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Study on Manufacturers' Operational Decisions under Different Production and R&D Strategies of New Energy Vehicle Batteries in the Context of Low Carbon Economy

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Abstract: The transition toward low-carbon transportation represents a critical strategy for mitigating climate change and reducing greenhouse gas emissions. New energy vehicles (NEVs), powered by advanced battery technologies, have emerged as a pivotal solution to address the dual challenges of energy security and environmental degradation. However, the high costs and technological uncertainties associated with battery research and development (R&D) present significant strategic dilemmas for NEV manufacturers in selecting optimal production modes. This study investigates the environmental and economic implications of three distinct battery production strategies—in-house R&D, outsourcing, and joint R&D collaboration—within a supply chain framework comprising traditional fuel vehicle manufacturers, NEV manufacturers, suppliers, and third-party battery producers. By developing game-theoretic models, we analyze how R&D efficiency, market distribution preferences, and R&D cost-sharing ratios influence equilibrium outcomes including pricing,

green performance, market demand, and profitability across supply chain participants.Key findings reveal that: (1) reduced R&D efficiency under in-house production negatively impacts NEV manufacturers' environmental performance and profitability while benefiting traditional automakers; (2) consumer market distribution significantly shapes strategic decisions, with traditional vehicle market dominance adversely affecting green innovation; (3) outsourcing proves superior only when battery suppliers demonstrate clear technological leadership; and (4) joint R&D strategies enhance supply chain profitability but are most effective in markets with high traditional vehicle demand. This research provides actionable insights for environmental management practitioners and policymakers seeking to promote sustainable manufacturing practices and accelerate the decarbonization of the automotive industry.

Keywords: Environmental management; Sustainable supply chain; New energy vehicles; Battery production strategies; Game theory; Low-carbon manufacturin

1.Introduction

Climate warming and greenhouse effect are the serious environmental problems faced by countries all over the world nowadays, and it has become a global consensus to enhance energy efficiency, reduce pollution emission and realize low-carbon development, and in order to cope with the double challenges of energy crisis and environmental degradation, new energy vehicles, an emerging sustainable development technology, have emerged [1-3]. New energy vehicles use power battery packs and electric motors as power sources, completely abandoning traditional fuel engines, and do not release any exhaust gases during the working process, thus avoiding tailpipe pollution. This feature is crucial for environmental protection and maintaining

clean air, almost reaching the ideal state of "zero pollution" [4]. Therefore, new energy vehicles are regarded as an effective innovative technology to solve the dual crisis of environment and energy, and are highly concerned and favored by the government and various industries [5-6]. Our government has successively introduced a series of supportive policies since 2001 to lower the entry threshold of the new energy industry and to improve the quality standards of new energy vehicle products so as to boost the development of the new energy vehicle industry.[7-8]

A new round of global scientific and technological revolution and industrial change is developing rapidly, and the automobile industry is in an era of great change that has not been seen in a hundred years. New energy automobile industry not only fits the current green development concept, helps to promote the economic and social transformation to eco-friendly, but also an important direction for the automobile industry to realize sustainable development [9]. As one of the core components of new energy vehicles, the power battery plays a crucial role in improving vehicle range and performance. At the same time, in recent years, with the development of lithium battery technology, a large number of new energy vehicles rely on its performance advantages favored by consumers, and gradually stand firm in the fierce market competition [10].

Limited range and low re-sale value are the biggest problems hindering consumers from choosing new energy vehicles, and these problems are related to power battery technology. Therefore, increasing the range of new energy vehicles and improving the durability of batteries through the development of power batteries and corresponding battery management

technologies are the key factors to improve the acceptance of new energy vehicle users [11-13]. Based on this, companies are actively taking action to increase R&D investment in the field of battery technology. At this stage, car companies have different strategies regarding the manufacturing of new energy vehicles, for example, Tesla, Build Your Dreams (BYD), Xiaopeng, and Azure only produce new energy vehicles, while Geely, Honda, and General Motors produce both new energy vehicles and fuel vehicles.[14-15] In addition, in the fierce competition, car companies have gradually differentiated into a variety of car-making mode, one is the independent research and development mode, such as Tesla has a complete battery production line, BYD's subsidiary Fudi Battery to provide battery components for it; the second is the battery outsourcing mode, for example, Geely battery production is mainly outsourced to contemporary amperex technology Co., Ltd.; the third is the joint vehicle building mode. Different production strategies have different advantages, which are highly related to the market positioning of enterprises.[16-17] In the context of the rapid development of new energy vehicles, most of the enterprises in the supply chain have chosen to maximize their own benefits as a business strategy, while the high cost of power battery research and development, uncertainty and other characteristics, so that many enterprises in the battery R & D investment in the concerns, cuts or even dare not invest. It is of great significance to study the battery R&D investment in new energy vehicle supply chain and analyze the best decision that can be achieved under different production modes, so as to how to promote power battery R&D more effectively [18-20]. This study analyzes the differences between the battery self-research, outsourcing and joint R&D production strategies of new energy vehicle enterprises by

constructing a game model, and digs out the optimal production strategies of new energy vehicle enterprises in different scenarios by analyzing factors such as consumer market distribution and R&D efficiency[21-23]. This paper considers the optimal R&D strategies under different modes to provide a decision-making basis for manufacturers and suppliers to maximize the development of new energy vehicles.

2.Model Assumptions

Given that new energy vehicle enterprises have different strategic modes for the production of battery components, this chapter discusses the production and pricing strategies of new energy vehicle manufacturers under three different modes, i.e., self-research strategy, outsourcing strategy, and joint R&D strategy.

Based on the above issues, this chapter assumes that there are both consumers who prefer conventional energy and those who prefer new energy vehicles in the market, in proportions of θ and$1-\theta$（$0<\theta<1$）, respectively. To simplify the analysis, it is assumed that there exists a supplier S, a traditional automobile manufacturer M_1 and a new energy automobile manufacturer M_2in the market, and manufacturers $M_1$and $M_2$are the dominant players in the market. Supplier Sall sells its products to Manufacturers $M_1$and M_2 at the same wholesale price of W.Due to the heterogeneity of Manufacturers $M_1$and M_1's products, they will be sold to consumers with different preferences at retail prices of P_1 and P_2, respectively, and the unit costs of Supplier S, Manufacturer M_1 and M_2 are C_s, C_{M1}, and C_{M2}, respectively.

Since the manufacturer is considered to be the dominant player in the market, for the purpose of subsequent model derivation and analysis, it is assumed in this chapter that manufacturers M_1 and M_2 sell their products at markups $m_1$and m_2, respectively, i.e. $P_{i=}W_i + m_i$.When the new energy vehicle manufacturer M_2 considers self-development for new energy battery components, it needs to invest an additional R&D cost $\frac{\mu G^2}{2}$. When it chooses an outsourcing strategy or a joint R&D strategy, it buys the third-party battery manufacturer K. The battery manufacturer Kproduces a unit of battery assembly product at a cost of $C_K$and sells it to the new energy vehicle M_2 at a price of T. Given that the R&D technologies and R&D efficiencies of new energy battery producers and manufacturersM_2 tend to be different, it is assumed here that the R&D cost of battery producers is $\frac{\varepsilon G^2}{2}$, μ and ε $(\mu, \varepsilon > 0)$ indicate that manufacturersM_2 and battery producers K have different R&D efficiencies for new energy battery R&D. For the convenience of the subsequent analysis, without losing the generality of the conclusions, it is assumed that the unit cost of each participant is 0,i.e.,$C_S = C_{M1} = C_{M2} = C_K = 0$ .At this point, $D_1 = \theta\alpha - \beta(W + m_1) + \gamma G_0$ and $D_{2=}(1-\theta)\alpha - \beta(W + m_2) + \gamma(G_0 + G)$ are used in this chapter to denote the market demand for traditional fuel vehicles and new energy vehicles, respectively, withα $(\alpha > 0)$ denoting the overall market capacity, β and γ $(\beta, \gamma > 0)$ denoting the parameters of consumers' preference for the product price and the green performance, $G_0$and$G_0 + G$ being the product green performance for traditional fuel vehicles and new energy vehicles, respectively. In view of the lower green performance of traditional fuel vehicles, without losing the generality of the conclusions, $G_0 = 0$ is set. In addition, in order to differentiate the differences in the production strategies of different scenarios, the

equilibrium results under the battery outsourcing strategy and the joint R&D strategy of the new energy vehicle manufacturers M_2 are denoted by superscripts*and**, respectively.

2.1. Production strategy for self-research

In the case where a new energy vehicle manufacturer M_2 decides to self-research its batteries, it needs additional inputs to realize the green performance improvement of its products [24-25]. Given that the participants in the supply chain all aim to maximize profits, denote the profits of the supplier, the conventional fuel manufacturer and the new energy manufacturer by π_S, $\pi_{M1}$and π_{M2}, respectively:

$$\pi_S = W[\theta\alpha - \beta(W + m_1)] + W[(1-\theta)\alpha - \beta(W + m_2) + \gamma G] \quad (1)$$

$$\pi_{M1} = m_1[\theta\alpha - \beta(W + m_1)] \quad (2)$$

$$\pi_{M2} = m_2[(1-\theta)\alpha - \beta(W + m_2) + \gamma G] - \frac{\mu G^2}{2} \quad (3)$$

Since the manufacturer is the dominant player in the market in the supply chain, the manufacturer M_1first decides the retail price of the product P_1.The manufacturer M_2determines both the retail price of the product $P_2$and the green performance G, and then the supplier is deciding the wholesale price of the product W.

Therefore, first let $\frac{\partial \pi_S}{\partial W} = 0$,which yields $W = \frac{\alpha - \beta(m_1 + m_2) + \gamma G}{4\beta}$,and further substituting π_{M2},at this point, the Hessian matrix of the manufacturerM_2profit $\pi_{M2}$with respect to its markup and green performance G is$\begin{bmatrix} -3\beta/2 & 3\gamma/4 \\ 3\gamma/4 & -\mu \end{bmatrix}$,Thus when the condition $\mu > \frac{3\gamma^2}{8\beta}$

is satisfied, there exists an extremal solution for profit $\pi_{M2}$with respect to m_2 and G.Further let$\frac{\partial \pi_M}{\partial m_1}=0$, $\frac{\partial \pi_{M2}}{\partial m_2}=0and\frac{\partial \pi_{M2}}{\partial G}=0$,the solution of the association can be obtained as $m_1=\frac{4\alpha(20\beta\theta\mu-3\beta\mu-6\gamma^2\theta)}{\beta(140\beta\mu-51\gamma^2)}$, $m_2=\frac{4\alpha\mu(17-20\theta)}{140\beta\mu-51\gamma^2}$ and $G=\frac{3\alpha\gamma(17-20\theta)}{140\beta\mu-51\gamma^2}$. The result can be substituted into the wholesale price can be obtained $W=\frac{3\alpha(7\beta\mu-3\gamma^2\theta)}{\beta(140\beta\mu-51\gamma^2)}$. Thus, when $\mu>\frac{3\gamma^2}{8\beta}$,the supply chain equilibrium results for the case where automaker M_2chooses to develop its own battery:

$$W=\frac{3\alpha(7\beta\mu-3\gamma^2\theta)}{\beta(140\beta\mu-51\gamma^2)},G=\frac{3\alpha\gamma(17-20\theta)}{140\beta\mu-51\gamma^2} \quad (4)$$

$$m_1=\frac{4\alpha[\beta\mu(20\theta-3)-6\gamma^2\theta]}{\beta(140\beta\mu-51\gamma^2)},m_2=\frac{4\alpha\mu(17-20\theta)}{140\beta\mu-51\gamma^2} \quad (5)$$

$$D_1=\frac{3\alpha[\beta\mu(20\theta-3)-6\gamma^2\theta]}{140\beta\mu-51\gamma^2},D_2=\frac{3\alpha\beta\mu(17-20\theta)}{140\beta\mu-51\gamma^2} \quad (6)$$

$$\pi_s=\frac{18\alpha^2(7\beta\mu-3\gamma^2\theta)^2}{\beta(140\beta\mu-51\gamma^2)^2},\pi_{M1}=\frac{12\alpha^2[\beta\mu(20\theta-3)-6\gamma^2\theta]^2}{\beta(140\beta\mu-51\gamma^2)^2} \quad (7)$$

$$\pi_{M2}=\frac{3\alpha^2\mu(17-20\theta)^2(8\beta\mu-3\gamma^2)}{2(140\beta\mu-51\gamma^2)^2} \quad (8)$$

To ensure that the equilibrium outcome makes economic sense, the condition $m_1,m_2,W,G>0$ needs to be satisfied. Given the precondition that the Hessian matrix has an extremal solution $\mu>\frac{8\gamma^2}{8\beta}$,it is clear that $140\beta\mu-51\gamma^2>1.5\gamma^2>0$.To ensure that $m_2,G>0$, and since $0<\theta<0$, the condition$0<\theta<\frac{17}{20}$ also needs to be satisfied. Visible, when the traditional fuel vehicle market demand comparison is too high, automakers M_2will no longer need to transition to new energy vehicles, which is also in line with the logic of reality, and the early development of new energy vehicles to match the reality of the situation. When$\theta=\frac{17}{20}$, $7\beta\mu-3\gamma^2\theta>\frac{3}{40}\gamma^2>0$,so when $0<\theta<\frac{17}{20}$, $W>0$is established. Based on the equilibrium resultm_1, it is clear that the condition $\theta>\frac{3}{20}$,needs to be satisfied. That is to say, when the market demand for traditional fuel vehicles

is low, automakers M_1 will be unprofitable, and will even be driven out of the market. In fact, Guangzhou Automobile, FAW and other fuel car as the main products of the old enterprises, in the new energy car enterprises under the double pressure of technological progress, cost reduction, is gradually being marginalized by the market, market share is shrinking. When $\theta > \frac{3}{20}$, ,if $\mu > \frac{6\gamma^2\theta}{\beta(20\theta-3)}$, Automakers M_1aise prices$M_1 > 0$.Therefore, to ensure that the equilibrium outcome makes economic sense, the parameters need to satisfy the conditions $\mu > max\left\{\frac{6\gamma^2\theta}{\beta(20\theta-3)}, \frac{3\gamma^2}{8\beta}\right\}$ and $\frac{3}{20} < \theta < \frac{17}{20}$.

2.2. Production strategies for outsourcing

And when the new energy vehicle manufacturer M_2 decides to outsource the battery production, it will buy the battery components directly from the battery manufacturer directly[26-27], and the third-party battery producer$K$will decide the green performance G and the unit outsourcing price T sold to the manufacturer M_2. At this time, the profit of the supplier in the supply chain π_S, the traditional fuel vehicle manufacturer π_{M1}, the new energy vehicle manufacturer π_{M2}, and the third-party battery producer π_K are respectively:

$$\pi_S^* = W^*[\theta\alpha - \beta(W^* + m_1^*)] + W^*[(1-\theta)\alpha - \beta(W^* + m_2^* + T^*) + \gamma G^*] \quad (9)$$

$$\pi_{M1}^* = m_1^*[\theta\alpha - \beta(W_1^* + m_1^*)] \quad (10)$$

$$\pi_{M2}^* = m_2^*[(1-\theta)\alpha - \beta(W^* + m_2^* + T^*) + \gamma G^*] \quad (11)$$

$$\pi_K^* = T^*[(1-\theta)\alpha - \beta(W^* + m_2^* + T^*) + \gamma G^*] - \frac{1}{2}\xi G^{*2} \quad (12)$$

In this case, as the dominant players in the supply chain, manufacturer$M_1$and manufacturer M_2continue to take the lead in determining the retail prices of the products, m_1^* and m_2^*.The

supplie S determines the wholesale price of the product W^* and the battery manufacturer K determines the outsourcing T^* and the green performance G^* of the battery module product. Based on this game sequence, it is first known that the Hessian function of the profit function π_K^* of the battery manufacturer K with respect to the outsourcing price T^* and the green performance of the battery product is $\begin{bmatrix} -2\beta & \gamma \\ \gamma & -\xi \end{bmatrix}$, and thus when $\xi > \frac{\gamma^2}{2\beta}$, there exists an extreme solution for profit π_K^* with respect to outsourcing price T^* and green performance G^*. Further, let $\frac{\partial \pi_\beta^*}{\partial W^*} = 0$, $\frac{\partial \pi_K^*}{\partial T^*} = 0$, and $\frac{\partial \pi_K^*}{\partial G^*} = 0$, which in turn leads to $W^* = \frac{\alpha[\beta(1+\theta)\xi - \gamma^2\theta] - \beta m_1(2\beta\xi - \gamma^2) - \beta^2\xi m_2}{\beta(7\beta\xi - 3\gamma^2)}$, $T^* = \frac{[\alpha(3-4\theta) + \beta(m_1 - 3m_2)]\xi}{7\beta\xi - 3\gamma^2}$, $G^* = \frac{\gamma[\alpha(3-4\theta) + \beta(m_1 - 3m_2)]}{7\beta\xi - 3\gamma^2}$, further substituting into Eqs. (10) and (11) and maki $\frac{\partial \pi_M^*}{\partial m_1^*} = 0$, $\frac{\partial \pi_{M2}^*}{\partial m_2^*} = 0$, we get $m_1^* = \frac{\alpha[\beta\xi(32\theta - 3) - 12\gamma^2\theta]}{\beta(59\beta\xi - 24\gamma^2)}$, $m_2^* = \frac{\alpha[\beta\xi(29 - 34\theta) - 2\gamma^2(6 - 7\theta)]}{\beta(59\beta\xi - 24\gamma^2)}$. So when $\xi > \frac{\gamma^2}{2\beta}$, the game equilibrium of the supply chain under the outsourcing strategy of the automaker M_2 battery production is:

$$W^* = \frac{\alpha[\beta^2\xi^2(36+29\theta) - \beta\gamma^2\xi(15+41\theta) + 12\gamma^4\theta]}{\beta(7\beta\xi - 3\gamma^2)(59\beta\xi - 24\gamma^2)} \tag{13}$$

$$T^* = \frac{3\alpha\xi[\beta\xi(29 - 34\theta) - 2\gamma^2(6 - 7\theta)]}{(7\beta\xi - 3\gamma^2)(59\beta\xi - 24\gamma^2)} \tag{14}$$

$$G^* = \frac{3\alpha\gamma[\beta\xi(29 - 34\theta) - 2\gamma^2(6 - 7\theta)]}{(7\beta\xi - 3\gamma^2)(59\beta\xi - 24\gamma^2)} \tag{15}$$

$$m_1^* = \frac{\alpha[\beta\xi(32\theta - 3) - 12\gamma^2\theta]}{\beta(59\beta\xi - 24\gamma^2)}, m_2^* = \frac{\alpha[\beta\xi(29 - 34\theta) - 2\gamma^2(6 - 7\theta)]}{\beta(59\beta\xi - 24\gamma^2)} \tag{16}$$

$$D_1^* = \frac{\alpha(5\beta\xi - 2\gamma^2)[\beta\xi(32\theta - 3) - 12\gamma^2\theta]}{(7\beta\xi - 3\gamma^2)(59\beta\xi - 24\gamma^2)} \tag{17}$$

$$D_2^* = \frac{3\alpha\beta\xi[\beta\xi(29 - 34\theta) - 2\gamma^2(6 - 7\theta)]}{(7\beta\xi - 3\gamma^2)(59\beta\xi - 24\gamma^2)} \tag{18}$$

$$\pi_S^* = \frac{2\alpha^2[\beta^2\xi^2(36+29\theta) - \beta\gamma^2\xi(15+41\theta) + 12\gamma^4\theta]^2}{\beta(7\beta\xi - 3\gamma^2)^2(59\beta\xi - 24\gamma^2)^2} \tag{19}$$

$$\pi_{M1}^* = \frac{\alpha^2(5\beta\xi - 2\gamma^2)[\beta\xi(32\theta - 3) - 12\gamma^2\theta]^2}{\beta(7\beta\xi - 3\gamma^2)(59\beta\xi - 24\gamma^2)^2} \tag{20}$$

$$\pi_{M2}^* = \frac{3\alpha^2\xi[\beta\xi(29 - 34\theta) - 2\gamma^2(6 - 7\theta)]^2}{(7\beta\xi - 3\gamma^2)(59\beta\xi - 24\gamma^2)^2} \tag{21}$$

$$\pi_K^* = \frac{9\alpha^2\xi(2\beta\xi - \gamma^2)[\beta\xi(29 - 34\theta) - 2\gamma^2(6 - 7\theta)]^2}{2(7\beta\xi - 3\gamma^2)^2(59\beta\xi - 24\gamma^2)^2} \tag{22}$$

Similarly, to ensure that the results make economic sense, the condition m_1^*, m_2^*, W^*, $G^*, T^* > 0$ needs to be satisfied. Due to $\xi > \frac{\gamma^2}{2\beta}$, it follows that $7\beta\xi - 3\gamma^2 > 0$ and $59\beta\xi - 24\gamma^2 > 0$.To ensure that $m_1^* > 0$,it is necessary to satisfy the condition $\frac{3}{32} < \theta < 1$and $\xi > \frac{12\gamma^2\theta}{\beta(32\theta-3)}$.And to ensure that $m_2^* > 0$,it is necessary to ensure that $\beta\xi(29 - 34\theta) - 2\gamma^2(6 - 7\theta) > 0$.if $\frac{29}{34} < \theta < 1$,then $\xi < \frac{2\gamma^2(6-7\theta)}{\beta(29-34\theta)}$ is required.Further,by making $G_1(\theta) = \frac{2\gamma^2(6-7\theta)}{\beta(29-34\theta)}$,we obtain $G_1'(\theta) = \frac{2\gamma^2}{\beta(29-34\theta)^2} > 0$, $G_1(\theta)$is monotonically increasing on $\frac{29}{34} < \theta < 1$,and hence $G_1(\theta) < G_1(1) < \frac{2\gamma^2}{5\beta}$,contrary to premise $\xi > \frac{\gamma^2}{2\beta}$,so $\frac{29}{34} < \theta < 1$is not valid. If $0 < \theta < \frac{29}{34}$,requires fulfillment of condition $\xi > \frac{2\gamma^2(6-7\theta)}{\beta(29-34\theta)}$.based on this, when $m_1^*, m_2^* > 0$,required to fulfill condition$\frac{3}{32} < \theta < \frac{29}{34}and\mu > max\left\{\frac{12\gamma^2\theta}{\beta(32\theta-3)}, \frac{2\gamma^2(6-7\theta)}{\beta(29-34\theta)}, \frac{\gamma^2}{2\beta}\right\}$,and at this point the conditions are also met$G^*, T^* > 0$.To ensure that$W^* > 0$, $F_1(\xi) = \beta^2\xi^2(36 + 29\theta) - \beta\gamma^2\xi(15 + 41\theta) + 12\gamma^4\theta$,we can get $F_1'(\xi) = 2\beta^2(36 + 29\theta)\xi - \beta\gamma^2(15 + 41\theta)$,thereby $F_1'(\xi) > F_1'\left(\frac{\gamma^2}{2\beta}\right) = 3\beta\gamma^2(7 - 4\theta) > 0$, $F_1(\xi)$,monotonically increasing on $\left(\frac{\gamma^2}{2\beta}, +\infty\right)$, $F_1(\xi) > F\left(\frac{\gamma^2}{2\beta}\right) = \frac{1}{4}\gamma^4(6 - 5\theta) > 0$,it follows that $T^* > 0$ is constant at this point. Therefore, the results are economically meaningful when the condition$\xi > max\left\{\frac{12\gamma^2\theta}{\beta(32\theta-3)}, \frac{2\gamma^2(6-7\theta)}{\beta(29-34\theta)}, \frac{\gamma^2}{2\beta}\right\}$and $\frac{3}{32} < \theta < \frac{29}{34}$ is satisfied. Similar to the self-research strategy, in a situation where the market demand for both traditional fuel vehicles and new energy vehicles is severely skewed, one type of automaker will be gradually driven out of the market.

2.3. Joint R&D Production Strategy

When a new energy vehicle manufacturer M_2 decides to jointly develop a new energy battery with a third-party battery manufacturer K,it will bear part of the R&D expenditures of

the battery manufacturer , assuming that the proportion of the R&D costs borne by the battery manufacturer is $\emptyset$ $(0 < \emptyset < 1)$. Correspondingly, the battery manufacturer will also be based on the proportion of the R&D undertaken by the manufacturer M_2 to purchase the battery product price concessions[28-32], assuming that the joint R & D production strategy under the new energy vehicle manufacturer purchase price of $(1-\phi)T$. At this time, the supply chain supplier profits π_S , traditional fuel vehicle manufacturers π_{M1} , new energy vehicle manufacturers π_{M2}G, and the third-party battery manufacturer K's profits, respectively:

$$\pi_S^{**} = W^{**}[\theta\alpha - \beta(W^{**} + m_1^{**})] + W^{**}[(1-\theta)\alpha - \beta(W^{**} + m_2^{**} + (1-\phi)T^{**}) + \gamma G^{**}] \quad (23)$$

$$\pi_{M1}^{**} = m_1^{**}[\theta\alpha - \beta(W^{**} + m_1^{**})] \quad (24)$$

$$\pi_{M2}^{**} = m_2^{**}[(1-\theta)\alpha - \beta(W^{**} + m_2^{**} + (1-\phi)T^{**}) + \gamma G^{**}] - \frac{1}{2}\phi\xi G^{**2} \quad (25)$$

$$\pi_K^{**} = (1-\phi)T^{**}[(1-\theta)\alpha - \beta(W^{**} + m_2^{**} + (1-\phi)T^{**}) + \gamma G^{**}] - \frac{1}{2}(1-\phi)\xi G^{**2} \quad (26)$$

Similarly, it is first known that the profit function of the battery producer K is π_K^{**},the Hessian function on the price T^{**} and green performance G^{**} of the battery product is $\begin{bmatrix} -2\beta(1-\phi)^2 & \gamma(1-\phi) \\ \gamma(1-\phi) & -\xi(1-\phi) \end{bmatrix}$,so when$\xi > \frac{\gamma^2}{2\beta(1-\phi)}$,there exists an extreme solution of the profit function $\pi_K^{**}$with respect to the price$T^{**}$and the green performance $G^{**}$of the battery product. Further let $\frac{\partial \pi_S^{**}}{\partial W^{**}} = 0$, $\frac{\partial \pi_K^{**}}{\partial T^{**}} = 0$ and $\frac{\partial \pi_K^{**}}{\partial G^{**}} = 0$,which in turn leads to $W^* = \frac{\alpha[\beta(1+\theta)\xi(1-\phi)-\gamma^2\theta]-\beta m_1[2\beta\xi(1-\phi)-\gamma^2]-\beta^2\xi m_2(1-\phi)}{\beta[7\beta\xi(1-\phi)-3\gamma^2]}$, $T^{**} = \frac{[\alpha(3-4\theta)+\beta(m_1-3m_2)]\xi}{7\beta\xi(1-\phi)-3\gamma^2}$, $G^{**} = \frac{\gamma[\alpha(3-4\theta)+\beta(m_1-3m_2)]}{7\beta\xi(1-\phi)-3\gamma^2}$.Substituting into equations (24) and (25),and let$\frac{\partial \pi_{M1}^{**}}{\partial m_1^{**}} = 0$and $\frac{\partial \pi_{M2}^{**}}{\partial m_2^{**}} = 0$,so when $\xi > \frac{\gamma^2}{2\beta(1-\phi)}$,the equilibrium result of the game for the supply chain under the joint R&D battery production strategy between the manufacturer and the third-party battery producer is:

$$W^{**}=\frac{\alpha\begin{Bmatrix}\beta^2\xi^2(36+29\theta)(1-\phi)^3+6\gamma^4\theta(2-3\phi)\\-\beta\gamma^2\xi(1-\phi)[15(1-\phi)+\theta(41-56\phi)]\end{Bmatrix}}{\beta A} \tag{27}$$

$$T^{**}=\frac{3\alpha\xi(1-\phi)B}{A},G^{**}=\frac{3\alpha\gamma(1-\phi)B}{A} \tag{28}$$

$$m_1^{**}=\frac{\alpha[7\beta\xi(1-\phi)-3\gamma^2]C}{\beta A},m_2^{**}=\frac{\alpha(1-\phi)[7\beta\xi(1-\phi)-3\gamma^2]B}{\beta A} \tag{29}$$

$$D_1^{**}=\frac{\alpha[5\beta\xi(1-\phi)-2\gamma^2]C}{A},D_2^{**}=\frac{3\alpha\beta\xi(1-\phi)^2B}{A} \tag{30}$$

$$\pi_{M1}^{**}=\frac{\alpha^2[5\beta\xi(1-\phi)-2\gamma^2][7\beta\xi(1-\phi)-3\gamma^2]C^2}{\beta A^2} \tag{31}$$

$$\pi_{M2}^{**}=\frac{3\alpha^2\xi(1-\phi)^2[14\beta\xi(1-\phi)^2-3\gamma^2(2-3\phi)]B^2}{2A^2} \tag{32}$$

$$\pi_S^{**}=\frac{2\alpha^2\begin{Bmatrix}\beta^2\xi^2(36+29\theta)(1-\phi)^3+6\gamma^4\theta(2-3\phi)\\+\beta\gamma^2\xi(1-\phi)[15(1-\phi)+\theta(41-56\phi)]\end{Bmatrix}^2}{\beta A^2} \tag{33}$$

$$\pi_K^{**}=\frac{9\alpha^2\xi(1-\phi)^3[2\beta\xi(1-\phi)-\gamma^2]B^2}{2A^2} \tag{34}$$

Superscript $A=413\beta^2\xi^2(1-\phi)^3-3\beta\gamma^2\xi(1-\phi)(115-144\phi)+36\gamma^4(2-3\phi)$, $B=\beta\xi(29-34\theta)(1-\phi)-2\gamma^2(6-7\theta)$ and $C=\beta\xi(32\theta-3)(1-\phi)^2-6\gamma^2\theta(2-3\phi)$.To ensure that the results are economically meaningful, $m_1^{**},m_2^{**},W^{**},G^{**},T^{**}>0$.First, let $F_2(\xi)=A$,which in turn leads to $F_2'(\xi)=826\beta^2\xi(1-\phi)^3-3\beta\gamma^2(1-\phi)(115-144\phi)andF_2''(\xi)=826\beta^2(1-\phi)^3$.Due to$0<\phi<1$, it follows that$F_2''(\xi)>0$, $F_2'(\xi)$ is monotonically increasing on$\left(\frac{\gamma^2}{2\beta(1-\phi)},+\infty\right)$,but$F_2'\left(\frac{\gamma^2}{2\beta(1-\phi)}\right)=\beta\gamma^2(68-49\phi-19\phi^2)>0$, $F_2(\xi)$is also monotonically increasing on$\left(\frac{\gamma^2}{2\beta(1-\phi)},+\infty\right)$, $F_2\left(\frac{\gamma^2}{2\beta(1-\phi)}\right)=\frac{\gamma^4(11+19\phi)}{4}>0$,so$A>0$is constant. Moreover, due to $\xi>\frac{\gamma^2}{2\beta(1-\phi)}$, $5\beta\xi(1-\phi)-2\gamma^2>0$ and $7\beta\xi(1-\phi)-3\gamma^2>0$can be obtained, and in order to guarantee $m_1^{**},m_2^{**},G^{**},T^{**}>0$, condition $B,C>0$ should be satisfied. Similarly, to ensure that $B>0$,if$\frac{29}{34}<\theta<1$,then $\xi<\frac{2\gamma^2(6-7\theta)}{\beta(29-34\theta)(1-\phi)}$ is required at this time, Based on the results above, it is clear that

$\frac{2\gamma^2(6-7\theta)}{\beta(29-34\theta)(1-\phi)} < \frac{2\gamma^2}{5\beta(1-\phi)}$,Contrary to premise$\xi > \frac{\gamma^2}{2\beta(1-\phi)}$, therefore$\frac{29}{34} < \theta < 1$ is not valid; if $0 < \theta < \frac{29}{34}$,Condition $\xi > \frac{2\gamma^2(6-7\theta)}{\beta(29-34\theta)(1-\phi)}$needs to be met. To ensure that$c > 0$, if$0 < \theta < \frac{3}{32}$, then condition C needs to be satisfied$\xi < \frac{6\gamma^2\theta(2-3\phi)}{\beta(32\theta-3)(1-\phi)^2}$,It is clear that when$\phi > \frac{2}{3}$, $\frac{6\gamma^2\theta(2-3\phi)}{\beta(32\theta-3)(1-\phi)^2} > 0$,Thus, $\phi > \frac{2}{3}$, and$\frac{\gamma^2}{2\beta(1-\phi)} < \xi < \frac{6\gamma^2\theta(2-3\phi)}{\beta(32\theta-3)(1-\phi)^2}$ are required at this point; if $\frac{3}{32} < \theta < 1$,Then condition $\xi > \frac{6\gamma^2\theta(2-3\phi)}{\beta(32\theta-3)(1-\phi)^2}$ needs to be satisfied .So, to ensure $m_1^{**}, m_2^{**}, G^{**}, T^{**} > 0$ .if $0 < \theta < \frac{3}{32}$, $max\left\{\frac{\gamma^2}{2\beta(1-\phi)}, \frac{2\gamma^2(6-7\theta)}{\beta(29-34\theta)(1-\phi)}\right\} < \xi < \frac{6\gamma^2\theta(2-3\phi)}{\beta(32\theta-3)(1-\phi)^2}and\phi > \frac{2}{3}$,if$\frac{3}{32} < \theta < \frac{29}{34}$, $\xi > max\left\{\frac{\gamma^2}{2\beta(1-\phi)}, \frac{2\gamma^2(6-7\theta)}{\beta(29-34\theta)(1-\phi)}, \frac{6\gamma^2\theta(2-3\phi)}{\beta(32\theta-3)(1-\phi)^2}\right\}$.In addition, condition $W^{**} > 0$, needs to be satisfied in order to ensure that$\begin{Bmatrix}\beta^2\xi^2(36+29\theta)(1-\phi)^3 + 6\gamma^4\theta(2-3\phi) \\ -\beta\gamma^2\xi(1-\phi)[15(1-\phi)+\theta(41-56\phi)]\end{Bmatrix} > 0$.

3.Results

3.1. Production strategy for self-research

Based on the equilibrium results under the self-research of the manufacturer's battery component products, the influence of the manufacturer's technology development parameters and the share of traditional fuel vehicle market demandθ on the equilibrium results is discussed, and in turn, Corollary 1 and Corollary 2 can be obtained[33].

Corollary1: Under the production strategy of battery self-research, an increase in the technology development parameterμ will lead to an increase in the pricing, market demand and profit of the fuel vehicle manufacturer's products, but it will lead to a decrease in the supplier's wholesale price and profit, as well as in the green performance, pricing, and sales of the new energy manufacturer's products, whereas the relationship of the new energy vehicle

manufacturer's profit function with the technology development parameter μ is also affected by the relationship between the size of μ and $\frac{17\gamma^2}{44\beta}$ .If $\frac{17\gamma^2}{44\beta} > max\left\{\frac{6\gamma^2\theta}{\beta(20\theta-3)}, \frac{3\gamma^2}{8\beta}\right\}$,when $max\left\{\frac{6\gamma^2\theta}{\beta(20\theta-3)}, \frac{3\gamma^2}{8\beta}\right\} < \mu < \frac{17\gamma^2}{44\beta}$,new energy vehicle manufacturer profit increases with increasing R&D parameter μ ,while at that time, $\mu \geq \frac{17\gamma^2}{44\beta}$, manufacturer profit decreases with increasing R&D parameter μ ;if $\frac{17\gamma^2}{44\beta} \leqslant max\left\{\frac{6\gamma^2\theta}{\beta(20\theta-3)}, \frac{3\gamma^2}{8\beta}\right\}$,then the manufacturer's profit always decreases as the R&D parameter μ increases.

Proof: Based on the equilibrium results in the case of the automaker's battery self-research, the derivation of the R&D parameter μ, respectively, leads to $\frac{\partial m_1}{\partial \mu} = \frac{36\alpha\gamma^2(17-20\theta)}{(140\beta\mu-51\gamma^2)^2}$, $\frac{\partial m_2}{\partial \mu} = -\frac{204\alpha\gamma^2(17-20\theta)}{(140\beta\mu-51\gamma^2)^2}$, $\frac{\partial G}{\partial \mu} = -\frac{420\alpha\beta\gamma(17-20\theta)}{(140\beta\mu-51\gamma^2)^2}$, $\frac{\partial W}{\partial \mu} = -\frac{36\alpha\gamma^2(17-20\theta)}{(140\beta\mu-51\gamma^2)^2}$, $\frac{\partial D_1}{\partial \mu} = \frac{27\alpha\beta\gamma^2(17-20\theta)}{(140\beta\mu-51\gamma^2)^2}$, $\frac{\partial D_2}{\partial \mu} = -\frac{153\alpha\beta\gamma^2(17-20\theta)}{(140\beta\mu-51\gamma^2)^2}$, $\frac{\partial \pi_S}{\partial \mu} = -\frac{756\alpha^2\gamma^2(17-20\theta)(7\beta\mu-3\gamma^2\theta)}{(140\beta\mu-51\gamma^2)^3}$, $\frac{\partial \pi_{M1}}{\partial \mu} = \frac{216\alpha^2\gamma^2(17-20\theta)[\beta\mu(20\theta-3)-6\gamma^2\theta]}{(140\beta\mu-51\gamma^2)^3}$, $\frac{\partial \pi_{M2}}{\partial \mu} = -\frac{27\alpha^2(17-20\theta)^2(44\beta\gamma^2\mu-17\gamma^4)}{2(140\beta\mu-51\gamma^2)^3}$ .Due to $\mu > max\left\{\frac{6\gamma^2\theta}{\beta(20\theta-3)}, \frac{3\gamma^2}{8\beta}\right\}$and $\frac{3}{20} < \theta < \frac{17}{20}$,it is clear that $\frac{\partial m_1}{\partial \mu}, \frac{\partial D_1}{\partial \mu}, \frac{\partial \pi_{M1}}{\partial \mu} > 0$, $\frac{\partial m_2}{\partial \mu}, \frac{\partial G}{\partial \mu}, \frac{\partial W}{\partial \mu}, \frac{\partial D_2}{\partial \mu}, \frac{\partial \pi_S}{\partial \mu} < 0$,And since $\frac{17\gamma^2}{44\beta} - \frac{3\gamma^2}{8\beta} = \frac{\gamma^2}{88\beta} > 0$,so when $\frac{17\gamma^2}{44\beta} > max\left\{\frac{6\gamma^2\theta}{\beta(20\theta-3)}, \frac{3\gamma^2}{8\beta}\right\}$, $\mu \in \left(max\left\{\frac{6\gamma^2\theta}{\beta(20\theta-3)}, \frac{3\gamma^2}{8\beta}\right\}, \frac{17\gamma^2}{44\beta}\right]$, $\frac{\partial \pi_{M2}}{\partial \mu} > 0$,when $\mu \in \left(\frac{17\gamma^2}{44\beta}, +\infty\right)$, $\frac{\partial \pi_{M2}}{\partial \mu} < 0$,and $\frac{\partial \pi_{M2}}{\partial \mu} < 0$ holds when $\frac{17\gamma^2}{44\beta} \leqslant max\left\{\frac{6\gamma^2\theta}{\beta(20\theta-3)}, \frac{3\gamma^2}{8\beta}\right\}$.

From Corollary 1, it can be seen that an increase in R&D parameter μ is favorable to traditional automakers in terms of pricing, sales and profits, while it is unfavorable to new energy automakers in terms of green performance, pricing and sales, as well as to suppliers in terms of pricing and profits. This is because an increase in R&D Parameter μ indicates that the cost conversion efficiency in the battery production of a new energy vehicle manufacturer becomes lower, leading to a lower green performance of its battery products and lower pricing

and sales of its products, while on the contrary, it is favorable for the traditional vehicle manufacturer, which realizes an increase in its pricing, sales, and profits. For suppliers, when the battery production efficiency of a new energy vehicle manufacturer is low, due to its high market position, it may reduce the purchase price of parts and components to alleviate the pressure of research and development, which will lead to lower pricing and profits for suppliers. In addition, new energy vehicle manufacturers in the R&D parameter μ in the smaller hours its increase leads to rising profits, while in the R&D parameter μ in the larger when its increase leads to a decline in profits, which may be mainly due to the higher R&D efficiency, the increase in R&D parameters will lead to a huge decline in its green performance, R&D's cost reduction effect is obvious, which may lead to this time to the overall profits of the upper body, the R&D efficiency is lower, the R&D parameter increase leads to a more pronounced marginal revenue reduction effect, and thus a decline in overall profits[34-35].

Corollary 2: Under the production strategy of battery self-research, an increase in the traditional automobile market demand share parameter θ will traditional automobile manufacturers pricing, sales and profits rise, while suppliers pricing and profits as well as new energy automobile manufacturers green performance, pricing, sales and profits fall.

Proof: Based on the equilibrium results in the case of the automaker's battery self-research, the equilibrium results are partial derivatives with respect to the parameter θ, which leads to $\frac{\partial m_1}{\partial \theta}=\frac{8\alpha(10\beta\mu-3\gamma^2)}{\beta(140\beta\mu-51\gamma^2)}$, $\frac{\partial m_2}{\partial \theta}=-\frac{80\alpha\mu}{140\beta\mu-51\gamma^2}$, $\frac{\partial G}{\partial \theta}=-\frac{60\alpha\gamma}{140\beta\mu-51\gamma^2}$, $\frac{\partial W}{\partial \theta}=-\frac{9\alpha\gamma^2}{\beta(140\beta\mu-51\gamma^2)}$, $\frac{\partial D_1}{\partial \theta}=\frac{6\alpha(10\beta\mu-3\gamma^2)}{140\beta\mu-51\gamma^2}$, $\frac{\partial D_2}{\partial \theta}=-\frac{60\alpha\beta\mu}{140\beta\mu-51\gamma^2}$, $\frac{\partial \pi_S}{\partial \theta}=-\frac{108\alpha^2\gamma^2(7\beta\mu-3\gamma^2\theta)}{\beta(140\beta\mu-51\gamma^2)^2}$, $\frac{\partial \pi_{M1}}{\partial \theta}=\frac{48\alpha^2(10\beta\mu-3\gamma^2)[\beta\mu(20\theta-3)-6\gamma^2\theta]}{\beta(140\beta\mu-51\gamma^2)^2}$, $\frac{\partial \pi_{M2}}{\partial \theta}=-\frac{60\alpha^2\mu(17-20\theta)(8\beta\mu-3\gamma^2)}{(140\beta\mu-51\gamma^2)^2}$. Given the parametric

constraints $\mu > max\left\{\frac{6\gamma^2\theta}{\beta(20\theta-3)}, \frac{3\gamma^2}{8\beta}\right\}$ and $\frac{3}{20} < \theta < \frac{17}{20}$,it is clear that $\frac{\partial m_1}{\partial \theta}, \frac{\partial D_1}{\partial \theta}, \frac{\partial \pi_{M1}}{\partial \theta} > 0and\frac{\partial m_2}{\partial \theta}, \frac{\partial W}{\partial \theta}, \frac{\partial G}{\partial \theta}, \frac{\partial D_2}{\partial \theta}, \frac{\partial \pi_S}{\partial \theta}, \frac{\partial \pi_{M2}}{\partial \theta} < 0$.

Corollary 2 suggests that an increase in the proportion of consumers with traditional preferences in the consumer market for automobiles is favorable to traditional automobile manufacturers and unfavorable to new energy automobile manufacturers; this is obvious, and the market share of consumers has a significant impact on the pricing power of the firm's market, which, in turn, affects sales volumes and profits. However, an increase in the market share of traditional consumers is detrimental to suppliers' pricing and profits, suggesting that in a market environment with both traditional and new energy vehicle manufacturers, the share of new energy vehicle manufacturers has a greater impact on the wholesale price of their products, and that greater market demand for new energy vehicles is more favorable to suppliers.

3.2.Production strategies for outsourcing

Based on the equilibrium results under the outsourcing of the manufacturer's battery component products, the effects of the third-party battery manufacturer's technology development parameters ξ and the share of traditional automotive market demand θ on the equilibrium results are further discussed, which in turn can lead to Corollary 3 and Corollary 4.

Corollary 3: Under the production strategy of battery outsourcing, the pricing of both conventional automobile manufacturers and new energy vehicle products increases with the increase of the technical R&D parameter ξ A of the battery producer. The relationship between the green performance and sales volume of conventional automakers, the wholesale price and

profit of suppliers, and the pricing of battery producers and the R&D parameter ξ is also affected by the parameter θ.

Proof: Based on the results in the case of outsourcing of battery production by an automobile manufacturer, the derivation of each with respect to the R&D parameter ξ leads to $\frac{\partial m_1^*}{\partial \xi} = \frac{12\alpha\gamma^2(6-5\theta)}{\beta(59\beta\xi-24\gamma^2)^2}$, $\frac{\partial m_2^*}{\partial \xi} = \frac{2\alpha\gamma^2(6-5\theta)}{(59\beta\xi-24\gamma^2)^2}$, $\frac{\partial G^*}{\partial \xi} = -\frac{3\alpha\beta\gamma L_1}{(59\beta\xi-24\gamma^2)^2(7\beta\xi-3\gamma^2)^2}$, $\frac{\partial T^*}{\partial \theta} = -\frac{3\alpha\gamma^2 L_2}{(59\beta\xi-24\gamma^2)^2(7\beta\xi-3\gamma^2)^2}$, $\frac{\partial W^*}{\partial \theta} = -\frac{\alpha\gamma^2 L_3}{(59\beta\xi-24\gamma^2)^2(7\beta\xi-3\gamma^2)^2}$, $\frac{\partial D_1^*}{\partial \theta} = \frac{\alpha\beta\gamma^2 L_4}{(59\beta\xi-24\gamma^2)^2(7\beta\xi-3\gamma^2)^2}$, $\frac{\partial D_2^*}{\partial \xi} = -\frac{3\alpha\beta\gamma^2 L_2}{(59\beta\xi-24\gamma^2)^2(7\beta\xi-3\gamma^2)^2}$, $\frac{\partial \pi_S^*}{\partial \xi} = -\frac{4\alpha^2\gamma^2 L_3 L_5}{(59\beta\xi-24\gamma^2)^3(7\beta\xi-3\gamma)^3}$.

where $L_1 = 413\beta^2\xi^2(29-34\theta) - 1652\beta\gamma^2(6-7\theta)\xi + 6\gamma^4(342-397\theta)$,

$L_2 = \beta^2\xi^2(5049-5948\theta) - 144\beta\xi\gamma^2(29-34\theta) + 144\gamma^4(6-7\theta)$,

$L_3 = \beta^2\xi^2(6225-6928\theta) - 24\beta\gamma^2(216-239\theta)\xi + 108\gamma^4(10-11\theta)$, $L_4 = \beta^2\xi^2(2697-3988\theta) - 48\beta\gamma^2(45-67\theta)\xi + 216\gamma^4(2-3\theta)$

$L_5 = \beta^2\xi^2(36+29\theta) - \beta\gamma^2(15+41\theta)\xi + 12\gamma^4\theta$.

Based on the above results, it is obvious that $\frac{\partial m_1^*}{\partial \xi}, \frac{\partial m_2^*}{\partial \xi} > 0$, both traditional and new energy vehicle manufacturers pricing is increased with the third-party battery manufacturer's R&D efficiency, which is mainly due to the fact that when the third-party battery manufacturer's efficiency is low, it may increase the manufacturer's price for purchasing the battery components to increase profitability, and accordingly, the new energy vehicle manufacturer will also increase pricing to obtain higher profits, when the price competition between traditional price competition between fuel and new energy vehicles is not intense, and thus traditional

manufacturers will also increase their pricing to gain more profit. In spite of $L_5 > 0$, the magnitude relationship between L_1, L_2, L_3, L_4 and 0 is uncertain, thus leading to an uncertain functional relationship between the equilibrium outcome and the parameters. In addition, due to the complexity of the functional relationship between the profit function of traditional automakers, new energy vehicle manufacturers and third-party battery producers and the R&D parameter ξ, its will be further analyzed in the numerical simulation section.

Corollary 4: Under the production strategy of battery outsourcing, an increase in the proportion of consumers θ in the market with a preference for conventional cars leads to an increase in pricing, sales, and profits for conventional car makers and a decrease in green performance, pricing, sales, and profits for new energy car makers, as well as in profits for third-party battery producers, while the impact on suppliers is not certain.if $\frac{\gamma^2}{\beta} > max\left\{\frac{12\gamma^2\theta}{\beta(32\theta-3)}, \frac{2\gamma^2(6-7\theta)}{\beta(29-34\theta)}, \frac{\gamma^2}{2\beta}\right\}$,when $\xi > \frac{\gamma^2}{\beta}$,supplier pricing and profitability increase with an increase in the consumer proportion parameter θ A and conversely decrease with an increase in the consumer proportion parameter θ;if $\frac{\gamma^2}{\beta} \leqslant max\left\{\frac{12\gamma^2\theta}{\beta(32\theta-3)}, \frac{2\gamma^2(6-7\theta)}{\beta(29-34\theta)}, \frac{\gamma^2}{2\beta}\right\}$,then the supplier's pricing and profits always increase with the increase in the consumer ratio parameter θ.

Proof: based on the equilibrium results in the case where the automaker chooses to outsource its batteries, partial derivatives are obtained with respect to the parameter θ, which leads to $\frac{\partial m_1^*}{\partial \theta} = \frac{4\alpha(8\beta\xi-3\gamma^2)}{\beta(59\beta\xi-24\gamma^2)}$, $\frac{\partial m_2^*}{\partial \theta} = -\frac{2\alpha(17\beta\xi-7\gamma^2)}{\beta(59\beta\xi-24\gamma^2)}$, $\frac{\partial G^*}{\partial \theta} = -\frac{6\alpha\gamma(17\beta\xi-7\gamma^2)}{(59\beta\xi-24\gamma^2)(7\beta\xi-3\gamma^2)}$, $\frac{\partial T^*}{\partial \theta} = -\frac{6\alpha\xi(17\beta\xi-7\gamma^2)}{(59\beta\xi-24\gamma^2)(7\beta\xi-3\gamma^2)}$, $\frac{\partial W^*}{\partial \theta} = \frac{\alpha(29\beta^2\xi^2-41\beta\gamma^2\xi+12\gamma^4)}{\beta(7\beta\xi-3\gamma^2)(59\beta\xi-24\gamma^2)}$,

$\frac{\partial D_1^*}{\partial \theta} = \frac{4\alpha(8\beta\xi-3\gamma^2)(5\beta\xi-2\gamma^2)}{(59\beta\xi-24\gamma^2)(7\beta\xi-3\gamma^2)}$, $\frac{\partial D_2^*}{\partial \theta} = -\frac{6\alpha\beta\xi(17\beta\xi-7\gamma^2)}{(59\beta\xi-24\gamma^2)(7\beta\xi-3\gamma^2)}$,

$\frac{\partial \pi_S^*}{\partial \theta} = \frac{4\alpha^2(29\beta^2\xi^2-41\beta\gamma^2\xi+12\gamma^4)L_5}{\beta(59\beta\xi-24\gamma^2)^2(7\beta\xi-3\gamma^2)^2}$, $\frac{\partial \pi_{M1}^*}{\partial \theta} = \frac{8\alpha^2(8\beta\xi-3\gamma^2)(5\beta\xi-2\gamma^2)L_6}{\beta(59\beta\xi-24\gamma^2)^2(7\beta\xi-3\gamma^2)}$,

$\frac{\partial \pi_{M2}^*}{\partial \theta} = -\frac{6\alpha^2\xi(34\beta\xi-14\gamma^2)L_7}{(59\beta\xi-24\gamma^2)^2(7\beta\xi-3\gamma^2)}$, $\frac{\partial \pi_K^*}{\partial \theta} = -\frac{9\alpha^2\xi(2\beta\xi-\gamma^2)(34\beta\xi-14\gamma^2)L_7}{(59\beta\xi-24\gamma^2)^2(7\beta\xi-3\gamma^2)^2}$.where

$L_6 = \beta\mu(32\theta-3) - 12\gamma^2\theta$, $L_7 = \beta\xi(29-34\theta) - 2\gamma^2(6-7\theta)$ .Given that the precondition $\frac{3}{32} < \theta < \frac{29}{34}$ and $\xi > max\left\{\frac{12\gamma^2\theta}{\beta(32\theta-3)}, \frac{2\gamma^2(6-7\theta)}{\beta(29-34\theta)}, \frac{\gamma^2}{2\beta}\right\}$ is satisfied between the parameter, it follows that$\frac{\partial m_1^*}{\partial \theta}, \frac{\partial D_1^*}{\partial \theta} > 0and\frac{\partial m_2^*}{\partial \theta}, \frac{\partial G^*}{\partial \theta}, \frac{\partial T^*}{\partial \theta}, \frac{\partial D_2^*}{\partial \theta}, \frac{\partial \pi_{M2}^*}{\partial \theta}, \frac{\partial \pi_K^*}{\partial \theta} < 0$.And the relationship between suppliers' wholesale prices and profits and parameters is also related to the size relationship between R&D parameters$\varepsilon$and$\frac{\gamma^2}{\beta}$.Given that A

$29\beta^2\xi^2 - 41\beta\gamma^2\xi + 12\gamma^4$is less than 0 on$\frac{12\gamma^2}{29\beta} < \xi < \frac{\gamma^2}{\beta}$,and greater than 0 at

$\xi < \frac{12\gamma^2}{29\beta}$ and $\xi > \frac{\gamma^2}{\beta}$ .so,if $\frac{\gamma^2}{\beta} > max\left\{\frac{12\gamma^2\theta}{\beta(32\theta-3)}, \frac{2\gamma^2(6-7\theta)}{\beta(29-34\theta)}, \frac{\gamma^2}{2\beta}\right\}$,when $\xi > \frac{\gamma^2}{\beta}$, $\frac{\partial W^*}{\partial \theta}, \frac{\partial \pi_S^*}{\partial \theta} > 0$,but when $max\left\{\frac{12\gamma^2\theta}{\beta(32\theta-3)}, \frac{2\gamma^2(6-7\theta)}{\beta(29-34\theta)}, \frac{\gamma^2}{2\beta}\right\} < \xi \leqslant \frac{\gamma^2}{\beta}$, $\frac{\partial W^*}{\partial \theta}, \frac{\partial \pi_S^*}{\partial \theta} \leqslant 0$; if $\frac{\gamma^2}{\beta} \leqslant max\left\{\frac{12\gamma^2\theta}{\beta(32\theta-3)}, \frac{2\gamma^2(6-7\theta)}{\beta(29-34\theta)}, \frac{\gamma^2}{2\beta}\right\}$, $\frac{\partial W^*}{\partial \theta}, \frac{\partial \pi_S^*}{\partial \theta} > 0$ is constant.

Similar to the results of Corollary 2, an increase in the proportion of consumers who prefer traditional fuel vehicles leads to an increase in pricing, sales, and profits for traditional manufacturers, but a decrease in pricing, sales, and profits for new energy vehicle manufacturers, as well as a decrease in green performance, pricing, and profits for third-party battery manufacturers. The difference, however, is that the impact on suppliers is inconsistent, with an increase in the proportion of consumers who prefer conventional cars leading to a decrease in supplier pricing and profits when the R&D parameters are small, and an increase in supplier pricing and profits when the R&D parameters are large. This is because when the battery manufacturer R & D efficient, it can significantly improve the green performance of the product, in the market with greater competitiveness, when the traditional fuel car market accounted for an increase in the new energy vehicle market demand will be significantly

reduced, which will lead to a reduction in the overall demand for suppliers as well as a reduction in profits, while in the battery manufacturer R & D inefficient, the two products in the market price competition is not obvious, the supplier's pricing power is higher, you can Realize greater profits in the form of higher wholesale prices.

3.3.Production strategies for joint R&D

Since the equilibrium results of the game under the joint R&D and production strategy are more complicated, the impact of the traditional fuel vehicle market preference ratio θ on the equilibrium results is mainly analyzed here, while the functional relationship between the third-party battery producer's technological research and development parameter ε and the new energy vehicle manufacturer's R&D commitment ratio $\emptyset$ and the equilibrium results is more complicated, which will be discussed and analyzed in the numerical simulation section further. Based on the results under the joint R&D and production strategy, Corollary 5 can be obtained[36-38].

Corollary 5: Under the production strategy of joint R&D, an increase in the proportion of consumers θ who prefer conventional cars leads to higher pricing, sales, and profits for conventional car makers, while green performance, pricing, sales, and profits for new energy car makers, as well as profits for third-party battery producers, decrease, and the effect on supplier pricing and profits is not certain.

Proof: Based on the equilibrium results in the case of joint research and development by the battery manufacturer and the new energy vehicle manufacturer, the partial derivatives are

obtained with respect to the parameter θ respectively, which in turn leads to $\frac{\partial m_1^{**}}{\partial \theta} = \frac{\alpha L_8[7\beta\xi(1-\phi)-3\gamma^2]}{\beta A}$, $\frac{\partial m_2^{**}}{\partial \theta} = -\frac{2\alpha L_9[17\beta\xi(1-\phi)-7\gamma^2]}{\beta A}$, $\frac{\partial G^{**}}{\partial \theta} = -\frac{6\alpha\gamma[17\beta\xi(1-\phi)-7\gamma^2](1-\phi)}{A}$, $\frac{\partial T^{**}}{\partial \theta} = -\frac{6\alpha\xi[17\beta\xi(1-\phi)-7\gamma^2](1-\phi)}{A}$, $\frac{\partial W^{**}}{\partial \theta} = \frac{\alpha L_{10}}{\beta A}$, $\frac{\partial D_1^{*}}{\partial \theta} = \frac{2\alpha L_{11}[5\beta\xi(1-\phi)-2\gamma^2]}{A}$, $\frac{\partial D_2^{**}}{\partial \theta} = -\frac{6\alpha\beta\xi[17\beta\xi(1-\phi)-7\gamma^2](1-\phi)^2}{A}$, $\frac{\partial \pi_S^{**}}{\partial \theta} = \frac{4\alpha^2 L_{10}L_{12}}{\beta A^2}$, $\frac{\partial \pi_{M1}^{**}}{\partial \theta} = \frac{4\alpha^2 C L_{11}[5\beta\xi(1-\phi)-2\gamma^2][7\beta\xi(1-\phi)-3\gamma^2]}{\beta A^2}$, $\frac{\partial \pi_{M2}^{**}}{\partial \theta} = -\frac{6\alpha^2\xi B L_{13}(1-\phi)^2[17\beta\xi(1-\phi)-7\gamma^2]}{A^2}$, $\frac{\partial \pi_K^{*}}{\partial \theta} = -\frac{18\alpha^2\xi B(1-\phi)^3[2\beta\xi(1-\phi)-\gamma^2][17\beta\xi(1-\phi)-7\gamma^2]}{A^2}$。

where$L_8 = 32\beta\xi(1-\phi)^2 - 6\gamma^2(2-3\phi)$, $L_9 = 7\beta\xi(1-\phi)^2 - 3\gamma^2(1-2\phi)$,

$L_{10} = 29\beta^2\xi^2(1-\phi)^3 - \beta\gamma^2\xi(1-\phi)(41-56\phi) + 6\gamma^4(2-3\phi)$,

$L_{11} = 16\beta\xi(1-\phi)^2 - 3\gamma^2(2-3\phi)$, $L_{13} = 14\beta\xi(1-\phi)^2 - 3\gamma^2(2-3\phi)$,

$L_{12} = \beta^2\xi^2(36+29\theta)(1-\phi)^3 - \beta\gamma^2\xi(1-\phi)[15(1-\phi)+\theta(41-56\phi)] + 6\gamma^4\theta(2-3\phi)$。

Due to$\xi > \frac{\gamma^2}{2\beta(1-\phi)}andA, B, C > 0$,It follows that $5\beta\xi(1-\phi) > 2\gamma^2$, $7\beta\xi(1-\phi) > 3\gamma^2$, $17\beta\xi(1-\phi) > 7\gamma^2$,so$\frac{\partial G^{**}}{\partial \theta}, \frac{\partial T^{**}}{\partial \theta}, \frac{\partial D_2^{**}}{\partial \theta}, \frac{\partial \pi_K^{**}}{\partial \theta} < 0$.In addition, given that $\xi > \frac{\gamma^2}{2\beta(1-\phi)}$,it follows that$L_8 > 2\gamma^2(2+\phi)$, $L_9 > \frac{1}{2}\gamma^2(1+5\phi)$, $L_{\mathrm{n}} > \gamma^2(2+\phi)$, $L_{13} > \gamma^2(1+2\phi)$,so $\frac{\partial m_1^{**}}{\partial \theta} > 0$, $\frac{\partial m_2^{**}}{\partial \theta} < 0$, $\frac{\partial D_1^{**}}{\partial \theta} > 0$, $\frac{\partial \pi_{M1}^{**}}{\partial \theta} > 0$, $\frac{\partial \pi_{M2}^{**}}{\partial \theta} < 0$ .Whereas L_{10} andL_{12} are not necessarily related to 0 in terms of magnitude. This in turn leads to uncertainty about the magnitude of $\frac{\partial W^{**}}{\partial \theta}$ and $\frac{\partial \pi_S^{**}}{\partial \theta}$ in relation to zero. Similar to the results of Corollary 4, under the production strategy of new energy vehicle manufacturers choosing joint R&D with battery producers, the increase in the proportion of consumers who prefer traditional fuel vehicles is favorable to traditional vehicle manufacturers and unfavorable to new energy vehicle manufacturers and battery producers, but the effect on suppliers is not necessarily the same, for reasons similar to those not discussed here. Given the complexity of the functional relationship

between some parameters and the equilibrium results, the analysis will be further discussed and analyzed through numerical simulation in the following.

4. Numerical simulation

Based on the above analysis of the equilibrium results, this section will explore the influence of key parameters on the equilibrium results under different scenarios through numerical simulation, and verify the correctness of the above inference[39]. In addition, this section will further compare and analyze the differences in the equilibrium results under different production strategies, and explore the optimal strategies for battery production of new energy vehicle manufacturers under different scenarios[40]. To ensure the consistency of the results, this part unifies the assumptions under different scenarios $\alpha = 100$, $\beta = 5$, $\gamma = 10$, $30 \leqslant \mu \leqslant 50$, $15 \leq \xi \leq 30$, $0.3 \leq \theta \leq 0.7$, $0 \leq \phi \leq 0.5$,we also discuss the effects of R&D parameter μ, R&D parameter ξ of the third-party battery manufacturer, traditional consumer market share θ, and R&D cost ratio $\emptyset$ of the new energy vehicle manufacturer under the joint R&D strategy on the equilibrium results, so as to find out the optimal production strategy of the new energy vehicle manufacturer under different scenarios. The subsequent numerical simulations are as follows: firstly, we analyze the effects of R&D parameter μ and traditional consumer market share θ on the equilibrium results in the self-research scenario, then we compare the results of the self-research and outsourcing scenarios to analyze the effects of R&D parameter ξ and traditional consumer market share Con the equilibrium results in the battery manufacturer scenario, and finally, we discuss the effects of

traditional consumer market share and traditional consumer market shareθon the equilibrium results by comparing the results of the outsourcing and joint research scenarios. Finally, we discuss the effects of traditional consumer market share $\theta$and R&D cost share$\emptyset$of new energy vehicle manufacturers on the equilibrium results by comparing the results of the outsourcing and joint R&D scenarios.

4.1. Production strategy for self-research

This part first analyzes the effects of parameters μ and θ on the equilibrium results under the battery production self-research strategy of new energy vehicle manufacturers, and with reference to existing studies and in the context of reality, it is assumed here that $30 \leqslant \mu \leqslant 50and0.3 \leq \theta \leq 0.7$,In turn, the relationship between the supplier's wholesale price $W$and profitπ_s, the traditional automobile manufacturer's product pricing m_1, sales volumeD_1, and profit π_{M1}, and the new energy automobile manufacturer's product green performance$G$, pricing m_2, sales volume D_2, ,and profit π_{M2} with the parameters μ and θ is obtained, and the specific results are shown in Figs. 1-3.

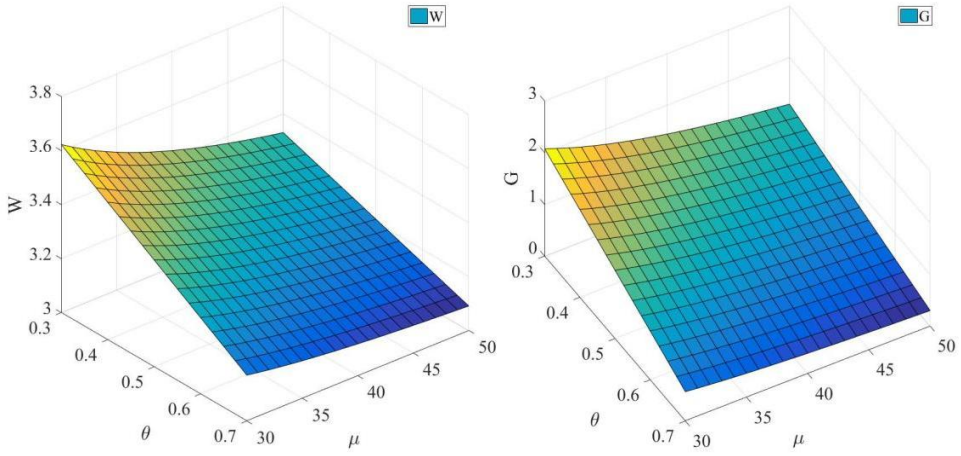


Fig. 1 Wholesale price$W$and green performance$G$versus parameters μ and θunder self-

research strategy

Figure.1 shows the relationship between supplier wholesale price and green performance of new energy vehicles with parameters μ andθ. Overall, the increase of R&D parameter$\mu$and traditional automobile market share$\theta$is unfavorable to the wholesale price of suppliers and the green performance of new energy vehicle products. It is obvious that the decrease of R&D efficiency will lead to the need of new energy vehicle manufacturers to spend more cost investment, which will lead to the reduction of green performance, while the increase of traditional automobile market share will further reduce the market competitiveness of new energy vehicles, which will also compress the R&D motivation of new energy vehicle manufacturers. The increase in the market share of traditional vehicles will further reduce the competitiveness of new energy vehicles, which will also compress the R&D motivation of new energy vehicle manufacturers. The trend in suppliers' wholesale prices suggests that new energy vehicle manufacturers have more influence over their pricing, as the investment in new energy vehicles allows them to price their products at a higher level than conventional vehicles, which in turn gives suppliers more pricing space, and thus changes in new energy vehicle pricing have a greater impact on suppliers' wholesale prices.

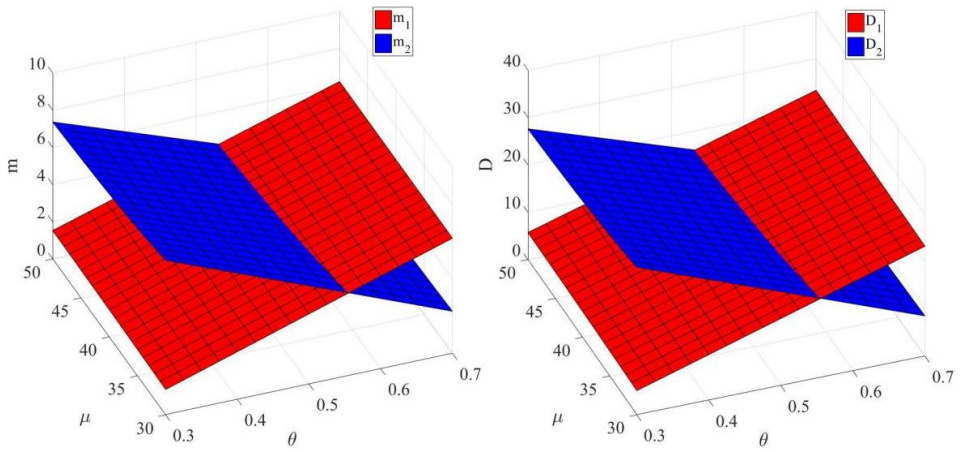


Fig. 2 Markup m_i and Market Demand$D_i$versus Parameters μ andθ under Self-Research Strategy

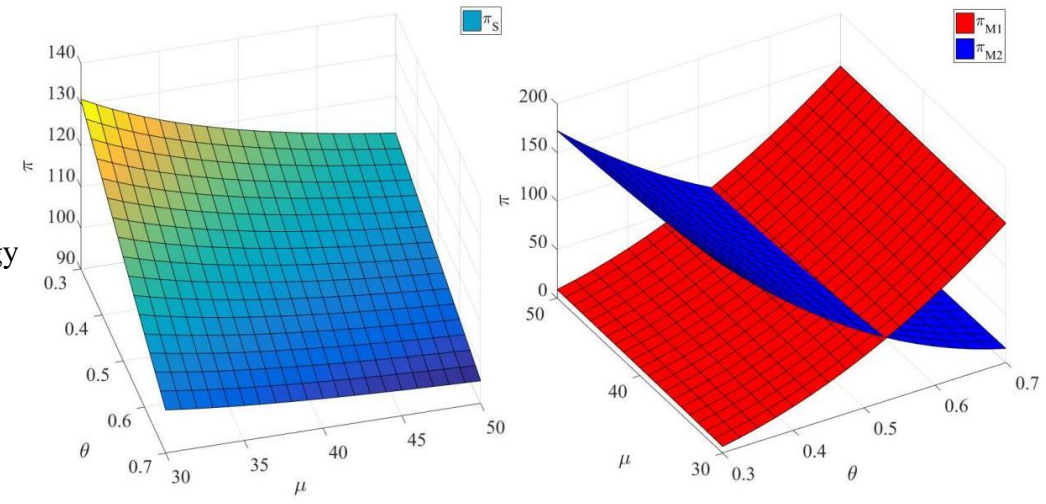


Fig. 3 Relationship between supplier profit π_s and manufacturer profit π_{Mi} and parameters μ and θunder the self-developed strategy

Figures 2 and 3 show the relationship between pricing, sales and profits of the two types of automakers as well as supplier profits and the two parameters. It is clear from Figures 2 and 3 that market share is the most significant factor influencing both conventional and new energy vehicle manufacturers in comparison, and that it has a clear opposite effect on both. It is not difficult to understand that when the market share is larger, the manufacturer has more pricing power and thus can make more profit. In addition, new energy vehicle manufacturers have higher pricing, market demand, and profits when the market share is equalized due to their higher green performance, which makes them more attractive for consumers to buy. Figure 3 also shows the relationship between supplier profits and parameters, and shows that an increase in the market share of traditional automakers leads to a decrease in supplier profits, which is more pronounced when the R&D parameters are small, because when the market share of traditional automakers increases, the pricing and sales of products from new energy automakers

decrease more than the pricing and sales of products from traditional automakers increase, and in combination with Figure 1, it can be seen that suppliers' wholesale prices will also fall, which in turn will lead to lower overall revenues.

4.2.Production strategies for outsourcing

This section will further consider analyzing the equilibrium results as a function of parameters under the outsourcing strategy of new energy vehicle manufacturers, focusing mainly on the impacts of parameter ξ of battery producers and parameter θ of traditional vehicle market demand share on the equilibrium results. According to the numerical simulation analysis of the self-research scenario, it is known that parameter θ has a greater impact on the equilibrium results, so this section uses $\theta = 0.4$ and $\theta = 0.6$ to represent the two scenarios of market dominance by new energy vehicle manufacturers and market dominance by traditional fuel vehicle manufacturers, respectively. Given that the professional technical level and productivity of the third-party outsourced battery manufacturer are also important reasons for automakers to adopt the outsourcing strategy, and in order to compare and analyze the differences in the equilibrium results between the self-research strategy and the outsourcing strategy, this section assumes that the R&D parameters of the manufacturer under the self-research strategy are $\mu = 40$, which is the same as that in the outsourcing strategy.While the range of R&D parameters of the battery manufacturer under the outsourcing strategy is $15 \le \xi \le 30$, the relationship between the supplier's wholesale price W and profit π_s, the traditional automobile manufacturer's product pricing m_1, sales volume D_1 and profit π_{M1}, the new energy automobile manufacturer's

product green performance G, pricing m_2, sales volume D_2 and profit π_{M2}, as well as the battery manufacturer's pricing T and profit π_K, and the relationship with parameters ε and θ can be obtained for the two scenarios, and the specific results are shown in Figures 4-6. shown in Fig. 4-6.

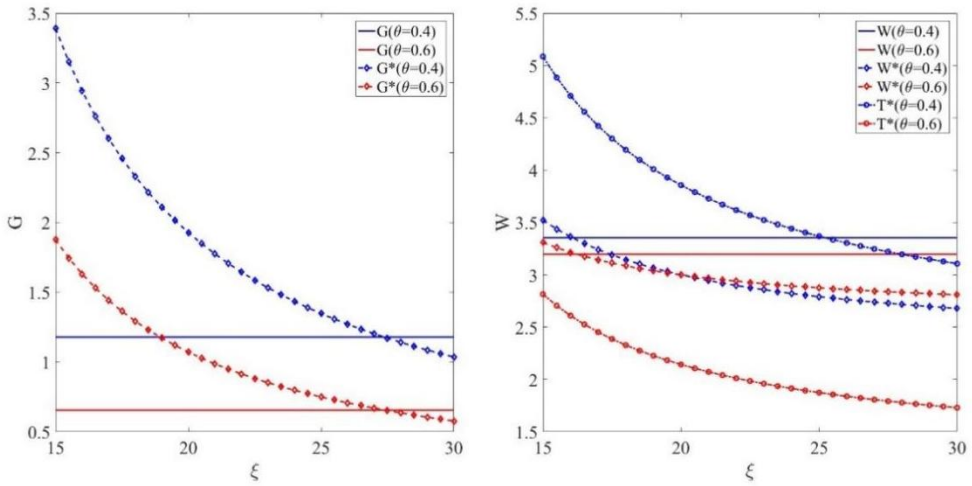
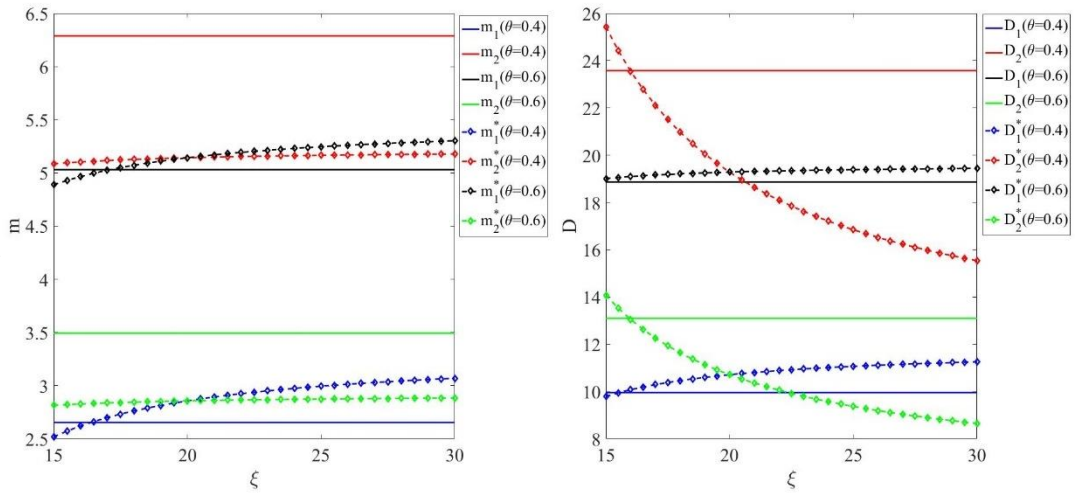


Fig. 4 Relationship between green performance G^*, wholesale price W^*, outsourcing price T^* and parameters ε and θ under the outsourcing strategy

According to Figure 4, the increase of R&D parameter ε of battery manufacturers is also unfavorable to the green performance of new energy vehicles, and when R&D parameter ε is larger, the green performance of the outsourcing scenario is even lower than that of the self-research scenario. It can be seen that when automobile manufacturers dominate the market, and when the technological leadership in battery production is not obvious, the green performance of products under self-research is better. Figure 4 also shows that battery manufacturers are only able to price their products higher when their R&D is more efficient, while in the rest of the cases the wholesale price of the suppliers is smaller than in the self-developed case. This is

mainly because the battery manufacturer's outsourcing makes the supplier's market pricing power is further reduced, only through the form of price reductions to increase the manufacturer's demand for its products, while in the battery manufacturer's R & D efficiency is relatively high, when the product greenness is higher than the case of self-research and development, to obtain a greater market demand, which leads to the enhancement of the wholesale price of the product pricing. In addition, in the case of self-research, the wholesale price is always greater in the new energy vehicle market demand, while outsourcing is not necessarily the case, in the battery manufacturer R & D efficiency is higher, the supplier wholesale price is still in the new energy vehicle market demand accounted for a high proportion of the larger, while in the battery manufacturer R & D efficiency is low, the traditional automotive market accounted for a high proportion of the more favorable to it, because the R & D efficiency is low when it will reduce the product's market price, and in the automaker-dominated market, it will further lead to lower product pricing, and thus high demand in the traditional automotive market at this time is unfavorable to suppliers. For battery producers, pricing decreases with increasing R&D parameters and is higher when demand is higher in the new energy vehicle market. It is clear that market demand has a significant impact on battery producers and that R&D inefficiencies can only lead to lower pricing.

577 .



578 Fig. 5 Relationship between manufacturer markup $m_i^*$and market demandD_i^* and parameters

579 ε and θ under the outsourcing strategy

580 Figure 5 mainly shows the relationship between R&D parameters and market distribution

581 with product pricing and market demand. First, regarding the relationship between

582 manufacturers' pricing and parameters, when comparing the pricing size of traditional and new

583 energy manufacturers horizontally, it is clear that manufacturers, whether they adopt self-

584 development or outsourcing production strategies, will increase the price of traditional fuel

585 vehicle manufacturers' products by a higher percentage of the market demand for traditional

586 fuel vehicles, and vice versa for new energy vehicle manufacturers. When comparing product

587 pricing vertically between the two scenarios, whether the market demand is dominated by

588 traditional fuel vehicles or new energy vehicles, the pricing of new energy vehicle

589 manufacturers is always lower in the outsourcing scenario, whereas the pricing of traditional

590 manufacturers is not necessarily the same in both scenarios, and it is only in the case of higher

591 R&D efficiency of the battery manufacturer that the outsourcing pricing is lower, and vice versa

592 for the self-research and development pricing is lower. In addition, unlike Figure 1, the markup

on the manufacturer's product increases with the R&D parameters in both outsourcing scenarios. Unsurprisingly, market share has a significant impact on both automakers, and both are able to price their products higher than their competitors when they have a larger market share. The fact that the price increase for the new energy vehicle manufacturer's products in the outsourcing scenario is always lower than the result in the in-house scenario is because in the outsourcing scenario the cost of battery R&D is no longer an in-house cost and it has to pay for the additional battery cost, so the price increase is lower than in the in-house scenario. The price increase of traditional manufacturers' products in both the self-research and outsourcing scenarios is only lower when the battery producer develops efficiently mainly because in the manufacturer-dominated market, the manufacturer has greater market pricing power, and its pricing will be higher when the battery producer develops efficiently, and at this time, new energy vehicle manufacturers can only reduce their prices in order to obtain market competitiveness, and similarly, the traditional manufacturers can only be forced to reduce their prices, even if the price increase is lower than in the self-research scenario. lower than in the case of self-research.

In addition, according to Figure 5, a horizontal comparison of the market demand for the two products shows that, again, when the market share of a certain type of automobile is large, the market demand for that type of automobile manufacturer is larger than that of its competitors. While comparing the market demand of the two products vertically, it can be seen that the market demand of traditional fuel automobile will be larger than that of self-research, while the market demand of new energy automobile will be larger than that of self-research when the

R&D parameters are smaller and smaller than that of self-research when the R&D parameters are larger, and the impact of the increase of R&D parameters on the market demand of the two products is opposite. It can be seen that the outsourcing strategy is favorable to the market demand of traditional fuel vehicles, slightly increasing the market sales of traditional fuel vehicles. However, the impact on the market demand for new energy vehicles is huge, and only when the outsourcing R&D efficiency is high can the market sales of new energy vehicles be greater than the results of the self-research scenario. This is because outsourcing the battery components, although it reduces the R&D cost, but it also reduces the pricing power of the market, which leads to the pricing of the final product is higher in the case of larger R&D parameters, which leads to a significant drop in market demand.

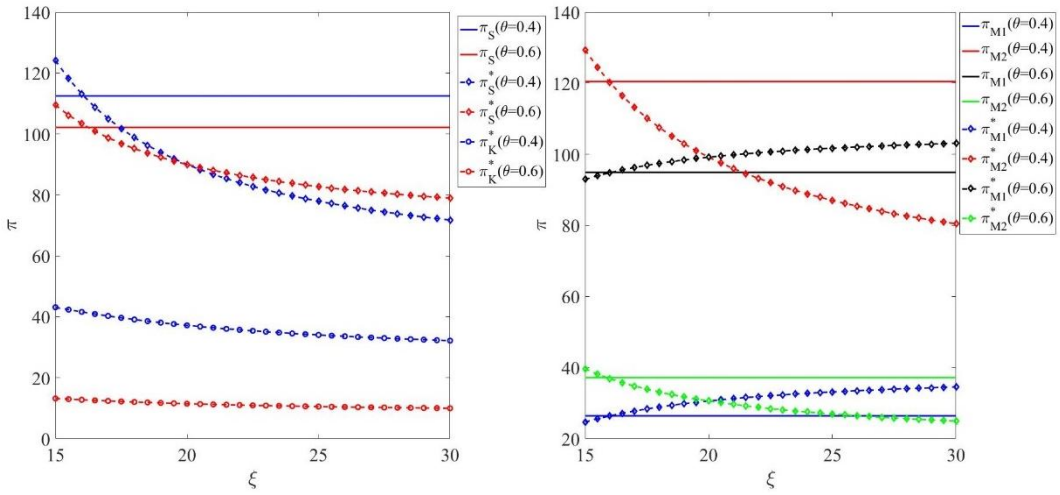


Fig. 6 Participants' profitsπ_S^*, π_K^*andπ_{Mi}^* in relation to parameters ε and θ under outsourcing strategy

Figure6 shows the relationship between profit and parameters for suppliers, conventional manufacturers, new energy manufacturers, and battery producers. First, the profits of battery

manufacturers decrease as the R&D parameters increase and are larger when the market share of new energy vehicles is larger, while the profits of suppliers are different from the results in the in-house scenario in that they are larger when the R&D parameters are smaller and when the R&D parameters are larger, they are larger when the traditional vehicle manufacturers have a larger market share. This is mainly due to the fact that when the battery manufacturer's R&D parameters are small, the new energy vehicle has greater green performance and market demand, and the supplier is able to obtain greater profits, while when the R&D parameters are large, although the demand in the traditional automobile market can increase, the demand in the new energy vehicle market declines even more, which may lead to a decline in the overall profits of the supplier. In addition, the supplier's profits will be greater than the new energy vehicle manufacturer's self-developed battery only if the battery manufacturer's R&D parameters are small, mainly because when the battery manufacturer's R&D is inefficient, the product's pricing and sales volume will be lower, and lead to a decrease in the supplier's profits. Overall, there is an inverse relationship between the profits of traditional and new energy vehicle manufacturers and the R&D parameters of battery manufacturers. Regardless of the market distribution of the two products, an increase in the R&D parameters of battery manufacturers will lead to an increase in the profits of traditional vehicle manufacturers and a decrease in the profits of new energy vehicle manufacturers, and the change in the R&D parameters has the greatest impact on the profits of new energy vehicle manufacturers when new energy vehicles dominate the market. When new energy vehicles dominate the market, changes in R&D parameters have the greatest impact on the profits of new energy vehicle manufacturers. The reason for this is that

the increase in R&D parameters indicates a decrease in the efficiency of battery manufacturers and a decrease in the greenness of their products, which leads to a significant decline in market competitiveness and a decrease in the profitability of new energy vehicle manufacturers, whereas traditional vehicle manufacturers benefit from this and realize a further increase in profitability. When the market share of traditional fuel vehicles is relatively large, due to the small market share of new energy vehicles, changes in the R&D efficiency of battery manufacturers will have less impact on the profitability of new energy vehicles, while in the case of new energy vehicles with a large market share, the reduction in R&D efficiency will greatly reduce the profitability of new energy vehicles. In addition, further comparing the results of the two strategies of new energy vehicle manufacturers' self-research and outsourcing, it can be seen that in most cases, it is favorable for the traditional automobile manufacturers to realize their profit enhancement, while for the new energy vehicle manufacturers, it is the opposite, and it is unfavorable for them in most cases, and the profit of the new energy vehicle manufacturers is greater only when the battery manufacturers' research and development is relatively efficient in the outsourcing situation. Visible, in the automobile manufacturers dominate the market, if the new energy vehicle manufacturers of R & D efficiency and third-party battery manufacturers efficiency gap is not too big, its own research has a greater profit margin, as the domestic BYD, Geely have chosen to self-research battery strategy.

4.3.Production strategies for joint R&D

This part will further analyze the impact of the joint development and production strategy,

the proportion of new energy vehicles and battery manufacturers ϕ and the demand ratio of traditional vehicles θ on the equilibrium results. Here assume battery manufacturers development parameters for $\xi = 20$, and θ=0.4 and $\theta = 0.6$ respectively said new energy vehicles in demand dominant and traditional fuel car demand market environment, new energy vehicles development range of $0 \le \phi \le 0.5$, and then can outsourcing strategy and joint development strategy and two cases supplier wholesale price W and profit π_S, automobile manufacturers product pricing m_i, sales D_i, and profit π_{Mi}, new energy automobile manufacturers product green performance G and battery manufacturers pricing T and profit π_K and parameters the relationship between ϕ and θ, the specific results as shown in figure 7-9.

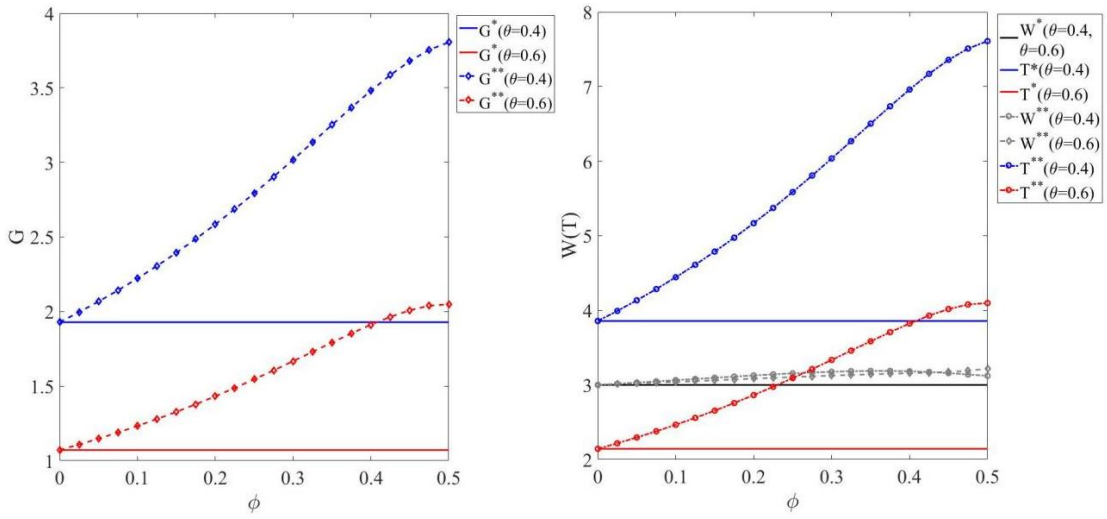


Fig.7 Relationship between green performance G^{**}, wholesale price W^{**} and pricing T^{**} and parameters ϕ and θ under the joint development strategy

According to figure 7, clearly know the higher the new energy automobile manufacturing, the more favorable green performance of the battery, this is because the new energy automobile manufacturers as the leader in the market, the money, cooperation with battery manufacturers can significantly reduce the production risk of battery manufacturers, which can improve the

687 green performance of the product. As for the relationship between parameters ϕ and θ and
688 the wholesale price of the product, it shows $\xi = \frac{\gamma^2}{\beta}$particularity, that is, when parameter$\xi = 20$,
689 the distribution of consumer market demand will not affect the pricing of the product. This
690 image verifies the result of inference 4, namely, the proportion of traditional car preference
691 consumers θ in the market will not affect the wholesale price of the product.In addition,
692 whether the demand of traditional automobile market is dominated or the demand of new energy
693 vehicle market is dominated, the increase of the proportion of R&D undertaking will lead to
694 the increase of wholesale price, when the proportion of undertaking is small, the wholesale
695 price is higher when the demand of new energy vehicle is dominated in the market, while when
696 the proportion of undertaking is large, the wholesale price is higher when the demand of
697 traditional automobile is dominated in the market, which also verifies that the supplier's
698 wholesale price in Corollary 5 and the market distribution parameter This also verifies that the
699 relationship between supplier wholesale prices and market distribution parameters in Corollary
700 5 is not certain and will be affected by other parameters. However, in comparison, the impact
701 on suppliers' wholesale prices is small, while the impact on battery producers is more significant,
702 which can significantly increase their product pricing. This may be due to the fact that when
703 new energy vehicles dominate the market, a certain degree of collaborative research and
704 development can enhance the realization of performance enhancement is also beneficial to the
705 supplier, but when the new energy vehicle manufacturers to bear a higher proportion of its
706 demand for discounts is also higher, which may lead to higher pricing of battery manufacturers,
707 which may lead to the wholesalers can only reduce the pricing.

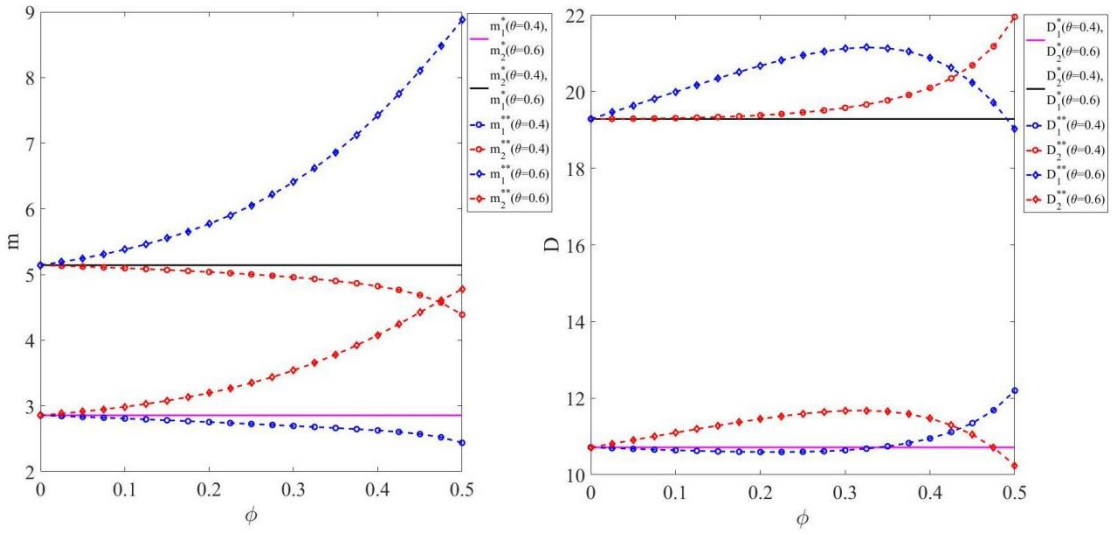


Fig.8 Relationship between manufacturer markup $m_i^{**}$and sales volume$D_i^{**}$and parameters ϕ and θ under the joint research and development strategy

As can be seen from Figure 8, the pricing and sales volume of traditional automobile manufacturers and new energy vehicle manufacturers are exactly opposite in the two market distribution situations, that is, the pricing of traditional automobile manufacturers at $\theta = 0.4$ and $\theta = 0.6$ is consistent with the price of new energy vehicle manufacturing at $\theta = 0.6$ and $\theta = 0.4$. First of all, the change of the two market distribution of traditional car manufacturers and new energy automobile manufacturers pricing influence is the same, in the new energy vehicles market demand dominated both pricing decline, while the traditional car market demand dominant lead to both prices rise, and the traditional car manufacturers in its market dominance pricing is always higher, and new energy automobile manufacturers pricing in parameter ϕ hours, the new energy vehicles market demand dominated high pricing, and when the parameter ϕ is larger, in the traditional car market demand dominated high pricing. Investigate its reason, the joint research and development of green performance and pricing will improve, and the traditional carmakers "free rider" effect will improve pricing, and new energy

automobile market demand dominated, given the new energy vehicles have obvious green performance advantage, it may expand the market competitiveness, even lower than the traditional consumer dominant pricing, while the traditional auto makers can only be forced to price.

In terms of the sales of the two products, when the market is dominated by consumers who prefer traditional cars, the sales of both products first increase and then decrease with the increase of parameterϕ, and even lower than the result under the outsourcing strategy, while when the market is dominated by consumers who prefer new-energy cars, the sales of the two products first decrease slightly and then increase sharply with the increase of parameterϕ, and ultimately higher than the result under the outsourcing strategy. The main reason is that in the market dominated by consumers who prefer new energy vehicles, the pricing of both products will decrease, and then the sales of both products will increase, and the more the proportion of new energy vehicles is taken up by the market demand will be greater, realizing the expansion of the overall market demand. In the traditional automobile preference consumers dominate the market, the green performance of the products under the joint R&D strategy will be enhanced, which will attract consumers to buy new energy vehicles, and then due to the fact that new energy vehicles are the main demand in the market, the market pricing power is strong, and in the case of a high proportion of R&D commitment, the high pricing of the products will also lead to a decline in consumer demand. Excessive pricing by new energy vehicle manufacturers and battery producers can even lead to a smaller market demand for their products than would result from an outsourcing strategy, while traditional automobile manufacturers have less

market pricing power, and their market demand will also decline.

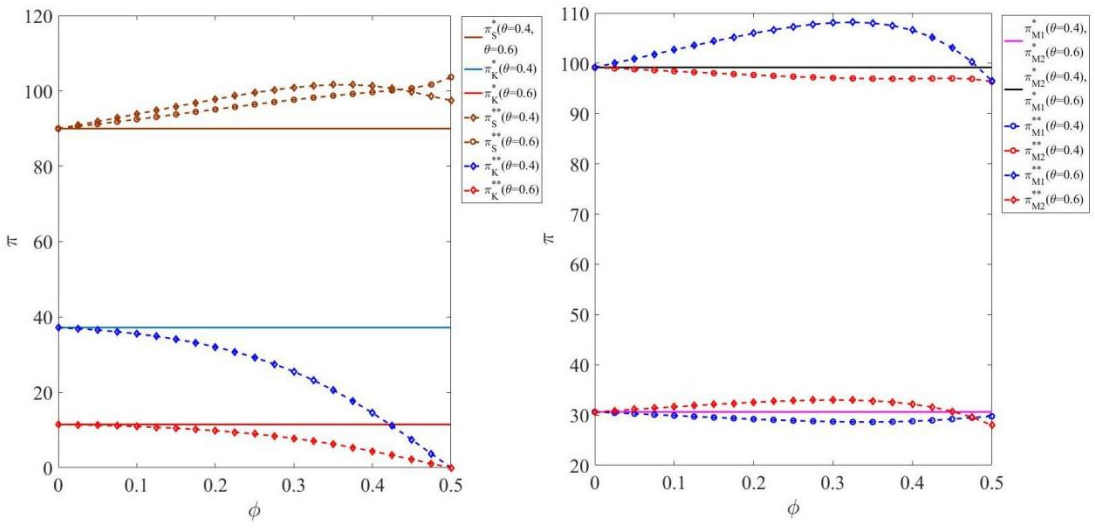


Fig. 9 Relationship between participant profits π_s^{**}, π_K^{**}, $\pi_{Mi}^{**}$and parameters $\phi$and θ under the joint development strategy

As can be seen from Figure 9, both traditional and new energy vehicles dominate the market demand, and the joint R&D strategy is unfavorable to the profits of battery producers, which will lead to a continuous decline in their overall profits, mainly because under the joint R&D strategy, the new energy vehicle manufacturers will require them to sell their battery component products at lower prices, which in turn will squeeze the profit margins of the battery producers, so the joint R&D is unfavorable to the profits of battery producers. Therefore, joint R&D is unfavorable to the profits of battery manufacturers, and to a certain extent, it will reduce their absolute competitiveness in the market and cut down their profit margins. Regardless of the market distribution of consumers, the joint R&D strategy is favorable to the profits of the supply chain, which can realize the profit improvement, in the traditional automobile preference consumers accounted for the majority of the market, the joint R&D strategy will lead to a continuous improvement of supplier profits, while in the new energy automobile preference

consumers accounted for the majority of the market, will lead to the supplier profits firstly rise and then fall, its in the proportion of the bearer is small, the new energy automobile Supplier profits are greater in consumer-dominated markets than in consumer-dominated markets for conventional cars. Since the supplier's profit is mainly composed of wholesale price and sales volume, combining Figures 7 and 8 shows that the proportion of new energy vehicle manufacturers' commitment in the joint research and development strategy has a smaller impact on their wholesale price, but the impact relationship on the sales volume of the two products is not the same, which leads to the impact between the supplier's profit and the proportion of commitment parameter presenting a similar functional relationship between the sales volume and the proportion of commitment parameter.

Further analyzing the relationship between the profit of traditional automobile manufacturers and new energy automobile manufacturers and the parameter of the proportion of undertaking under the joint R&D strategy, it can be clearly seen that when the demand of the new energy automobile market is dominant, the joint R&D strategy at this time will lead to the decline of the profit of traditional automobile manufacturers and new energy automobile manufacturers, while when the demand of the traditional automobile market is dominant in the market, an increase in the proportion of R&D undertaken by the new energy automobile manufacturers will When the market demand for traditional vehicles dominates, the increase in the proportion of R&D undertaken by the new energy vehicle manufacturers will lead to a decrease in the profits of both manufacturers, and the result will be lower than that under the outsourcing strategy when the parameter of the proportion of R&D is larger. Combined with

Figures 7 and 8, this is mainly due to the fact that when the market for new energy vehicles is more dominant, despite the fact that R&D cooperation can improve the green performance of the product, the pricing of the automakers will be lower, and thus the overall profits of both will be lower. When traditional consumers dominate the market, R&D collaboration can lead to higher pricing and sales, which is beneficial to both traditional and new energy vehicle manufacturers, leading to higher profits. Figure 9 shows that for automakers aiming to transition to new energy and with a strong market position, outsourcing production is more effective than joint R&D when demand is high in the new energy market, while when demand is high in the traditional automotive market, they should collaborate with battery manufacturers to advance technology and realize higher profits at the same time.

5. Conclusions

Based on the coexistence of traditional fuel vehicles and new energy vehicles in the market environment, this study considers three production strategies of new energy vehicle manufacturers, namely, self-development, outsourcing and joint research and development of battery components, and constructs the corresponding game model to discuss in depth the impact of R&D efficiency, market distribution, R&D commitment ratio and other parameters on the equilibrium results, and explore the appropriate development strategies of new energy vehicle manufacturers in different situations by comparing and analyzing the results under different production strategies. vehicle manufacturers in different situations. The main conclusions of this study are as follows:

(1) The reduction of R&D efficiency under the self-research production strategy of new energy vehicle manufacturers is unfavorable to their own sales, pricing and profits, but favorable to traditional vehicle manufacturers. Under the outsourcing strategy and joint R&D strategy, the reduction of battery manufacturers' R&D efficiency is unfavorable to battery manufacturers and new energy vehicle manufacturers, but traditional manufacturers can profit from it.

(2) Consumer market distribution is an important factor influencing supply chain decisions. Under the battery self-development strategy, the increase in the market share of traditional vehicles leads to the rise in pricing, sales and profits for traditional automakers, and the decline in pricing and profits for suppliers and green performance, pricing, sales and profits for new energy vehicle manufacturers. The outsourcing strategy and R&D strategy will also lead to a decline in pricing and profits for battery manufacturers, while the impact on pricing and profits for suppliers at this time is not certain.

(3) new energy vehicle manufacturers have a dominant position in the market, only when the battery manufacturer's technology R & D efficiency leading edge is obvious, the choice of outsourcing strategy is more favorable to them. When the R&D efficiency of the battery producer is only large, the supplier and the new energy vehicle manufacturer can obtain higher profits than under the self-research strategy, but the traditional manufacturer can always obtain higher profits.

(4) The joint R&D strategy of new energy vehicle manufacturers and battery manufacturers is only relatively effective when the demand of the traditional vehicle market is

high, while the outsourcing strategy is better when the demand of the new energy vehicle market is high. Under the joint R&D strategy, suppliers are always profitable and able to increase their profits, while battery producers' profits continue to be cut.

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Data availability

Study data will be made available upon request.

Ethics approval and consent to participate

Not applicable

Competing interests

The authors declare no competing interests.

Consent for publication

Not applicable.

Author Contributions Statement

Junlan Tan: Writing - review & editing;Writing - original draft

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Rong Wang:Formal Analysis;Investigation;Supervision;Resources

Deibin Yang:Project Administration; Investigation

Yuling Shi:Visualization, Investigation;Funding Acquisition

Yong Lv:Visualization, Writing - Review & Editing

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