new energy vehicle battery suppliers and manufacturers is positive and decreasing year by year.

4. Conclusion

This article uses a differential game model to construct production decisions among the main players in the new energy vehicle industry, considering the carbon sharing contract model. It constructs profit models between new energy vehicle battery suppliers and new energy vehicle manufacturers under decentralized and carbon sharing contract situations, and obtains the optimal parameter values and optimal profit values of each main player in the new energy industry under different situations. Empirical analysis is conducted using the BYD new energy vehicle industry. Research has found that:

(1) The carbon sharing contract will weaken the willingness of new energy vehicle battery suppliers to innovate in carbon reduction, but it will effectively improve their innovation in vehicle mileage. After considering the introduction of carbon sharing contracts, new energy vehicle manufacturers will bear a certain proportion of the carbon emissions from the production and manufacturing of new energy vehicle battery suppliers. This will directly reduce the innovative driving force for carbon reduction of new energy vehicle battery suppliers, thereby reducing some research and development costs. This research and development cost will then become an innovation in the performance of new energy vehicle batteries, which increases the mileage of new energy vehicles and thus increases the carbon credits of new energy vehicle manufacturers; And this trend becomes increasingly evident with the increase of carbon sharing coefficient. It can be seen that the introduction of carbon sharing contracts will weaken the willingness for carbon reduction innovation and enhance innovation in battery range.

(2) The market price of new energy vehicle manufacturers under carbon sharing contracts decreases with the increase of the carbon sharing coefficient. When the carbon contract sharing coefficient increases, new energy vehicle manufacturers bear more carbon emissions, allowing new energy vehicle battery suppliers to allocate more research and development costs on battery range, improving the range of new energy vehicles, increasing new energy vehicle points and market sales volume, thereby reducing market prices.

(3) Carbon sharing contracts can significantly increase the profits of the main players in the new energy vehicle industry system, and are directly proportional to the carbon sharing coefficient of the contract. Under the carbon sharing contract, both new energy vehicle battery suppliers and new energy vehicle manufacturers can achieve optimal profits higher than decentralized decision-making; And as the carbon contract sharing coefficient increases, the optimal profits of all entities in the new energy vehicle industry gradually increase.

Therefore, in the ecosystem of new energy vehicles, the main body of the new energy vehicle industry can appropriately consider the carbon emission sharing mechanism, enhance the innovation drive of new energy vehicle battery suppliers in battery range, and improve the profits of all entities in the new energy vehicle industry system. But at the same time, we cannot ignore its impact on carbon reduction innovation willingness. The government and industry should supplement carbon reduction incentive strategies with carbon sharing contracts to effectively balance the carbon reduction willingness of new energy vehicle battery suppliers.

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References

Bigerna, S., Wen, X., Hagspiel, V., & Kort, P. M. (2019). Green electricity investments: Environmental target and the optimal subsidy. *European Journal of Operational Research, 279*(2), 635-644.

Cui, C., Zhang, L., Yang, Z., & Wang, J. (2021). Two stage supply chain coordination based on revenue sharing contracts under carbon quota trading policies. *Chinese Management Science, 29* (7), 214-226.

Han, C. Q., Gu, H. Y., Sui, L. H., & Shao, C. P. (2021). Carbon Emission Reduction Decision and Revenue-Sharing Contract with Consumers' Low-Carbon Preference and CER Cost under Carbon Tax. *Mathematical Problems in Engineerings, 2021*(1), 3458607.

Huang, J., Leng, M., Liang, L., & Liu, J. (2013). Promoting electric automobiles: Supply chain analysis under a government's subsidy incentive scheme. *IIE transactions*, *45*(8), 826-844.

Joo, H. Y., Seo, Y. W., & Min, H. (2018). Examining the effects of government intervention on the firm's environmental and technological innovation capabilities and export performance. *International journal of Production Research, 56*(18), 6090-6111.

Jun, H., Jie, W., Fei, Z., & Mengzhe, W. (2024). Contract selection for collaborative innovation in the new energy vehicle supply chain under the dual credit policy: Cost sharing and benefit sharing. *International Journal of Industrial Engineering Computations, 15*(1), 209-222.

Kumar, P., Jakhar, S. K., & Bhattacharya, A. (2021). Two-period supply chain coordination strategies with ambidextrous sustainable innovations. *Business Strategy and the Environment, 30*(7), 2980-2995.

Li, W., & Li, Y. (2024). Research on Collaborative Innovation Evolution of New Energy Vehicle Industry: Based on Dynamic Network Perspective Technological. *Progress and Countermeasures, 5*.

Liu, C., Liu, J., Shao, L., & Zheng, Y. (2022). Research on Contract Selection for Encouraging Supplier Innovation in New Energy Vehicle Manufacturers under the "Dual Credit". *Policy Journal of Management, 6*, 928-937

Liu, X., Yang, P., & Ding, X. (2023). Central real estate industry policy coordination and development of new energy vehicle industry: based on the perspective of innovative ecosystem Chinese. *Soft Science, 11*, 38-53.

Peng, H., & Luo, J. (2015). Design of incentive contracts for cost sharing in supply chain under asymmetric information. *Journal of Systems Management, 24*(2), 8.

Quan, Z., Mengting, C., Shaobo, W., & Li, Z. (2024). Research on the collaborative construction of the innovation ecosystem of new energy vehicle enterprises. *Science Research Management, 45*(4), 32.

Shafiq, M., & Luong, H. T. (2021). Optimal quantity allocation decision in revenue sharing contract. *International Journal of Industrial Engineering, 28*(6).

Shao, L., Yang, J., & Zhang, M. (2017). Subsidy scheme or price discount scheme? Mass adoption of electric vehicles under different market structures. *European Journal of Operational Research, 262*(3), 1181-1195.

Shi, D., & Ming, X. (2023). Can the "dual-credit" policy promote substantive innovation of new energy vehicles. *Journal of Beijing Institute of Technology (social Sciences Edition)*, *25*(4), 40-51.

Suo, Q., & Li, C. (2023). Research on the Evolutionary Mechanism of China's New Energy Vehicle Industry from the Perspective of Technology Cooperation Network. *Journal of Management, 20* (3), 329-338.

Tao, Z. H. A. N. G., Xi, T. A. N. G., Junmin, W. U., Xiangyu, M. A. O., & Xiaozhuo, W. E. I. (2023). Research on Technology Collaborative Innovation Strategy between Internet Enterprises and New Energy Automobile Enterprises Based on Differential Game. *Operations Research and Management Science*, *32*(10), 43.

Wang, B., Ji, F., Zheng, J., Xie, K., & Feng, Z. (2021). Carbon emission reduction of coal-fired power supply chain enterprises under the revenue sharing contract: Perspective of coordination game. *Energy Economics, 102,* 105467.

Wang, X., Qiu, L., Hu, F., & Hu, H. (2024). Characteristics and influencing factors of the industry-university-research collaborative innovation network in China's new energy vehicle industry. *Energy Strategy Reviews, 55,* 101505.

Yuan, Y., Guo, J., & Guo, Z. (2023). An Evolutionary Analysis of Higher-Order Interaction Collaborative Innovation Networks in China's New Energy Vehicle Industry. *Sustainability, 15*(15), 11478.

Zhang, H., Zhang, J., & Lai, M. (2015). Analysis of Government Behavior and Supply Chain Cooperative R&D Game under Low Carbon Background Chinese. *Management Science (10)*, 57-66.

Zhou, Z., & Qiu, Y. (2023). The impact of the "dual credit" policy on the competitiveness of automobile manufacturing enterprises. *Research on Technology Management, 43*(8), 210-221.

Zhu, Z., Kong, L., Aisaiti, G., Song, M., & Mi, Z. (2021). Pricing contract design of a multi-supplier-multi-retailer supply chain in hybrid electricity market. *Industrial Management & Data Systems, 121*(7), 1522-1551.