Research Article

Influence of Dual-Credit Policy on the R&D Cooperation Mode of Chinese Auto Industry

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The dual-credit policy is regarded as an important measure in the postsubsidy era of energy conservation and emission reduction in the auto industry and is concerned with all aspects of society. In this paper, a research and development cooperation model of the duopoly supply chain between suppliers and manufacturers in the automotive industry is constructed, and the influence of the double integral policy on the research and development cooperation between suppliers and manufacturers in the automotive industry is discussed based on the power perspective theory in the supply chain. The results show that cooperation is more effective than noncooperation in promoting both parties’ R&D investment in fuel economy, as well as the fuel economy of the final product. The government should encourage R&D cooperation in the upstream and downstream of the supply chain of the automotive industry. The influence on the R&D cooperation between the supplier and the manufacturer was the combined effect of fuel consumption saving. The government’s intention to formulate a dual-credit policy to guide the R&D cooperation behavior in the auto industry supply chain should consider not only the impact of credit unit price but also the public’s consciousness of fuel saving and environmental protection. The combined effect of fuel consumption saving on the R&D cooperation led by different powers, which meant that the government was aiming to encourage R&D cooperation, should consider different situations in the auto industry supply chain to formulate the dual-credit policy to adjust the supply and demand relationship of the dual-credit policy to affect the credit unit price, thus affecting the combined effect of fuel consumption saving, encouraging R&D cooperation in the auto industry supply chain, and realizing energy conservation and emission reduction.

1. Introduction

To effectively promote the high-quality development of China’s industry is a strategic move for China to deal with energy conservation and emission reduction and focus on a new round of industrial reform and competition in the transportation field. In the Decision on Accelerating the Cultivation and Development of Strategic Emerging Industries, which was issued by the State Council in October 2010, the new energy vehicles (NEV) industry represented by electric vehicles is clearly listed as a strategic emerging industry. The Energy Conservation and Development Plan for New Energy Vehicle Industry, which was issued in 2012, points out that it should promote the development of China’s electric vehicle industry in terms of technological innovation, industrial layout, and pilot projects. It requires all departments to actively formulate the standard systems and fiscal policies to promote the rapid development of all links of electric vehicles. Improving the market ownership of electric vehicles to drive the R&D level of Chinese automakers is the main logic of the subsequent policy formulation of core technologies. However, the advance results suggest China’s administrative guidance in the electric vehicle industry in recent years is not satisfactory [1]. In September 2016, the Ministry of Finance issued the Circular on the Disclosure of Local Budgets and Final Accounts and the Special Inspection of Subsidies for the Promotion and Application of New Energy Vehicles, which checked 90
automakers for their special funds for financial subsidy in 2013–2015. It found frauds in their behavior and failure to make a significant breakthrough to narrow the gap with Europe, America, and Japan in battery, electric control, and other core technology. To solve the above problems, the Concurrency Management for the Credit of Average Fuel Consumption and New Energy Vehicle of Automakers (hereinafter referred to as the dual-credit policy), which was issued by the Ministry of Finance on September 28, 2017, requires the automakers to calculate the credit of both corporate average fuel consumption (CAFC) and new energy vehicle (NEV), which must meet the standard. The automakers whose credit fails to meet the standard can carry forward or buy the credit, otherwise will be punished. The government is trying to use more flexible control means to increase the R&D efforts of Chinese automakers in the NEV industry and improve the energy conservation and emission reduction of the whole industry.

Compared with many foreign policies of car energy consumption, carbon emission, or new energy promotion, China’s dual-credit policy is similar to the CAFE (Corporate Average Fuel Economy) in the United States and the ZEV (Zero Emission Vehicle) in California, the United States. There have been many foreign studies on the influence of CAFC and ZEV, however, their effects are controversial. Cristello and Kim [2] believed that ZEV promotes manufacturers to conduct effective R&D and innovation of NEV from the aspects of vehicle quality, collision safety, and manufacturing economy. Sykes and Axsen [3] proposed that ZEV effectively prevents the free-rider behavior in inter-regional spillover effect, and they argued that only by earnestly implementing ZEV in the region can the energy conservation and environmental protection be effectively realized. Jun et al. [4] believed that CAFC promotes the development of fuel economy technology and stimulates consumers’ interest in energy conservation and environmental protection, which has a direct impact on fuel economy car sales. Sen et al. [5], by building a potential market share assessment model of electric vehicles, argued that CAFC can accelerate the penetration of electric vehicle market, help America reduce the consumption of traditional vehicles, and thus get rid of the dependence on fuel. However, other scholars disagreed on the implementation effect of CAFC and ZEV. Anderson and Salle [6] believed that manufacturers depart from the aim of CAFC, which is set by the U.S. to reduce fuel consumption. They are more than innovative, however, they pursue profit maximization, i.e., to exploit loopholes in regulations and increase flexible fuel vehicles to reduce costs. Wesseling et al. [7] believed that ZEV introduced in 1990 plays little role in promoting policies as it allows automakers to passively develop electric vehicles, which, however, do not actually enter the market. Only when the public and buyers increase demands for electric vehicles effectively, the automakers will take the initiative to innovate in electric vehicles. Demand-driven policies should be complementary to technology-driven policies. Wesseling [8] believed that the realization of NEV target is not related to the ZEV of various countries. Hammond et al. [9] believed that although ZEV is effective among single policies, it cannot realize the national greenhouse gas emission reduction target, which needs multiple policies.

The implementation of dual-credit policy draws Chinese scholars’ attention. Cheng and Mu [10] established a decentralized decision model of automakers based on shareholding ratio and internal option protocol and discussed the credit equilibrium value range under the three credit strategies and the production plan of different models. Zheng et al. [11], by building a three-stage model, studied the impact of credit price and market scale on R&D investment under the dual-credit policy. By constructing a three-stage model of the interaction between government and enterprises, Lu and Yan [12] studied and compared the optimal output, range research and development, CAFC score efficiency and social welfare under cooperation, and competition situations. Based on the system dynamics model, Zhou and Shen [13] studied the impact of the changes of CAFC and NEV ratios on the production capacity, output, and R&D investment of NEV. Zhang et al. [14] analyzed the optimal decision-making and optimal social welfare of various producers in the case of three market powers. Li and Xiong [15] divided the dual-credit policy into brewing period and implementation period and analyzed the dynamic change characteristics of the operating performance and environmental performance of NEV makers. Yu et al. [16] believed that the dual-credit policy enabled automakers to constantly improve the R&D level, increase the needs of NEV, and promote the development of NEV.

Compared with the existing research, this paper focuses on the R&D cooperation between manufacturers and upstream suppliers or downstream retailers in the auto industry supply chain under the dual-credit policy [17–20]. A lot of literature has discussed the R&D cooperation among manufactures. Earlier literature focuses on how to make strategic decisions among duopoly manufactures with different technical levels when a spillover effect exists [21]. The cooperation between such manufactures of the same industry is horizontal R&D cooperation, which is no better than vertical R&D cooperation [22–25]. Bidault et al. [26] proposed the early supplier involvement (ESI) in product development and regarded reducing costs, expanding market, and increasing sales as the main reasons for cooperation with suppliers. Kesavayuth and Zikos [27] studied the mutual influence between horizontal R&D networks formed by upstream and downstream enterprises in vertical related industries. Ge et al. [28] targeted cost reduction for R&D cooperation in the supply chain, which is realized through the spillover effect in the supply chain, and they compared the two modes of spillover and alliance to study the threshold condition for enterprises to choose the optimal model. Dai et al. [29] studied the green R&D investment cooperation mechanism of supply chain members with a technical difference. While considering the relationship of technology spillover and supply chain power, Chen et al. [30] evaluated the impact of green R&D cooperation on the economic, environmental, and social performance of the supply chain and proposed that there is a Pareto optimal area that has a positive effect on the upstream and downstream of
the supply chain. According to the literature of R&D cooperation and the powers perspective theory of the supply chain, this paper solves the following three problems: firstly, under the dual-credit policy, whether suppliers should be encouraged to cooperate with manufacturers to promote the energy conservation and emission reduction of the auto industry. Secondly, why do cooperation and noncooperation between suppliers and manufacturers coexist in the real auto industry supply chain? What kind of threshold conditions of credit policy impact and efficiency will promote the cooperation between suppliers and manufacturers? Third, do the different powers perspectives in the auto industry supply chain have an impact on the choice of R&D cooperation between suppliers and manufacturers?

2. Model Building

2.1. Basic Setting. This paper built a duopoly supply chain structure consisting of a supplier and a manufacturer. The supplier sold semifinished products directly to the manufacturer at wholesale price. The manufacturer sold finished products to the market at retail price. The semifinished and finished products had their alternative products available in their respective markets. Consumers who would buy the finished products must consider their retail price and energy conservation level.

Based on this, this paper made the following hypothesis:

(1) Suppose the fuel consumption saving level of the supplier (s) and the manufacturer (m) was $x_s$ and $x_m$; the fuel consumption saving level of the final product was $x = x_s + x_m$; the retail price of the final product was $p$; consumers’ sensitivity to the fuel consumption saving level of the final product was $d$ (hereinafter referred to as the fuel consumption sensitivity); the potential market demand for cars was $A$. The actual market demand was affected by the retail price of the product and the fuel consumption saving level, i.e., the higher the retail price, the lower the actual demand, the higher the fuel consumption saving level, and the more it will stimulate consumers and increase the actual demand. Referring to Dai et al. [29], we set the market demand function for cars as $q = A - p + d(x_s + x_m).

(2) The supplier and the manufacturer develop their respective new products to improve the fuel consumption saving level. Suppose their R&D cost was related to their fuel consumption saving level $x_i$ ($i = s, m$) and technology transformation capability. To simplify, this research sets the R&D cost coefficient of the supplier as 1 without affecting the analysis results. To show the manufacturer’s R&D cost comparison with the supplier, this research sets the R&D cost comparative efficiency coefficient of the manufacturer as $\rho$. Referring to the law of scale remuneration reduction and Li’s et al. [31] emission reduction cost function, the R&D cost of the supplier and the manufacturer was $x_i^2/2$ and $\rho x_m^2/2$, respectively. Suppose the supplier’s unit production cost was $c_s$, the supplier’s wholesale price was $w$, and the manufacturer’s unit production cost was $c_m$.

2.2. Dual-Credit Policy Setting. The dual-credit policy requires manufacturers to calculate the credit of both CAFC and NEV, and then determine the credit to be purchased (or transferable credit). In calculating CAFC credit, to simplify the regulation of the state that sets fuel consumption target value standards for different models in the specific dual-credit rules, suppose the actual fuel consumption level of different models was the same, just like Zheng et al. [11] proposed, and the negative difference from the target value stipulated by the state was the fuel consumption saving level (i.e., the fuel consumption saving level was negative if the actual value was greater than the target value and positive if the actual value was smaller than the target value), then the manufacturer’s CAFC credit was $\delta_1 q$.

In calculating NEV credit, to simplify the regulation of the state that sets conversion ratio for different NEV models in the specific dual-credit rules, assume that the conversion ratio of different NEV models was 1 and the manufacturer’s actual NEV output ratio was $\delta_2$. Then, the actual output was $\delta_1 q$. Suppose the dual-credit policy required that the manufacturer’s NEV output ratio was $\delta_2$, then the output was $\delta_1 q + \delta_2 q$. The difference between the actual NEV output ratio and the NEV output ratio required by the dual-credit policy was $\delta = \delta_1 - \delta_2$. Then, the manufacturer’s NEV credit was $\delta q$.

Suppose the credit unit price was $p_c$. The manufacturer’s income from the sale of credits was $p_c (x + \delta) q$ by summarizing the above dual-credits. The symbols and their meanings are shown in Table 1.

According to the above assumptions, the profit function of the supplier was as follows:

$$\pi_s = q(w - c_s) - \frac{1}{2} x_s^2.$$  (1)

The profit function of the manufacturer was as follows:

$$\pi_m = (p - w - c_m) q - \frac{1}{2} \rho x_m^2 + p_c (x + \delta) q$$

$$= [p - w - c_m + p_c (x + \delta)] [A - p + d(x_s + x_m)] - \frac{1}{2} \rho x_m^2.$$  (2)

The profit function of the supply chain was as follows:

$$\pi_w = \pi_s + \pi_m.$$  (3)

2.3. Classification of R&D Cooperation Mode of the Auto Industry Supply Chain. The R&D cooperation mode of the auto industry supply chain was classified into two categories, which are as follows: one was the competitive mode, namely the noncooperation mode between suppliers and manufacturers (hereinafter referred to as N mode), such as the mode between battery suppliers, e.g., Guoxuan High-tech Corporation, Lishen Battery and auto manufacturers,
2.3.1. Noncooperation Mode (N Mode). The N mode meant that the manufacturer and the supplier made their own fuel consumption saving R&D level decisions according to their profit functions to maximize their profits. It can be divided into three modes according to different Stackelberg game predominance: supplier-led N mode (SN), manufacturer-led N mode (MN), and vertical N mode (VN).

SN: it was divided into two stages. The first stage was that the supplier determined the wholesale price \( w \) of the final product, based on which the manufacturer determined the retail price \( p \) of the final product. The process was as follows:

\[
\begin{align*}
\max_{x_s} & \pi_s \longrightarrow \max_w \pi_w \longrightarrow \max_p \pi_p.\
\end{align*}
\]  

MN: it was divided into two stages. The first stage was that the manufacturer determined the retail price \( p \) of the final product, based on which the supplier determined the wholesale price \( w \) of the semifinished product. The process was as follows:

\[
\begin{align*}
\max_{x_s} & \pi_s \longrightarrow \max_p \pi_p \longrightarrow \max_w \pi_w.\
\end{align*}
\]  

VN: it was divided into two stages. The first stage was that the supplier and the manufacturer determined their respective fuel consumption saving R&D level according to their profit function to maximize their profit. The second stage was that the parties maximized their own profit according to their profit function, i.e., the supplier determined the wholesale price \( w \) of the semifinished product, and the manufacturer determined the retail price \( p \) of the final product, respectively. The process was as follows:

\[
\begin{align*}
\max_{x_s} & \pi_s \longrightarrow \max_w \pi_w \longrightarrow \max_p \pi_p.\
\end{align*}
\]  

The above three modes were multistage noncooperation games, which can be solved by backward induction. The optimal fuel consumption saving R&D level \( \{x_s, x_m\} \), the optimal wholesale price \( w \), and the optimal profit \( \{\pi_s, \pi_m\} \) of the supplier and the manufacturer after fuel consumption saving R&D investment were shown in Table 2.

2.3.2. Cartel Cooperation Mode (C Mode). The C mode meant that the supplier and the manufacturer jointly determined the fuel consumption saving level to maximize the profit of the supply chain. It can be divided into three modes according to different Stackelberg game predominance: supplier-led C mode (SC), manufacturer-led C mode (MC), and vertical C mode (VC).

SC: it was divided into two stages. The first stage was that the supplier and the manufacturer jointly determined the fuel consumption saving level to maximize the profit of the final product. The second stage was that the parties maximized their own profit in the manner of supplier-dominated Stackelberg game, i.e., the supplier determined the wholesale price \( w \) of the semifinished product, based on which the manufacturer determined the retail price \( p \) of the final product. The process was as follows:

\[
\begin{align*}
\max_{x_s} & \pi_s \longrightarrow \max_w \pi_w \longrightarrow \max_p \pi_p.\
\end{align*}
\]  

MC: it was divided into two stages. The first stage was that the supplier and the manufacturer jointly determined the fuel consumption saving level to maximize the profit of the supply chain. The second stage was that the parties maximized their own profit in the manner of manufacturer-dominated Stackelberg game, i.e., the manufacturer determined the retail price \( p \) of the final product, based on which the supplier determined the wholesale price \( w \) of the semifinished product. The process was as follows:

\[
\begin{align*}
\max_{x_s} & \pi_s \longrightarrow \max_p \pi_p \longrightarrow \max_w \pi_w.\
\end{align*}
\]  

The equilibrium result of MC was the same as that of SC.
Table 2: Table of equilibrium solutions of N mode and C mode.

<table>
<thead>
<tr>
<th>Mode</th>
<th>S mode</th>
<th>M mode</th>
<th>V mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>x_s</td>
<td>[2\rho (A + \delta p_m - c_m - c) (d + p_e)/M_1]</td>
<td>[2\rho (A + \delta p_m - c_m - c) (d + p_e)/M_1]</td>
<td>[2\rho (A + \delta p_m - c_m - c) (d + p_e)/M_1]</td>
</tr>
<tr>
<td>x_m</td>
<td>[(A + \delta p_e - c_m - c_e)(d + p_e)/M_1]</td>
<td>[(A + \delta p_e - c_m - c_e)(d + p_e)/M_1]</td>
<td>[(A + \delta p_e - c_m - c_e)(d + p_e)/M_1]</td>
</tr>
<tr>
<td>(\pi_s)</td>
<td>[2\rho^2 (A + \delta p_e - c_m - c_e)^2 (8\rho - k)/2M_1^2]</td>
<td>[2\rho^2 (A + \delta p_e - c_m - c_e)^2 (8\rho - k)/2M_1^2]</td>
<td>[2\rho^2 (A + \delta p_e - c_m - c_e)^2 (8\rho - k)/2M_1^2]</td>
</tr>
<tr>
<td>(\pi_m)</td>
<td>[\rho (A + \delta p_e - c_m - c_e)^3 (8\rho - 9k)/2M_1^2]</td>
<td>[\rho (A + \delta p_e - c_m - c_e)^3 (8\rho - 9k)/2M_1^2]</td>
<td>[\rho (A + \delta p_e - c_m - c_e)^3 (8\rho - 9k)/2M_1^2]</td>
</tr>
</tbody>
</table>

**VC**: It was divided into two stages. The first stage was that the supplier and the manufacturer jointly determined the fuel consumption saving level to maximize the profit of the supply chain. The second stage was that the parties maximized their own profit according to their profit function, i.e., the supplier determined the wholesale price \((w)\) of the semifinished product and the manufacturer determined the retail price \((p)\) of the final product, respectively. The process was as follows:

\[
\max_{x_s, x_m} \pi_s \quad \text{max}_{x_s, x_m} \pi_m
\]

The above three modes were multistage games, which can be solved by backward induction. The optimal value for each indicator at the profit equilibrium value between the supplier and the manufacturer was deduced, as shown in Table 2.

### 3. Model Analysis

For the three modes led by different powers, namely N mode, C mode, and V mode, their optimal fuel consumption saving R&D level, wholesale price, retail price, and profit equilibrium value among the supplier, the manufacturer, and the supply chain were deduced, which are shown in Table 2. Where \(M_1 = 8\rho - (2d\rho + 2d^2\rho + 2p_2^2\rho + d^2 + p_2^2 + 4d\rho)p; M_2 = 8\rho - (4d\rho + d^2\rho + p_2^2\rho + 2d^2 + 2p_2^2 + 2d\rho)\); \(M_3 = 9\rho - (4d\rho + 2d^2\rho + 2p_2^2\rho + 2d^2 + 2p_2^2 + 4d\rho)\); \(M_4 = 8\rho - (6d\rho + 3d^2\rho + 3p_2^2\rho + 3d^2 + 3p_2^2 + 6d\rho)\); \(M_5 = 9\rho - (8d\rho + 4d^2\rho + 4p_2^2\rho + 4d^2 + 4p_2^2 + 8d\rho)\). Referring to Dai et al. [29], suppose \(k = (d + p_2^2)/\rho\), which was referred to as the combined effect of fuel consumption saving. It indicated the combined effect of the public's consciousness of fuel saving and environmental protection in the consumer market and the credit price in the credit trading market under the dual-credit policy. If \(k\) was large, it meant that the credit trading price was high or the public had strong consciousness of fuel saving and environmental protection, or both. If \(k\) was small, it meant that the credit trading price was low or the public had weak consciousness of fuel saving and environmental protection. \(k\) played an important role in encouraging the fuel-saving R&D of manufacture in the auto industry supply chain.

To ensure that the profit of the supplier and the manufacturer was greater than 0 in the S mode and the M mode, \(\rho > 9k/8\) and \(k < 16/9\) must be met. Similarly, to ensure that the profit of the parties was greater than 0 in the V mode, \(\rho > 8k/9\) and \(k < 9/8\) must be met.

#### 3.1. Comparison between C Mode and N Mode

**Inference 1.** In the three modes led by different powers, \(x_s^c > x_s^m, x_m^c > x_m^m, x_e^c > x_e^m (i = S, M, V)\) were correct.

The inference showed that in the C mode, the supplier and the manufacturer were willing to make greater R&D investment, resulting in higher fuel consumption saving level, and thus, the highest fuel consumption saving level of the final product. It was in line with the views of existing literature, i.e., the R&D cooperation between the upstream and the downstream of the supply chain can promote the fuel consumption saving level of the parties and improve the overall fuel consumption saving level of the final product.

#### 3.2. Study on the Threshold Range of the R&D Cooperation between Both Sides in the Supply Chain under the Dual-Credit Policy
Theorem 1. In the S mode, if \((3k - 16)\sqrt{(9k - 16)(k - 4)} + 128 + 9k^2 - 68k/8(4 - k) < \rho < (16 - 3k) \sqrt{(9k - 16)(k - 4)} + 128 + 9k^2 - 68k/8(4 - k)\), then \(\pi_{sc} > \pi_{sn}\), where the supplier would choose to cooperate, and if \(\rho > (16 - 3k) \sqrt{81k^2 - 224k + 256 + 27k^2 - 128k + 256/16(16 - 5k)}\) or \(\rho < (3k - 16) \sqrt{81k^2 - 224k + 256 + 27k^2 - 128k + 256/16(16 - 5k)}\), then \(\pi_{sn} < \pi_{sc}\), where the manufacturer would choose to cooperate in its own interests. In addition to considering that the profit of cooperation must be greater than the profit of noncooperation, we also need to ensure that the profit of both parties is greater than 0. Therefore, \(\rho < (3k - 16) \sqrt{81k^2 - 224k + 256 + 27k^2 - 128k + 256/16(16 - 5k)}\), as shown in Figure 1.

Theorem 1 indicated that in the S mode, without considering the cooperation cost, whether the supplier and the manufacturer chose to cooperate depended on the relationship between \(\rho\) and \(k\). When \(\rho\) was lower than the corresponding threshold, which was related to \(k\), the supplier would obtain a higher profit in the C mode than in the N mode. Thus, it would choose to cooperate. When \(\rho\) was higher than a certain threshold, the manufacturer would obtain a higher profit in the C mode than in the N mode. Thus, it would choose to cooperate. The manufacturer and the supplier can find common cooperation areas in their respective cooperation areas for win-win cooperation and Pareto Optimum.

Theorem 2. In the M mode, if \(0 < k < 8/5\), \(\rho > 9/8k\), then \(\pi_{mc} > \pi_{mn}\). If \(8/5 < k < 16/9\), \(9/8k < \rho < -k[80k + (3k + 8)\sqrt{(16 - 9k)(8 - k)} - 9k - 64]/8(5k^2 - 48k + 64)\), then \(\pi_{mc} > \pi_{mn}\). Consequently, in the above two cases, the supplier would choose to cooperate. According to manufacturer’s view, if \(0 < k < 40 - 16\sqrt{2}/17\), the manufacturer would not obtain a higher profit in the C mode than in the N mode. Thus, it would not choose to cooperate. If \(40 - 16\sqrt{2}/17 < k < 16/9\), \(\rho > -(13k + 8)\sqrt{81k^2 - 80k + 64 + 304k - 27k^2 - 192)/16(17k^2 - 80k + 64)\), then \(\pi_{mc} > \pi_{mn}\), where the manufacturer would choose to cooperate. In the cooperation range between the parties, if \(0 < k < 40 - 16\sqrt{2}/17\), the supplier and the manufacturer would not choose to cooperate. If \(40 - 16\sqrt{2}/17 < k < 16/9\), \(\rho > -(13k + 8)\sqrt{81k^2 - 80k + 64 + 304k - 27k^2 - 192)/16(17k^2 - 80k + 64)\), then the supplier and the manufacturer would choose to cooperate, forming the phase I cooperation area. If \(8/5 < k < 16/9\), \(-k[80k + (3k + 8)\sqrt{(16 - 9k)(8 - k)} - 9k - 64]/8(5k^2 - 48k + 64)\), then the supplier and the manufacturer would choose to cooperate, forming the phase II cooperation area, as shown in Figure 2.

Theorem 2 indicated that in the M mode, without considering the cooperation cost, whether the supplier and the manufacturer chose to cooperate depended on the relationship between \(\rho\) and \(k\). When \(k\) was different, the threshold for the supplier to choose cooperation was different. As described above, under the limiting condition of \(\rho > 9k/8\) and \(k < 16/9\), when \(k\) was low, namely \(0 < k < 8/5\), \(\rho\) was greater than the limiting condition. Thus, the supplier would choose to cooperate. When \(k\) was high, namely \(8/5 < k < 16/9\), \(\rho\) was smaller than the limiting condition. Thus, the supplier would not choose to cooperate. When \(k\) was low, namely \(0 < k < 40 - 16\sqrt{2}/17\), the manufacturer would not obtain a higher profit in the C mode than in the N mode. Thus, it would not choose to cooperate. When \(k\) was high, \(\rho\) was higher than a certain threshold, and the manufacturer would obtain a higher profit in the C mode than in
the N mode. Thus, it would choose to cooperate. The manufacturer and the supplier can find common cooperation areas in their respective cooperation areas for win-win cooperation and Pareto optimum.

**Theorem 3.** In the V mode, if \( 8/9k < \rho < 1 + \sqrt{(2k - 9)(8k - 9)/9 - 2k} \), then \( \pi_x^{VC} > \pi_x^{VN} \), where the supplier would choose to cooperate. If \( \rho > \max\{4k + 9 + \sqrt{64k^2 - 72k + 81/12(3 - k)}, 8/9k\} \), then \( \pi_m^{VC} > \pi_m^{VN} \). The manufacturer would choose to cooperate. It was given that the prerequisite for cooperation between the supplier and the manufacturer was that their profit was greater than 0. Then, \( 0 < k < 9/8, \text{ and } \max\{4k + 9 + \sqrt{64k^2 - 72k + 81/12(3 - k)}, 8/9k\} < \rho < 1 + \sqrt{(2k - 9)(8k - 9)/9 - 2k} \), where the supplier and the manufacturer would choose to cooperate, as shown in Figure 3.

Theorem 3 indicated that in the V mode, without considering the cooperation cost, whether the supplier and the manufacturer chose to cooperate depended on the relationship between \( \rho \) and \( k \). When \( \rho \) was lower than a certain threshold, the supplier would obtain a higher profit in the C mode than in the N mode. Thus, it would choose to cooperate. When \( \rho \) was higher than a certain threshold, the manufacturer would obtain a higher profit in the C mode than in the N mode. Thus, it would choose to cooperate. The manufacturer and the supplier can find common cooperation areas in their respective cooperation areas for win-win cooperation and Pareto optimum.

### 4. Research Conclusion and Policy Inspiration

**4.1. Research Conclusion.** According to the powers perspective theory of the supply chain, this paper built an R&D cooperation model between the supplier and the manufacturer in the auto industry under the dual-credit policy and analyzed the impact of dual-credit policy on the R&D cooperation between the supplier and the manufacturer. The results showed that the in the C mode, the supplier and the manufacturer were willing to make greater R&D investment, resulting in a higher fuel consumption saving level, and thus, the highest fuel consumption saving level of the final product. For the healthy development of the auto industry supply chain and the whole industry, R&D cooperation between upstream suppliers and downstream retailers in the auto industry supply chain is encouraged. However, cooperation and noncooperation between suppliers and manufactures coexist in the real auto industry supply chain. Why do some manufacturers choose to cooperate and some manufacturers give up the cooperation? This paper discussed the threshold conditions for R&D cooperation between the upstream and the downstream of the supply chain in the three modes led by different powers under the dual-credit policy and found whether the supplier and the manufacturer chose to cooperate depended on the relationship between \( \rho \) and \( k \).

The threshold for the cooperation between the supplier and the manufacturer in the three modes led by different powers under the dual-credit policy was different.

1. In the S mode, when \( k \) was close to 0, the range of acceptable \( \rho \) for the cooperation between the supplier and the manufacturer became narrow, indicating the small possibility of cooperation. When \( k \) was close to 1.2, the range of acceptable \( \rho \) for the cooperation became the biggest, indicating the greatest possibility of cooperation. When \( \rho \) was small, the parts still chose to cooperate, suggesting the biggest effect of \( k \) to stimulate the cooperation. When \( k \) was greater than 1.2, the range of acceptable \( \rho \) for cooperation became narrow, indicating the small possibility of cooperation. When \( \rho \) was around 2, the possibility of cooperation was great, regardless of \( k \).

2. In the M mode, when \( k \) was smaller than 40 – 16\( \sqrt{2}/17 \), the incentive was not strong. Hence, the parties would not choose to cooperate in their own interests. With the increase of \( k \), the areas of cooperation between the parties became bigger. When \( k \) was close to 1.6, the range of acceptable \( \rho \) for cooperation between the parties became the biggest, and then it became smaller. When \( \rho \) was around 5, the possibility of cooperation was great, regardless of \( k \).

3. In the V mode, the supplier and the manufacture realized the promotion effect of cooperation on R&D level. When \( k \) was smaller than the critical value (about 1.1), the possibility of cooperation was great regardless of \( k \). However, when compared with the S mode and the M mode, this mode required a higher R&D level of the supplier and the manufacturer, and only when \( \rho \) was between 0.5 and 2 can the parties realize cooperation.

According to the three modes, further conclusions can be as follows:

1. It has a common conclusion about \( k \), reflected comprehensively by the fuel consumption market. \( k \) represents the comprehensive influence of the public awareness of fuel saving and environmental protection (\( d \)) in the consumer market and the point price (\( p_c \)) in the point trading market under the double-point policy. The effects are similar in the research level of fuel saving. When the public awareness of fuel saving and environmental protection is low, it can change the supply and demand relationship in the integral market through strict integral conditions as increasing the unit price to realize the comprehensive influence degree of \( k \). Only when \( k < 16/9 \), the cooperation will be possible, which means \( k \) should not be too high. If \( k \) is too high, the supplier and manufacturer can get enough profit even without cooperation. As a result, when the public awareness of fuel saving and environmental protection is high, it can lower the point price to promote the cooperation between the supplier and manufacturer.

2. In the three modes, we find that when \( k \) is not high, which means the pressure of fuel consumption is not
very great, if the comparative production efficiency of the supplier and manufacturer is equal, then the possibility of establishing cooperation in VC modes is still relatively greater. For example, Panasonic got the core technology of solar battery from Sanyo in 2009. Then, it cooperated with Tesla in 2010. The manufacturer and CATL signed the strategic cooperation contract in 2020 September.

In the new energy vehicle industry, BYD has formed a complete industrial chain through vertical integration. Suppliers have weak bargaining power, which basically meets the power perspective dominated by manufacturers. When $k$ is weak ($0 < k < 40 - 16\sqrt{2}/17$) and fuel economy pressure is not high, it is difficult to form R&D cooperation between the supplier and manufacturer. Only when the production efficiency of the manufacturer is relatively low and $\rho$ is higher than a certain threshold will the manufacturer have the motivation to do cooperation.

However, for some emerging new energy vehicle enterprises, they choose to save costs by OEM or most parts procurement. Suppliers take the leading position basically in line with the power perspective of the supplier. When $k$ is low, the area of cooperation is small, and most of them adopt independent research and development behavior, which makes it difficult to achieve Pareto optimization. For example, Xpeng G3 purchased the parts from four different battery suppliers, and Weltmeister Motor purchased from 5 different battery suppliers. Only when $k$ reaches close to 1.2, the pressure of fuel saving on the supplier and manufacturer is high, and the cooperation is in the greatest possibility.

4.2. Policy Inspiration. This paper has the following policy inspiration: (1) in the C mode, the supplier and the manufacturer were willing to make greater R&D investment, resulting in a higher fuel consumption saving level, and thus, the highest fuel consumption saving level of the final product, and the government should encourage R&D cooperation between the upstream and the downstream in the auto industry supply chain. (2) The influence on the R&D cooperation between the supplier and the manufacturer was the combined effect of fuel consumption saving formed by the credit unit price and the public consciousness of fuel saving and environmental protection. The government’s intention to formulate a dual-credit policy to guide the R&D cooperation behavior in the auto industry supply chain should consider not only the impact of credit unit price but also the public consciousness of fuel saving and environmental protection. (3) The combined effect of fuel consumption saving on R&D cooperation in the three modes led by different powers was different. It meant that the government aimed to encourage R&D cooperation, and it should consider different situations in the auto industry supply chain to formulate the dual-credit policy to adjust the supply and demand relationship of the dual-credit policy to affect the credit unit price. In turn, it affects the combined effect of fuel consumption saving, encouraging R&D cooperation in the auto industry supply chain and realizing energy conservation and emission reduction.

Data Availability
The data used to support the findings of this study are within the article.

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

References


