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Development Strategy of New Energy Business for Traditional Car Manufacturers under the Dual-Credit Policy

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Abstract

With the track of new energy vehicles continuously booming and accelerating, more and more automobile manufacturers are seeking effective methods to help companies stand out. Some of them attempt to split the new energy vehicle (NEV) business module in order to boost brand competitiveness for the top spot in an increasingly competitive market. The dual-credit policy, however, makes Chinese automakers consider whether the benefits of adopting the splitting strategy exceed the drawbacks, yet few domestic studies can offer assistance. As a result, the study develops split strategy and integrative development strategy's optimal decision models under the dual-credit policy. The paper also addresses which scenario the Integrative development approach or the splitting strategy is more advantageous and effective under using model comparison and numerical analysis. According to the study, manufacturers of fuel vehicles frequently reduce their output and raise their prices in response to the dual-credit policy. The credit price should receive significant attention from both traditional car manufacturers and NEV manufacturers due to its profound impact on both. Whether traditional car manufacturers should split the NEV business module independently depends on the pricing of NEV credits as well as the supply and demand for NEV credits. Traditional car manufacturers can only use a splitting strategy when the price of NEV credits is within a particular range and the NEV credit is surplus.

Keywords

Dual-Credit Policy, Credit Price, New Energy Business, Splitting Strategy, Traditional Car Manufacturers

1. Introduction

Since 2010, one of the primary strategies to encourage the technological and commercial advancement of alternative energy vehicles has been the "subsidy strategy" of tax exemptions and government subsidies. The problem of environmental protection is becoming more and more serious in China, the country with the largest automobile market, as the number of vehicles sold rises year after year. In the case of the subsidy policy of "expenses" which continually results in issues, the new policy has replaced the direct subsidies. The Ministry of Industry and Information Technology put into place the "Measures for Passenger Cars Corporate Average Fuel Consumption and New Energy Vehicle Credit Regulation" (dual-credit policy), combining the actual situation in our nation with the Zero Emission Vehicle Mandate (ZEVM) of the United States and the European Union Emission Trading Scheme (EUETS). The ability of manufacturers of new energy vehicles to conduct research and development (R & D) more effectively will improve. It will also force the creation of crucial NEV technology and lessen business reliance on the government. The Corporate Average Fuel Consumption Credits (CAFC credit) and the New Energy Vehicle Credits (NEV credit) make up the "dual-credit" policy's two main components. NEV credits are only given to NEV manufacturers under the dual-credit program. Each accounting year, it is necessary to review and compute the CAFC credits and NEV credits individually. Positive credits will start to appear as soon as the corporate average fuel usage falls below the actual value or the actual value of NEV credits exceeds the target value. On the other hand, the NEV credits must be purchased or transferred in order to counter the negative credits. The development and production plan for new energy vehicles is greatly hampered by this. The global automobile industry is currently dealing with a fresh round of technological and scientific advancements as well as a rapidly accelerating industrial transition. The trend in the automotive industry has changed to one that is electric, networked, and intelligent as the technology integration of cars, energy, communication, and other industries accelerate. The opening of the traditional car manufacturers is accelerating as a result of the new energy track's highlight. The current car manufacturing pattern, built around the new energy vehicle industry chain, has undergone a substantial transformation from the previous traditional auto industry. Some auto businesses attempt to divide their core business and gain more market backing through the capital market in order to pursue better development and growth. Now, all are paying attention to this occurrence. Therefore, in addition to the dual-credit strategy, traditional automakers must take into account the following: 1) How does the dual-credit policy affect traditional automakers' ability to produce new energy vehicles? 2) Can the production of new energy vehicles be divided across all traditional automakers to increase economic benefits? 3) Do the financial advantages vary depending on the circumstance? And what selection is the best one?

First, this paper will examine some of the typical problems that automakers deal with when deciding how to produce a product under the dual-credit policy, like manufacturing and price. In reaction to the dual-credit policy, numerous scholars have concentrated on production strategies. In order to maximize the decision-making of the automotive supply chain, Lu et al. (2021) analyzed a two-level supply chain made up of two auto manufacturers and one auto dealership. They did this by taking into account variables like the cost, pollution reduction, and range of their vehicles. The results indicated that rising consumer awareness of low-carbon choices and rising anxiety over the variety of vehicles might increase automobile sales prices and boost manufacturer and dealer profitability. The proliferation of new energy vehicles is inhibited by demand-side consumer anxiety related to range and charging pile coverage tissues, according to research by Tang et al. (2020) into the decision optimization driven by both supply and demand sides in the manufacturing of automobile companies. They found that the higher the NEV credit ratio requirement, the more favorable the proliferation of new energy vehicles. Cheng and Mu (2018) solved a planning model with limited trading according to three credit strategies: credit deficiency, credit surplus, and credit balance. The results showed that automakers can manage production plan perturbation and switch credit strategies through a price response mechanism. The optimal output of loss-averse producers would be decreased under the emergency production strategy, but the maximum expected utility would increase, according to Chunye Zhang and Xiang Zhang's (2015) analysis of the optimal production strategies of new energy vehicles manufacturers under emergency production and loss aversion scenarios.

Huang et al. (2014) consider the pricing and production strategy of a dual-channel supply chain under simultaneous demand and cost perturbations and show that the initial production plan is somewhat robust due to the interaction of demand perturbation effects and production cost perturbation effects. The optimal wholesale pricing decisions of manufacturers with higher unit production costs were more effectively influenced by the subsidy cap than they were by the discount rate, according to a study by Luo et al. (2014) that examines the optimal production and pricing decisions of an automotive supply chain under a government price discount incentive scheme. The impact of the dual-credit policy on traditional vehicle manufacturers' production and financial performance would be adverse, while the impact on new energy vehicle manufacturers' production, financial performance, and social welfare was unclear (Zhang et al., 2020). Therefore, traditional cars must consider the electrification transition and continue to investigate and develop new energy industries if they are to survive and flourish. These researchers have thought about the best production plans for automakers in terms of many variables and scenarios, which can be helpful to automakers. However, with the dual credit policy is more and more accepted in China, traditional automakers have developed some fresh approaches to deal with it. Geely Automobile decided to upgrade Geely New Energy to a major independent brand in 2019 after holding a conference on organizational restructuring. This move not only saves a significant amount of R & D costs by converting traditional fuel vehicles (FV) to new energy vehicles, but also lowers marketing and promotion costs by utilizing the existing fuel vehicle sales channels. By taking advantage of the current fuel vehicle sales channels, marketing and promotion expenses will be decreased. The domestic new energy car sector now has a new way of thinking as a result of this significant change in Geely's new energy business development strategy. In an effort to strengthen their companies, look for new growth opportunities, and find additional financial support in this competitive new energy race, SAIC, BYD, and Great Wall Motors have since started to aggressively plan for the division of their associated industries into independent operations. From an industry standpoint, this strategy is in fact helpful for accelerating market expansion. It is also anticipated to increase the parent company's entire market valuation, making it deserving of further strategic study.

Second, it can be anticipated that the credit price, which is characterized by high volatility and complex fluctuation rules, will play a larger role in the production strategy of automakers as the dual-credit policy is tightened further and the target fuel consumption of fuel vehicles is reduced year after year (Yang et al., 2017). From the perspective of traditional car manufacturers, Chai et al. (2022) constructed the optimal decision model for traditional energy vehicle enterprises under the purchase, association, and production strategies, respectively, and the results showed that the implementation of the dual-credit policy will reduce the production of traditional energy vehicles and the profits of traditional car manufacturers. Therefore, traditional manufacturers should be aware of the credit price and the new energy vehicle credit ratio requirement and select various tactics in response to varying credit prices. When the vertical R & D spillover rate surpasses the threshold, companies' R & D investment will decline without taking R & D subsidies into account as the price of positive credit rises (Zheng et al., 2019). In their analysis of the cooperative innovation game between upstream and downstream corporations of new energy vehicles, Li Wenying and Dai Liangping (2021) discovered that only a credit trading price that is high enough can effectively encourage upstream and downstream businesses to collaborate and innovate. Sun et al. (2020) studied the effects of credit price, product substitution rate, and production efficiency gap on manufacturers' R & D strategies, and showed that more R & D efforts would be invested in the product R & D cooperation model when the credit price was higher, and the change in manufacturers' output under both strategies was closely related to the credit price. These studies indicate a direct connection between the point price and firms' R & D spending, therefore it is important to take this relationship into account when analyzing how the credit price affects production plans. Tang et al. (2021) studied credit prices, consumer preferences, and credit approach adjustments to examine the best production and pricing strategies of manufacturers and merchants. They discovered that fluctuations in loan prices had an impact on the market size for new energy cars as well as the revenue generated by the automotive supply chain. In a cross-chain cooperation scenario, Li et al. (2020) investigated the best manufacturing strategy for new energy vehicles and discovered ideal pricing for new energy points to maximize the profitability of the entire supply chain system under the dual-credit policy. This offers some recommendations for the quantitative investigation of credit prices. As the dual-credit policy evolves and the credit market improves, the role of credit price becomes more prominent and an unavoidable factor to consider. All of these studies have taken credit costs into account, but they are primarily qualitative analyses from the standpoint of traditional car manufacturers. The price of credits will be considered as a key factor in this paper, and the impact of this key factor on traditional car manufacturers' decisions to split their new energy business into separate operations will be examined quantitatively and comprehensively.

As a response to the phenomenon of some vehicle enterprises splitting new energy business to operate independently under the dual-credit policy, this paper will study the credit strategies of vehicle enterprises under different scenarios to obtain the optimal credit strategies of each vehicle enterprise under different scenarios. This is in contrast to the current research, which primarily focuses on subsidy policy and production optimization in the new energy vehicle industry. In order to provide the best option for vehicle manufacturers to deal with the dual-credit policy and direct their best decision-making, the paper compares the optimal profit function of the model under various strategies to investigate whether traditional vehicle enterprises should split their new energy business or not under various scenarios. This paper will also conduct a combined optimization study of production and credit strategies in cross-supply chain scenarios, in contrast to other literature that focuses on a single new energy vehicle supply chain, in order to provide decision support for whether traditional vehicle enterprises choose to split new energy business under various scenarios.

2. Model Background

This paper analyses a traditional car manufacturer that initially focuses primarily on producing traditional fuel vehicles before fervently developing new energy vehicles. Both traditional fuel vehicles and new energy vehicles are currently produced and sold by the company. The government has gradually implemented the dual-credit policy and strongly promoted the development of new energy vehicles in an effort to lower carbon emissions and attain carbon neutrality. The average fuel consumption of the fuel-powered vehicles made by the traditional car manufacturer is believed to be: ω_t. The difference between real fuel consumption and the government-set standard fuel consumption is ω_0. The actual value of the average fuel consumption specified by the government is ω ($\omega = \omega_t - \omega_0$). The market price of new energy credits is p_d ($p_d \geq 0$). Under the dual-credit policy, the proportion requirements for NEV credit are as follows: α ($0 \leq \alpha \leq 1$). q_i and p_i are the quantity and price of car sales, respectively. Where $i = 1$ represents new energy vehicles and $i = 2$ represents traditional fuel vehicles. Π represents the profits of car manufacturers in various situations, including Π, Π^{CP}, Π^{SP}, which represents the profit under the benchmark model, the integrative development strategy model, and the splitting strategy model. The cost of production for different models is $c_i \left(i = 1, 2\right)$. Therefore, under the current dual-credit policy, the CAFC credit of the manufacturers is: $-\omega q_2$, and the NEV credit is: $\lambda q_1 - \alpha q_2$, where αq_2 is the government's standard value of NEV credit. When faced with negative credit, car manufacturers can only buy from the external market at this time.

Given that new energy vehicles are the auto industry's future orientation and have attracted special attention from investors and the government, many manufacturers have divided their new energy businesses and operate independent operations. We assume that the split subsidiaries have some autonomy and that they are able to decide for themselves how to use the NEV credit transaction for their own growth. Additionally, it is believed that as production costs rise, consumer demand for products declines. This article also implies that the two types of vehicle markets are mostly independent due to the model's processability and the differences between fuel and new energy cars in many current characteristics, including mileage, vehicle purchase cost, and regulatory variables. As a result, following the division, only traditional fuel vehicles are produced by the parent company, while all new energy vehicles are produced by the subsidiary. At this time, the market demand for new energy vehicles and fuel vehicles is $q_1 = \gamma a - b_1 p_1$, $q_2 = \left(1-\gamma\right) a - b_2 p_2$. And $\gamma \left(\gamma > 0\right)$ represents the proportion of new energy vehicles in the market. $a \left(0 \le a \le 1\right)$ represents the potential car market size, $\left(1-\gamma\right)$ is the proportion of the traditional car market in the total market. b_1 and b_2 ($b_1, b_2 > 0$) respectively represent the price sensitivity coefficients of consumers for new energy vehicles and fuel vehicles.

The parent business that produces traditional fuel vehicles may purchase NEV credits from the subsidiary that produces new energy vehicles at the internally agreed-upon price or may purchase NEV credits from the market to offset the negative credits under the dual-credit policy. At this time, it can be divided into three scenarios based on the capacity of subsidiaries: 1) credit surplus; 2) credit deficiency; and 3) credit balance. The three scenarios are analyzed by developing decision models. Figure 1 depicts the differences in development models.

3. Model Construction

3.1. Benchmark Model

To investigate the impact of the dual-credit policy on traditional car manufacturers' production and development strategies, the study first builds a benchmark model of traditional car manufacturers without the dual-credit policy. In this benchmark model, the profit of traditional car manufactures comes from selling self-made traditional fuel vehicles. The demand for fuel vehicles is $q_2 = \left(1-\gamma\right) a - b_2 p_2$. The selling price of traditional fuel vehicles is $p_2 \le \dfrac{\left(1-\gamma\right) a}{b_2}$

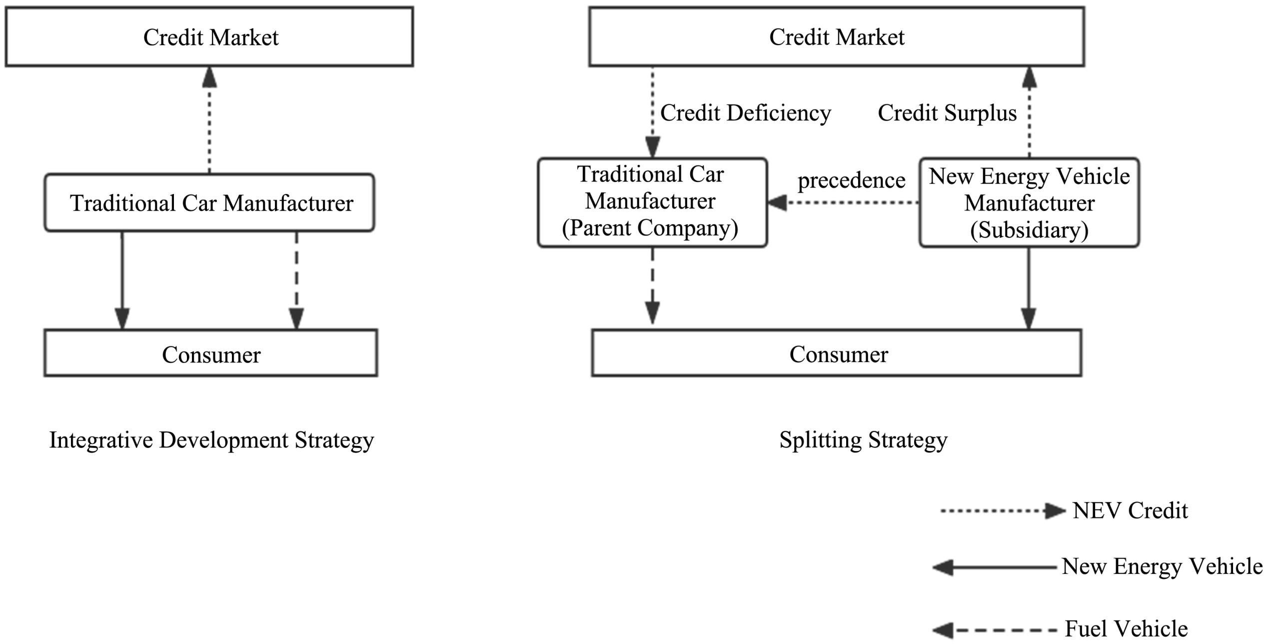


Figure 1. Model structure of different development strategies under the dual-credit policy.

to ensure the $q_2 > 0$, and production cost is c_2. The profit function of traditional car manufacturers is as follows:

$$\text{Max } \Pi = (p_2 - c_2)q_2 c_2)q_2 \tag{1}$$

By optimization algorithm on function (1), the following conclusion can be drawn. The optimal production decision for a conventional vehicle company under the benchmark model is $p_2^* = \frac{b_2c_2 + (1-\gamma)a}{2b_2}$, $q_2^* = \frac{(1-\gamma)a - b_2c_2}{2}$, and now the maximum profit is $\Pi^* = \frac{\left(b_2c_2 + (1-\gamma)a\right)^2}{4b_2}$.

In order to ensure that the traditional car manufacturers reach the optimal production $q_2^* \geq 0$, it is necessary to assume that $c_2 \leq \frac{(1-\gamma)a}{b_2}$. At this point, the optimal sales price of fuel cars needs to satisfy $p_2^* \leq \frac{(1-\gamma)a}{b_2}$, so as to ensure the non-negativity of the optimal decision of traditional car manufactures under non-dual-credit policy.

3.2. Integrative Development Strategy

After the dual-credit policy is in place, traditional car manufacturers can obtain NEV credits by growing their new energy business and creating new energy vehicles, with the result that their investment in R & D is represented by the variable *k*, which is correlated to *R*, which stands for the endurance mileage of new energy vehicles. According to the policy, λ is positively correlated to ($\lambda = 0.012R + 0.8$), where λ stands for NEV bonus credit and $\lambda \leq 5$. The amount of NEV credits owned by the company is λq_1, demonstrating a positive correlation between k and λ. The analysis makes the assumption that $k = \lambda^2/(2t)$, which implies the decreasing influence of expanding R & D expenditure on NEV credits, in accordance with the investigation of relevant papers (Sun et al., 2020; Wei et al., 2015; Lou et al., 2020). And t is a symbol for research and development efficiency; the higher the value, the better the efficiency. If α is the percentage of up to standard NEV credits, then αq_2 is the NEV negative credit that manufacturers must compensate for creating traditional fuel cars. Assuming that the D-value between the actual fuel consumption of company-produced fuel vehicles and the government-specified standard fuel consumption is ω, the average fuel consumption of enterprises is ωq_2. In this case, traditional car manufacturers must use previously carried forward positive CAFC credit or NEV credit to offset. Because the study only considers the selection of a single-cycle strategy without considering the credit carry-over from year to year, the total credit that the company must compensate for is $(\omega+\alpha)q_2$. NEV credits obtained from car manufacturers' production are first used to offset negative CAFC credits. The remaining NEV credits are then sold to the market at the price of p_d. Given that companies have invested heavily in R & D in new energy vehicles to maximize profits, the study assumes that companies will no longer incur additional costs by purchasing NEV credit as an offset. So, under the current strategy, traditional car manufacturers can generate NEV credit to compensate for negative CAFC credit (Chai et al., 2022). The output of new energy vehicle companies is $q_1^{CP} = \gamma a - b_1 p_1^{CP}$, where c_1 represents the cost of production of new energy vehicles and k represents R & D costs. The output of fuel vehicles is $q_2^{CP} = (1-\gamma)a - b_2 p_2^{CP}$, where c_2 represents the cost of production of fuel vehicles. The superscript CP indicates the integrative development model. The profit function of traditional car manufactures is as follows:

$$\text{Max } \pi^{CP} = \left(p_2^{CP} - c_2\right)q_2^{CP} + \left(p_1^{CP} - c_1\right)q_1^{CP} + p_d\left(\lambda q_1^{CP} - (\omega+\alpha)q_2\right) - \frac{\lambda^2}{2t} \tag{2}$$

$\left(p_2^{CP} - c_2\right)q_2^{CP}$ and $\left(p_1^{CP} - c_1\right)q_1^{CP}$ separately shows the profit of new energy vehicles and traditional fuel vehicles. $p_d\left(\lambda q_1^{CP} - (\omega+\alpha)q_2\right)$ indicates the profit from the sale of excess NEV credits. The last one represents the R & D cost for the production of new energy vehicles.

By solving function (2), the optimal production strategy is as follows:

$p_1^{CP*} = \dfrac{b_1 c_1 + \gamma a - b_1 p_d \lambda}{2b_1}$, $q_1^{CP*} = \dfrac{\gamma a - b_1 c_1 + b_1 p_d \lambda}{2}$,

$p_2^{CP*} = \dfrac{(1-\gamma)a + b_2\left(c_2 + p_d(\omega+\alpha)\right)}{2b_2}$ and $q_2^{CP*} = \dfrac{(1-\gamma)a - b_2\left(c_2 + p_d(\omega+\alpha)\right)}{2}$.

Let p_1^{CP*}, q_1^{CP*}, p_2^{CP*} and q_2^{CP*} be substituted into function (2). We can obtain the maximum profit from traditional car manufacturers as follows:

$$\pi^{CP*} = \frac{b_2\left(n + b_1 p_d \lambda\right)^2 + b_1\left(m - b_2 p_d r\right)^2}{4b_1 b_2} - \frac{\lambda^2}{2t},$$

where $m=(1-\gamma)a-b_2c_2$, $n=\gamma a-b_1c_1$ *and* $r=\omega+\alpha$.

By taking the partial derivative of p_1^{CP*}, q_1^{CP*}, p_2^{CP*} and q_2^{CP*} on p_d, we can draw conclusions that $\frac{\partial p_1^{CP*}}{\partial p_d}<0$, $\frac{\partial q_1^{CP*}}{\partial p_d}>0$, $\frac{\partial p_2^{CP*}}{\partial p_d}>0$ *and* $\frac{\partial q_2^{CP*}}{\partial p_d}<0$. The result prove that p_d has influence on p_1, p_2, q_1 and q_2. Specifically, as the market price of NEV credits rises, the price of NEV falls and the price of FV rises. Meanwhile, in this situation, traditional car manufacturers will produce more NEV and less FV. When the integrative development strategy is compared to the benchmark model, the following property is obtained:

Property 1. The dual-credit policy, influenced by credit trading, raises the selling price of traditional fuel vehicles by $\frac{b_2p_d(\omega+\alpha)}{2b_2}$ while decreasing production by $\frac{b_2p_d(\omega+\alpha)}{2}$. Meanwhile, car manufacturers can gain a share of the market for new energy vehicles with a selling price of p_1^{CP*} and a production volume of q_1^{CP*}.

3.3. Splitting Strategy

We are now considering traditional car manufacturers splitting the NEV business module for an independent operation, which means that the traditional car manufacturers and the new NEV company will become parent and subsidiary companies, such as Geely, GWM, SAIC, GAC and other car manufacturers. In this case, the parent FV company will receive revenue from the NEV subsidiary and will bear the risk based on the proportion of share. However, the parent company will not be involved in the decision-making process of the subsidiaries. For internal transactions, the parent company and the subsidiary can negotiate the price of NEV credit (represented by p_c). The study assumes that the sharing holding ratio is ϕ, and according to the "Several Provisions on the Pilot Domestic Listing of Subsidiaries of Listed Companies", it is known that the net assets of the proposed spin-off subsidiary cannot exceed 30% of the net assets attributable to shareholders of the listed company, so we can know the $0<\phi\le 0.3$. The new energy credits λq_1 obtained from the production of the subsidiary's new energy vehicle manufacturers will be sold to the parent company's traditional vehicle manufacturers in priority at an internally negotiated price p_c to offset the negative credits, where $p_c<p_d$, i.e., the internally negotiated price is lower than the market price.

The new energy credits produced by the subsidiary company need to satisfy the needs of the parent company's traditional car company at an internally negotiated price p_c first, and if there are still credits left after satisfying the parent company's NEV credits demand, which is $(\omega+\alpha)q_2$, the new energy car company can profitably sell the excess NEV credits to the market through the market price p_d. Thus, depending on the number of new energy credits produced by the subsidiary, there are three scenarios under this strategy that need to be specifically analysed: 1) Surplus credits that the subsidiary has surplus credits. 2) Deficiency credits that the subsidiary is unable to meet the demand of the parent company for NEV credits. 3) Balanced credits that the subsidiary has just credited that the parent company needs. $p_{ij}^{SP}, q_{ij}^{SP}, \pi_{ij}^{SP}$ separately represents the selling price of new energy vehicles and fuel vehicles, the output and the profit of two companies, which $i = 1, 2$ indicates NEV subsidiary company and FV parent vehicles and $j = 1, 2, 3$ respectively corresponding to the above three situations. The superscript *SP* is on behalf of the splitting strategy. With this strategy, $q_{1j}^{SP} = \gamma a - b_1 p_{1j}^{SP}$ and $q_{2j}^{SP} = (1-\gamma) a - b_2 p_{2j}^{SP}$. Under this strategy, the demand for new energy vehicles produced by the subsidiary is $q_{1j}^{SP} = \gamma a - b_1 p_{1j}^{SP}$, the production cost is c_1 and the R & D investment is *k*. The parent company produces a number of fuel vehicles is $q_{2j}^{SP} = (1-\gamma) a - b_2 p_{2j}^{SP}$, with production costs of c_2. The profit functions of the parent company by producing fuel vehicles and the subsidiary by producing new energy vehicles are as follows.

$$\begin{aligned} \text{Max } \Pi_1^{SP} &= \left(p_1^{SP} - c_1\right) q_1^{SP} + p_c \operatorname{Min}\left\{(\omega+\alpha) q_2^{SP}, \lambda q_1^{SP}\right\} \\ &\quad + p_d [\lambda q_1^{SP} - (\omega+\alpha) q_2^{SP}]^+ - \lambda^2/(2t) \\ \text{Max } \Pi_2^{SP} &= \left(p_2^{SP} - c_2\right) q_2^{SP} - p_c \operatorname{Min}\left\{(\omega+\alpha) q_2^{SP}, \lambda q_1^{SP}\right\} \\ &\quad - p_d \left[\lambda q_1^{SP} - (\omega+\alpha) q_2^{SP}\right]^+ + \Phi \Pi_1^{SP} \end{aligned} \tag{3}$$

Next, we conduct specific analysis on three situations under the splitting strategy with considering the output of the subsidiary.

1) Credits surplus

In this situation, the subsidiary has excessive credits so that it can sell the rest of the NEV credits to the market after providing them to the parent company to compensate for negative CAFC and NEV credits. At this time, the simplified model is as follows.

$$\begin{aligned} \text{Max } \Pi_{11}^{SP} &= \left(p_{11}^{SP} - c_1\right) q_{11}^{SP} + p_c (\omega+\alpha) q_{21}^{SP} \\ &\quad + p_d \left[\lambda q_1^{SP} - (\omega+\alpha) q_2^{SP}\right] - \lambda^2/(2t) \\ \text{Max } \Pi_{21}^{SP} &= \left(p_{21}^{SP} - c_2\right) q_{21}^{SP} - p_c (\omega+\alpha) q_{21}^{SP} + \Phi \Pi_{11}^{SP} \\ \text{s.t. } & (\omega+\alpha) q_{21}^{SP} < \lambda q_{11}^{SP} q_{11}^{SP} \end{aligned} \tag{4}$$

In function (4), $\text{Max } \pi_{11}^{SP}$ is the profit function of the subsidiary company. The first term represents the profit of the subsidiary company by selling new energy vehicles. The second term is the income by providing NEV credits for the parent company at the price of p_c. The third term is the income by selling the rest credits and the last term represents the R & D cost. $\text{Max } \pi_{21}^{SP}$ reflects the profit of the parent company. The first term is the profit from selling fuel vehicles. The second term represents the cost of compensating for negative CAFC and NEV credits. The last term is the bonus from the subsidiary.

By optimization solution, we can first obtain the optimal strategy for the subsidiary producing new energy vehicles. The best selling price of NEV is

$p_{11}^{SP*} = \frac{b_1 c_1 + \gamma a - b_1 p_d \lambda}{2b_1}$ and the optimal production quantities for NEV are $q_{11}^{SP*} = \frac{\gamma a - b_1 c_1 + b_1 p_d \lambda}{2}$.

Let p_{11}^{SP*} and q_{11}^{SP*} be substituted into Π_{21}^{SP}. We can obtain the optimal strategy from the parent company producing fuel vehicles. The best selling price is $p_{21}^{SP*} = \frac{(1-\gamma)a + b_2\left(c_2 + \left((1-\phi)p_c + \phi p_d\right)(\omega+\alpha)\right)}{2b_2 b_2}$ and the optimal production quantities are $q_{21}^{SP*} = \frac{(1-\gamma)a - b_2\left(c_2 + \left((1-\phi)p_c + \phi p_d\right)(\omega+\alpha)\right)}{2}$.

Thus, we can draw the conclusion. The maximum profit of subsidiary is $\Pi_{11}^{SP*} = \frac{(n + b_1 p_d \lambda)^2 + 2b_1 r(p_c - p_d)(m - x - b_2 p_d r\phi)}{4b_1} - \frac{\lambda^2}{2t}$ and $\Pi_{21}^{SP*} = \frac{b_2\phi(n + b_1 p_d \lambda)^2 + b_1(m - x - b_2 p_d r\phi)^2}{4b_1 b_2} - \phi\frac{\lambda^2}{2t}$ is the maximum profit of the parent company. There are four critical variables, that is $m = (1-\gamma)a - b_2 c_2$, $n = \gamma a - b_1 c_1$, $x = b_2(1-\Phi)(\omega+\alpha)p_c$ and $r = \omega + \alpha$. To ensure that the optimal production decision of the vehicle firm is non-negative, the conditions $q_{11}^{SP*} \ge 0$ and $q_{21}^{SP*} \ge 0$ need to be satisfied, i.e., the conditions $c_1 - p_d\lambda \le \frac{\gamma a}{b_1}$ and $\left((1-\Phi)p_c + \Phi p_d\right)(\omega+\alpha) + c_2 \le \frac{(1-\gamma)a}{b_2}$. Where $c_1 - p_d\lambda$ represents the total cost of producing a new energy vehicle for a subsidiary, which consists of the production cost minus the profit from the sale of new energy credits. $\left((1-\Phi)p_c + \Phi p_d\right)(\omega+\alpha) + c_2$ represents the total cost of traditional car manufacturers producing fuel vehicles, which includes the production cost and the purchase of the cost of NEV credits used to offset negative credits, $(1-\Phi)p_c + \Phi p_d$ denotes the combined cost per credit purchased in the credit surplus scenario.

By taking the partial derivative of p_{11}^{SP*}, q_{11}^{SP*}, p_{21}^{SP*} and q_{21}^{SP*} on p_d, we can draw conclusions that $\frac{\partial p_{11}^{SP*}}{\partial p_d} < 0$, $\frac{\partial q_{11}^{SP*}}{\partial p_d} > 0$, $\frac{\partial p_{21}^{SP*}}{\partial p_d} > 0$ and $\frac{\partial q_{21}^{SP*}}{\partial p_d} < 0$.

Property 2. p_d has an influence on both the subsidiary and the parent company. When p_d rise, the parent company undertakes higher costs so it prefers to raise the selling price of traditional fuel vehicles and reduce production for maximum profits. Nevertheless, with p_d rising, the subsidiary makes more profits by selling NEV credits. It's inclined to lower the price of new energy vehicles and improve yield for maximum profits.

To summarize, the price of NEV credits has a significant impact on the automobile market. A relatively high price can encourage car manufacturers to produce more new energy vehicles in order to promote the development of the new energy automobile market, while a lower price benefits traditional car manufacturers.

In addition, based on the result, the subsidiary's production strategy is not affected by p_c. However, fuel vehicles' prices will rise and the output will decline when p_c rises. If $\frac{\partial^2 \Pi_{11}^{SP^2}}{\partial p_c^2 p_c^2} = -(1-\phi)(\omega+\alpha)^2 b_2 < 0^2$, then $p_{c1} = \frac{(1-\gamma)a - b_2((2\phi-1)(\omega+\alpha)p_d + c_2)}{2b_2(1-\phi)(\omega+\alpha)}$. In $[0, p_{c1}]$, the profit of the subsidiary will be increased when p_c rises. So the subsidiary prefers p_{c1} as the internal credits negotiated price. The interval of negotiation is $(0, p_{c1}]$.

As for the parent company, due to $\frac{\partial^2 \Pi_{21}^{SP*}}{\partial p_c^2} = \frac{1}{2}(1-\phi)^2(\omega+\alpha)^2 b_2 > 0$, the best internally negotiated price is $p_{c2} = \frac{(1-\gamma)a - b_2(\phi(\omega+\alpha)p_d + c_2)c_2}{b_2(1-\phi)(\omega+\alpha)}$. In the interval of negotiation of $[0, p_{c2}]$, the profit of traditional car manufacturers declines as p_c rising. Therefore, the parent company tends to quote around 0. And the interval of negotiation is $[0, p_{c2})$.

Meanwhile, combined with the fact that $(\omega+\alpha)q_{21}^{SP} < \lambda q_{11}^{SP}$, the results is $p_c > p_c > \frac{((1-\gamma)a - b_2c_2)(\omega+\alpha) - \lambda(\gamma a + (p_d\lambda - c_1))b_1b_1}{b_2(1-\phi)(\omega+\alpha)^2} - \frac{\phi p_d}{1-\lambda} = \hat{p}_{c1}$.

Through the above analysis, the proposition 1 is as follows.

Proposition 1. When NEV credits are surplus, p_c is in the range of $(\hat{p}_{c1}, \min(p_{c1}, p_{c2}, p_d))$. With p_c rising, the profit of the subsidiary will be increased and of the parent company will decline.

Comparing the splitting strategy in case of credits surplus with the benchmark model, we can obtain the following property.

Property 3. Under the dual-credit policy, if the subsidiary takes the splitting strategy in case of credits surplus, the selling price of fuel vehicles produced by the parent company will be increased by $\frac{((1-\phi)p_c + \phi p_d)(\omega+\alpha)}{2}$ and the output will decrease by $\frac{b_2((1-\phi)p_c + \phi p_d)(\omega+\alpha)}{2}$. In the meantime, by splitting the NEV business module for independent operation, the subsidiary can capture the NEV market share at the price of p_{11}^{SP*} and the output of q_{11}^{SP*}.

From Property 3, the study concludes that the optimal production strategy of the parent company is influenced by the price of NEV credits and the weighted negotiated price $p = (1-\Phi)p_c + \Phi p_d$ under the dual-credit policy. When $p = 0$, this model is the same as the benchmark model and p is affected by ϕ in this model. Along with the increase of ϕ, p also rises, which means the value-added in the selling price of traditional fuel vehicles and the value-reduced in output is directly proportional to ϕ. It also means that the higher the shareholding ratio, the fewer fuel vehicles the parent company will produce and the higher the selling price. This is because the parent company has better control over the NEV market by increasing the shareholding ratio. The parent company is able to cut down on the negative credits from yield reduction for a higher profit in credits trading.

2) Credit deficiency

In this situation, the NEV credits generated by the subsidiary are not enough to compensate for the negative credits of the parent company. Thus, except for purchasing NEV credits from the subsidiary, the parent company needs to buy the rest insufficient credits from the market at the price of p_d. The model is simplified as follows:

$$\begin{aligned}&\text{Max } \Pi_{12}^{SP} = \left(p_{12}^{SP} - c_1\right) q_{12}^{SP} + p_c \lambda q_{12}^{SP} - \lambda^2 / (2t) \\ &\text{Max } \Pi_{22}^{SP} = \left(p_{22}^{SP} - c_2\right) q_{22}^{SP} - p_c \lambda q_{12}^{SP} - p_d \left[\left(\omega + \alpha\right) q_{22}^{SP} - \lambda q_{12}^{SP}\right] + \Phi \Pi_{12}^{SP} \\ &\text{s.t.} \left(\omega + \alpha\right) q_{21}^{SP} > \lambda q_{11}^{SP} q_{11}^{SP}\end{aligned} \quad (5)$$

In function (5), $\text{Max } \pi_{12}^{SP}$ is the profit function of the subsidiary company. The first term represents the profit of the subsidiary company by selling new energy vehicles. The second term is the income by providing all the NEV credits for the parent company at the price of p_c. The last term represents the R & D cost. $\text{Max } \pi_{22}^{SP}$ reflects the profit of the parent company. The first term is the profit from selling fuel vehicles. The second term and the third term separately represent the cost of compensating for negative credits by purchasing NEV credits from the subsidiary and the market. The last term is the bonus from the subsidiary.

By optimization solution, we can obtain the optimal strategy for the subsidiary producing new energy vehicles. The optimal selling price is $p_{12}^{SP*} = \frac{b_1 c_1 + \gamma a - b_1 p_c \lambda}{2b_1}$ and the optimum yield is $q_{12}^{SP*} = \frac{\gamma a - b_1 c_1 + b_1 p_c \lambda}{2}$. Let p_{12}^{SP*} and q_{12}^{SP*} be substituted into π_{22}^{SP}. We can obtain the optimal strategy from the parent company producing fuel vehicles. The optimal selling price of FV is $p_{22}^{SP*} = \frac{(1-\gamma)a + b_2\left(c_2 + (\omega+\alpha)p_d\right)}{2b_2 b_2}$ and the optimum yield of FV is $q_{22}^{SP*} = \frac{(1-\gamma)a - b_2\left(c_2 + (\omega+\alpha)p_d\right)}{2}$. From this, we can solve that the maximum profit of the subsidiary is $\Pi_{12}^{SP*} = \frac{\left(\gamma a - b_1\left(-p_c\lambda + c_1\right)\right)^2}{4b_1} - \frac{\lambda^2}{2t}$ and that of the parent company is $\Pi_{22}^{SP*} = \frac{b_2 \phi \left(n + b_1 p_c \lambda\right)^2 + 2b_1\left(m - x - b_2 p_d r \phi\right)^2}{4b_1 b_2} - \phi \frac{\lambda^2}{2t}$, where $m = (1-\gamma)a - b_2 c_2$, $n = \gamma a - b_1 c_1$ and $r = \omega + \alpha$. In order to guarantee the non-negativity of the optimal production strategy, $q_{12}^{SP*} \ge 0$ and $q_{22}^{SP*} \ge 0$ must be satisfied, that is $c_1 - p_c \lambda \le \frac{\gamma a}{b_1}$ and $p_d\left(\omega+\alpha\right) + c_2 \le \frac{(1-\gamma)a}{b_2}$. Comparing conditions $c_1 - p_d \lambda \le \frac{\gamma a}{b_1}$ and $\left((1-\Phi)p_c + \Phi p_d\right)\left(\omega+\alpha\right) + c_2 \le \frac{(1-\gamma)a}{b_2}$

in the credit surplus scenario reveals that, due to $p_c < p_d$ and $(1-\phi)p_c + \phi p_d < p_d$, the conditions in the credit surplus scenario are also satisfied at the same time as the constraints in this section are satisfied, implying that hypothesis $c_1 - p_d\lambda \le \frac{\gamma a}{b_1}$ and $((1-\phi)p_c + \phi p_d)(\omega+\alpha) + c_2 \le \frac{(1-\gamma)a}{b_2}$ of this paper is correct, i.e. the non-negativity of the vehicle manufacturers' optimal production decision is guaranteed in both the credit surplus and credit deficiency scenarios.

By analyzing the optimal production strategy of two companies, we can find the $\frac{\partial p_{12}^{SP*}}{\partial p_c} < 0$, $\frac{\partial q_{12}^{SP*}}{\partial p_c} > 0$, $\frac{\partial p_{22}^{SP*}}{\partial p_d} > 0$ and $\frac{\partial q_{22}^{SP*}}{\partial p_d} < 0$. The property 4 is as follows.

Property 4. When NEV credits are deficient, the optimal production strategy of the subsidiary is influenced by p_c. And the optimal production strategy of the parent company is affected by p_d. Specifically, when p_c goes up, the subsidiary prefers to take the strategy of cutting the price and increasing the output to boost profits. When p_d goes up, the parent company prefers to take the strategy of increasing the price and reducing the output.

In the situation of credit deficiency, the condition $(\omega+\alpha)q_{21}^{SP} > \lambda q_{11}^{SP}$ need to be met and through substitution simplification, we can learn $p_c < \frac{(\omega+\alpha)((1-\gamma)a - b_2(p_d(\omega+\alpha)+c_2)) - \lambda(\gamma a - b_1)}{\lambda^2 b_1} = \hat{p}_{c2}$. From $\frac{\partial^2 \pi_{12}^{SP*}}{\partial p_c^2} > 0$ and $\frac{-\gamma a + b_1 c_2}{\lambda b_1} < 0$, when p_c is in the range $[0, \hat{p}_{c2}]$, the subsidiary's profit increases as p_c increases, so the subsidiary's offer for the internally negotiated price tends to be $\hat{p}_{c2}$.

And the analysis of the maximum profit of the parent company shows that $\frac{\partial^2 \pi_{22}^{SP*}}{\partial p_c^2} = \frac{1}{2}(\Phi-2)\lambda^2 b_1 < 0$. As a result, the optimal internal credits negotiated price for the parent company is $p_{c4} = \frac{(1-\Phi)(\gamma a - b_1 c_1) - b_1 p_d \lambda}{b_1(\Phi-2)\lambda}$, and the profit is maximized at this time. However, the positive or negative value of this price is determined by the value of the parameter, so parent company tends to set the internally negotiated price around $\max(0, p_{c4})$, when at $p_c > p_{c4}$ the parent company's profit decreases with increasing p_c.

Comprehensively, the proposition 2 are as follows.

Proposition 2. In the situation of credit deficiency, the internal credits negotiated price will be achieved in the range of $[\max(0, p_{c4}), \hat{p}_{c2})$. In this range, with p_c rising, the profit of the subsidiary will be increased and of the parent company will decline.

3) Credit balance

Under such circumstances, NEV credits generated by the subsidiary are just compensated for the negative credits of the parent company. The model can be simplified as follows.

$$\begin{aligned}&\text{Max } \Pi_{13}^{SP} = \left(p_{13}^{SP} - c_1\right) q_{13}^{SP} + p_c \lambda q_{13}^{SP} - \lambda^2 / (2t) \\ &\text{Max } \Pi_{23}^{SP} = \left(p_{23}^{SP} - c_2\right) q_{23}^{SP} - p_c\left(\omega + \alpha\right) q_{23}^{SP} + \Phi \Pi_{13}^{SP} \\ &\text{s.t.} \left(\omega + \alpha\right) q_{23}^{SP} = \lambda q_{13}^{SP} q_{11}^{SP}\end{aligned} \tag{6}$$

By solving the function, the optimal production strategy of the subsidiary is $p_{13}^{SP*} = \dfrac{b_1 c_1 + \gamma a - b_1 p_c \lambda}{2b_1}$ and $q_{13}^{SP*} = \dfrac{\gamma a - b_1 c_1 + b_1 p_c \lambda}{2}$. Let p_{13}^{SP*} and q_{13}^{SP*} substituted into π_{23}^{SP*}. The optimal production strategy of the parent company is $p_{23}^{SP*} = \dfrac{b_2 c_2 + (1-\gamma) a}{2b_2}$ and $q_{23}^{SP*} = \dfrac{(1-\gamma) a - b_2 c_2}{2}$. At this point, the maximum profit of the subsidiary is $\Pi_{13}^{SP*} = \dfrac{\left(\gamma a - b_1\left(-p_c \lambda + c_1\right)\right)^2}{4b_1} - \dfrac{\lambda^2}{2t}$ and the maximum profit of the parent company is

$$\Pi_{23}^{SP*} = \frac{b_2 \phi \left(n + b_1 p_c \lambda\right)^2 - 2b_1 b_2 \lambda p_c \left(n + p_c \lambda b_1\right) + b_1 m^2}{4b_1 b_2} - \phi \frac{\lambda^2}{2t}, \text{ where}$$

$m = (1-\gamma) a - b_2 c_2$, $n = \gamma a - b_1 c_1$, $r = \omega + \alpha$. Based on the proof for the credit deficiency scenario, it is clear that the optimal production decisions of both firms under credit balance satisfy non-negativity. The constraint condition $(\omega + \alpha) q_{23}^{SP} = \lambda q_{13}^{SP}$ can be simplified to $p_c < \dfrac{(\omega + \alpha)\left((1-\gamma) a - b_2 c_2\right) - \lambda\left(\gamma a - b_1 c_1\right)}{\lambda^2 b_1} = \hat{p}_{c3 \cdot c2}$ Since the parent company does not need to purchase NEV credits externally at this point, the market credit price p_d does not affect the parent company's optimal production decision and is not affected by the internally negotiated price p_c.

Property 5. When compared to the benchmark model, optimal production strategies in the case of credit balance under the dual-credit policy are the same as those of the benchmark model under the non-dual-credit policy.

4. Model Comparison and Numerical Analysis

4.1. Comparison between Integrative Development Strategy and Splitting Strategy

In the case of the splitting strategy, there are three situations: credit surplus, credit deficiency and credit balance. The maximum profits in these three cases are expressed by Π_{21}^{SP*}, Π_{22}^{SP*} and Π_{23}^{SP*} respectively, and the maximum profits of manufacturers under the integrative development strategy are expressed by Π^{CP*}. This will not be discussed in this paper because the balance of credits requires that the credits generated and consumed be exactly equal between the new energy subsidiary and the parent company of the traditional vehicle company, which is unlikely to occur in practice. By comparing the maximum profit under the two strategies, the following proposition is obtained.

Proposition 3. If $\dfrac{M + \sqrt{N + M^2}}{Y} < P_d < \dfrac{M - \sqrt{N + M^2}}{Y}$, then $\Pi^{CP*} < \Pi_{21}^{SP*}$. If

$P_d < \frac{M+\sqrt{N+M^2}}{Y}$ or $P_d > \frac{M-\sqrt{N+M^2}}{Y}$, then $\Pi^{CP*} > \Pi_{21}^{SP*}$ where $M = (1-\phi)(-mr+n\lambda) - rx\phi$,

$N = \frac{\left(b_1 k (m-x)^2 + \left(2b_1 b_2 \lambda^2 - b_2 kn^2\right)(-1+\phi)\right)(-1+\phi)\left(b_1\lambda^2 + b_2 r^2 (1+\phi)\right)}{b_1 b_2 k}$ and

$Y = (-1+\phi)\left(b_1\lambda^2 + b_2 r^2 (1+\phi)\right)$.

Proposition 4. When $P_d > 0$, $\Pi^{CP*} > \Pi_{22}^{SP*}$.

From the above proposition, it can be seen that adopting the splitting strategy under the dual credit policy, that is, splitting the new energy business for independent operation, can reduce the impact of the policy on the profits of car manufacturers. In the case of credit surplus after the independent operation, when the market price of credit is in the range of $\frac{M+\sqrt{N+M^2}}{Y}, \frac{M-\sqrt{N+M^2}}{Y}$, the adoption of the splitting strategy will obtain more profits than the adoption of the integrative development strategy. In other words, in this case, implementing the splitting strategy will reduce the impact of the dual credit policy on automakers. Otherwise, the credit price is outside of this range, and car manufacturers should pursue an integrative development strategy to increase profits. The profit after the independent operation is always lower than the profit after the integrative development strategy in the case of deficient new energy credits. As a result, if it is predicted that the new energy business will be in a credit deficiency after the split, the splitting strategy should be avoided; that is, the new energy business should not be split for independent operation while in a credit deficiency situation.

From this, it can be concluded that the optimal strategy choice of traditional car manufacturers is: The splitting strategy should be chosen if the market credit price is in the range $\frac{M+\sqrt{N+M^2}}{Y}, \frac{M-\sqrt{N+M^2}}{Y}$, and the NEV credit is surplus at this time following the independent operation of the new energy business. If not, the integrative development strategy should be chosen. If it is anticipated that the NEV credit following the split won't be enough, the integrated development approach ought to be used. The traditional automakers are considering a splitting strategy under the dual credit policy, which would separate the new energy business from the independent operation. Table 1 displays the chosen marketing strategy for the traditional manufacturers.

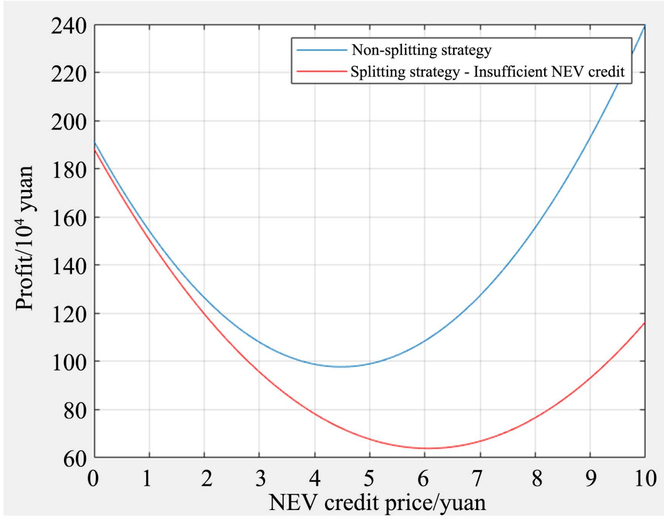
4.2. Case Analysis of Integrative Development Strategy and Splitting Strategy

Case: Consider the indigenous automaker Chang'an Automobile as an illustration. Chang'an new energy was founded in 2018. Chang'an New Energy's round a financing plan was finished in 2019. It made history as China's first major automaker to split and independently develop its new energy sector and implement mixed ownership reform. The numerical analysis is completed along with the

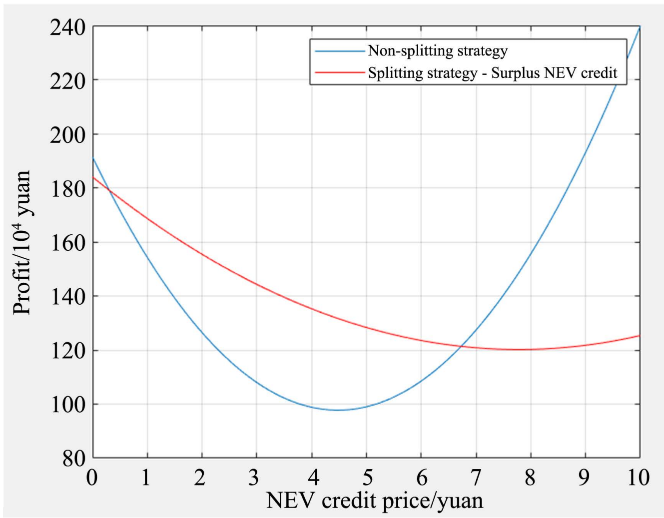
Table 1. Strategy selection between the non-splitting strategy and splitting strategy for the traditional car manufacturer.

	credit surplus	credit deficiency
P_d is low, $P_d < \frac{M+\sqrt{N+M^2}}{Y}$	Integrative development strategy	Integrative development strategy
$\frac{M+\sqrt{N+M^2}}{Y} < P_d < \frac{M-\sqrt{N+M^2}}{Y}$	Splitting strategy	Integrative development strategy
P_d is high, $P_d > \frac{M-\sqrt{N+M^2}}{Y}$	Integrative development strategy	Integrative development strategy

national automobile production and sales data for 2021. The same background is used throughout the entire case. According to information on national car sales in 2021, 2.8832 million new energy vehicles were sold in that year, making up 13.88% of the total number of passenger cars sold (The terminal sales data of new energy passenger vehicles in 2021 was released by the intelligent electric vehicle Professional Committee of China electronics Chamber of Commerce). In mature markets, such as Shanghai, the sales volume of new energy vehicles is 254,000, accounting for 34.47% of total passenger vehicle sales volume (Data refer to "the annual report of Shanghai green transport development in 2021"). This paper assumes a relatively mature new energy vehicle market, with a potential scale of $a=1$ million and a market share of new energy vehicles of $\gamma=25\%$. The production cost for new energy vehicles is $c_1=70000$ yuan/vehicle and $c_2=50000$ yuan/vehicle for traditional vehicles. The price sensitivity coefficients of the two vehicles are $b_1=2$ and $b_2=4$, respectively. Refer to the requirements on the proportion of NEV credit meeting the standard in the "measures for the parallel management of average fuel consumption and new energy vehicle points of passenger vehicle enterprises" revised in 2020 for the percentage of NEV credits to be achieved $\alpha=14$, the actual average fuel consumption of Chang'an fuel vehicles (take Chang'an cs75 with the highest sales volume as an example) is $\omega_t=8.92$, the standard value specified by the government is $\omega_0=7.15$ (refer to "evaluation methods and indicators for fuel consumption of passenger cars gb27999-2019" for calculation, see Appendix), and the difference between the two is taken as the approximate value $\omega=1.7$. The shareholding ratio of Chang'an Automobile after splitting financing of the new energy business is $\phi=40$. The average NEV credit obtained by the production of each new energy vehicle is $\lambda=1.6$ (refer to the calculation method for the points of plug-in hybrid passenger vehicles in the "measures for the parallel management of the average fuel consumption of passenger vehicle enterprises and the points of new energy vehicles"). The change diagram of the optimal profit function of the new energy vehicle manufacturers with the integral price under the two conditions of high internal agreement price ($p_c=5000$ yuan/credit) and low internal agreement price ($p_c=2000$ yuan/credit) is drawn respectively. The results are shown in **Figure 2**.



(a)



(b)

Figure 2. The traditional car manufacturer's profits under non-splitting strategy and splitting strategy. (a) $p_c = 0.5$; (b) $p_c = 0.2$.

It can be seen from the above figure that the vertical axis is the profit of traditional cars under the integrative development strategy, and the horizontal axis is the NEV credit market price. Figure 2(a) and Figure 2(b) clearly show the profit curve of the integrative development strategy and the splitting strategy under the corresponding scenario. In Figure 2(a), the internal agreement price is high, and the p_c is taken as 5000 yuan/credit. It can be seen that the profit obtained by adopting the integrative development strategy is always higher than the splitting strategy. In Figure 2(b), two profit curves under two strategies are more complicated. From 0 yuan to 3030 yuan, the profit gained by adopting the non-splitting strategy is always higher than by adopting the splitting strategy, yet the two curves are both going down while the slope of the profit curve under the non-splitting strategy is bigger. So two curves have an intersection at the point of

3030 yuan, after which the profit under the splitting strategy is higher. In Stage 1 that from 0 to 3030 yuan, it's wise for companies to adopt the non-splitting strategy for a higher profit. When NEV credits price is about 5000 yuan, the profit curve by adopting the non-splitting strategy reaches the minimum and begins to show an upward trend while the other curve still goes down. Two profit curves have another intersection at the point of 67,680 yuan. We can conclude that at Stage 2 from 3030 yuan to 67,680 yuan, splitting the NEV business module is more reasonable so that traditional car manufacturers have a higher profit. And after 67,680 yuan, Stage 3 shows a dramatic rise in the profit curve by adopting the non-splitting strategy, and also the profit is much higher than by adopting the splitting strategy. Comprehensively speaking from Stage 1, Stage 2, and Stage 3, only when NEV credits price is between 3030 yuan and 67,680 yuan can traditional car manufacturers obtain higher profit by splitting strategy. Otherwise, adopting a non-splitting strategy is more sagacious.

4.3. Numerical Analysis of Two Strategies and Benchmark Models

Next, we will use numerical analysis to compare the benchmark model, the integrative development strategy and the splitting strategy (including the three situations of credit surplus, credit deficiency and credit balance). The parameter values are consistent with those in the case. In addition, it is assumed that $p_d = 6000$ yuan/credit and $p_c = 3000$ yuan/credit. And calculate the profit and optimal decision under different strategies. The results are shown in Table 2.

Since it is difficult to establish in reality the condition where the creation and consumption of credits between traditional business and new energy business are exactly equal when the credit is balanced, we will not concentrate on this analysis and elaboration in the following. The table above shows that following the introduction of the dual credit policy, the output of traditional fuel vehicles has declined under both methods, while the price has climbed in both strategies. Production decreases from 27.5 to 25.29 and prices rise from 11.88 to 12.43 under the integrative development strategy, while production decreases to 25.95 and 25.29 under the splitting strategy. At the same time, the profits of traditional car manufacturers have decreased. Under the integrative development strategy,

Table 2. Numerical analysis of two strategies and benchmark models.

	Benchmark model	Integrative development strategy	Splitting strategy		
			Credit surplus	Credit deficiency	Credit balance
Π_{2*}^{*}	189.06	167.99	171.63	164.82	188.22
p_{2*}^{*}	11.88	12.43	12.26	12.42	10.37
q_{2*}^{*}	27.5	25.29	25.95	25.29	33.5

prices increased from 11.88 to 12.43 and profits decreased from 189.06 to 167.99. While under the splitting strategy, prices increased to 12.43 and 12.26, respectively, and profits decreased to 171.63 and 164.82, respectively. According to the numerical analysis of this case, if the splitting strategy is employed in the case of credit deficiency, the maximum loss of profit is 12.8%. In the case of credit surplus the loss of profit is 9.2% when splitting the new energy business to operate independently, and 11.14% when using the overall strategy. Although it is difficult to justify the balance of credits scenario, the profit loss in this case is minimised to 0.44% by choosing the splitting strategy. Therefore, it is very necessary to make an appropriate strategic choice under the dual credit policy.

In conclusion, under the background of this numerical analysis, if the traditional car manufacturers predict that the credit after the split is insufficient, traditional car manufacturers should choose the integrative development strategy. If it is predicted that there will be a credit surplus after the split and the price of credits is within the range of $\left[\frac{M+\sqrt{N+M^2}}{Y},\frac{M-\sqrt{N+M^2}}{Y}\right]$, the numerical analysis case is within the range of [0.53, 6.56], then the splitting strategy should be selected, otherwise, the integrative development strategy should be selected.

5. Conclusions and Future Studies

Under the dual-credit policy, the study conducts research on the new energy business of traditional manufacturers. The study examines whether traditional manufacturers split the NEV business module in light of the dual-credit policy to maximize profit. The study investigates a benchmark model without dual-credit restrictions as a starting point and then proceeds to investigate if traditional manufacturers split the NEV business module. This allows for the development of the best possible manufacturing methods. We can see the impact of the dual-credit policy on the volume and selling price of traditional manufacturers according to the comparison between the integrative development strategy and the benchmark model. To determine the ideal production strategies and the range of internal credit trading prices, models under the three subdivisions of credits surplus, credits deficiency, and credits balance are solved. The impact of the policy on traditional manufacturers is also evident from the comparison of the splitting strategy and benchmark model. To confirm the accuracy of the model results, policy analysis, and numerical analysis are done after the study.

Through literature analysis, constructing models and strategic game comparison and numerical analysis, we conclude the following: 1) The dual-credits strategy will result in a rise in the selling price of fuel vehicles and a decrease in output. Traditional automakers often choose the “low output but high pricing” strategy when the price of NEV credits is high. This is because the price of NEV credits has a significant impact on their bottom line. 2) It is preferable to implement the splitting strategy when forecasting the subsidiary’s excess NEV credits after splitting and when the market price of the credits is in the range of

$\left[\frac{M+\sqrt{N+M^2}}{Y}, \frac{M-\sqrt{N+M^2}}{Y}\right]$. If not, the integrated development strategy is better suited for maximizing profitability. It shouldn't be split if it is estimated that the current new energy business module is producing insufficient new energy credits. The above research results are of practical significance.

According to the dual-credit policy, the study investigates the best production strategy and development of the NEV industry from the standpoint of traditional vehicle companies maximizing profits. The analysis, however, ignores the negative effects that the unbundling of the NEV industry has had on traditional automakers' FV business modules, which reduces their initial benefits. Additionally, the study hasn't offered any specific management or operating recommendations for NEV manufacturers. Future research will be done on the issues mentioned.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix

1) For passenger cars with three rows of seats, the target fuel consumption values shall be calculated according to Equations (1) to (3), rounded off to two decimal places:

If the overall vehicle mass $CM \leq 1090$, then $T = 4.02$ (1)

If $1090 < CM \leq 2510$, then $T = 0.0018 \times (CM - 1415) + 4.$ (2)

If $\text{CM} > 2510$, then $T = 6.57$ (3)

where T is the target value of fuel consumption of the vehicle model in litres per 100 kilometres (L/100 KM).

CM is the overall vehicle mass in kilograms (kg).

2) For passenger vehicles with three or more rows of seats, the fuel consumption target value of the vehicle model shall be increased by 0.20 L/100 KM on the basis of the calculation result of 1, and the calculation result shall be rounded off to two decimal places.

3) Annual requirements for the average fuel consumption of enterprises is that the ratio of the average fuel consumption of each enterprise to the target value of the average fuel consumption of the enterprise shall not be greater than the following, the ratio of the average fuel consumption of the enterprise to the target value of the average fuel consumption of the enterprise 123% in 2021, 120% in 2022, 115% in 2023, 108% in 2024, 100% in 2025 and beyond.

4) The Changan cs75 is a 5-seater car with an average weight of 1700 kg, and the 2021 standard is used in this case. The Changan cs75 new energy vehicle in this case is a plug-in hybrid, and the model credit is 1.6 calculated according to the Measures for Passenger Cars Corporate Average Fuel Consumption and New Energy Vehicle Credit Regulation.