

Pricing of New Energy Vehicles Considering the Dual Credit Policy

Huijun Huang* and Mengran Li

School of Economics and Management, Nanjing University of Science and Technology, Nanjing

*Corresponding author: ad7342163@163.com

Abstract. Considering the “dual credit” policy, this paper builds three different power structures to explore price strategies in the supply chain, which is composed of new energy vehicle manufacturers and traditional automobile manufacturers. It has found that when the positive credit value of new energy vehicles is higher than the negative credit value of fuel consumption, new energy vehicle manufacturers will gain higher profits. When the power structure is imbalanced, wholesale and retail prices are mainly determined by the highest price that consumers can accept for passenger cars. When new energy vehicle manufacturers dominate, the clearing price of new energy vehicle credits is mainly influenced by the production cost of new energy vehicles.

Keywords: Supply chain; new energy vehicles; Dual Credit Policy; Power structure.

1. Introduction

Under the goal of “carbon peak” in 2030, the government introduced the "Dual Credits" policy [1] in September 2017. It stipulates that passenger car manufacturers in the market must meet both the Corporate Average Fuel Value (CAFC) and New Energy Vehicle (NEV) credits. If the average fuel consumption is higher than the standard value, the CAFC credits will be negative, and it is necessary to purchase excess NEV scores from other new energy vehicle manufacturers in the market to offset. New energy vehicle manufacturers can earn NEV credits by producing new energy vehicles, and then sell excess credits in the credits trading market to obtain certain profits. Compared to previous government subsidies, the dual credit policy has shifted from policy driven to market driven, guiding the development of the new energy vehicle industry through credit trading.

After the implementation of the Dual Credit policy in China, several scholars have conducted research on its effects. By conducting in-depth research on both the dual point policy and the government subsidy policy, Shi L [2] has convincingly shown that the dual point policy effectively alleviates automakers' reliance on government subsidies. Jun [3] found that the average fuel economy policy and zero emission vehicle policy have a significant impact on vehicle energy conservation and emission reduction. Wang [4] investigated the pricing decision model for the supply chain of new energy vehicle manufacturers with varying production structures. They discovered that selling NEV credits in the credits trading market can yield considerable profits for manufacturers. Zhao [5] studied how new energy vehicle manufacturers balance sales prices and practicality under the dual point policy. Yang [6] discovered that the dual point policy can effectively reduce the overall energy consumption of the automotive industry and facilitate sustainable development. Huo [7] conducted a comparative analysis of optimal credit strategies for automakers with different investment amounts.

The main research content of this paper is as follows: The second section provides an explanation of the problem and outlines the basic assumptions. In the third section, we establish and solve a game model between new energy vehicle manufacturers with varying power structures and traditional automobile manufacturers, and obtains the optimal equilibrium solution under different power structures. The fourth section conducts theoretical analysis on the obtained model results and studies the optimal equilibrium state under different power structures. Finally, we demonstrate and analyze the model results through numerical analysis.

2. Basic Assumptions and Symbol Description

2.1. Basic Assumptions

The basic assumptions are as following:

Assumption 1: Suppose there are new energy vehicle manufacturers and traditional vehicle manufacturers in the market. We define traditional car manufacturers as Car Company 1 (M1), new energy car manufacturers as Car Company 2 (M2) and dealers as R.

Assumption 2: Assuming the unit production costs of traditional and new energy vehicles are c_1 and c_2 . Considering that new energy cars need certain research costs, the production costs are higher than those of traditional vehicles, without loss of generality, which can make $c_1 = 0, c_2 = c > 0$.

Assumption 3: Assuming a linear relationship between the demand and price, we can obtain the following reverse demand function: $Q_i = \alpha - p_i$

2.2. Symbol Description

Symbolic description of relevant variables in the model are shown in the following table.

Table 1. Symbol description.

Symbol	definition
i	i=1 (traditional car producer), i=2 (new energy producer)
α	maximum consumer acceptance of sales prices
p_i	wholesale price for car producer i
Q_i	consumer demand of car for manufacturer i
c_i	production cost of car for manufacturer i
P	clearing price of new energy vehicle/credit prices
a	requirements for credit proportion of new energy vehicles
s_1	CAFC credits generated by each traditional car
s_2	NEV credits obtained for each new energy vehicle produced
π_{Mi}	profit of new energy producer / traditional car producer
π_R	profit of dealer

3. Modeling

In this chapter, we will construct game models based on different power structures to derive the optimal equilibrium solution for the passenger car market under the "dual credit" policy.

3.1. Profit function

We can obtain the profit function expressions for M1, M2 and R as follows:

$$\pi_{M1} = w_1 Q_1 - (s_1 + a) P Q_1 \quad (1)$$

$$\pi_{M2} = (w_2 - c) Q_2 + s_2 P Q_2 \quad (2)$$

$$\pi_R = (p_1 - w_1) Q_1 + (p_2 - w_2) Q_2 \quad (3)$$

3.2. Model Solving

3.2.1. Neither manufacturer dominates

In this model, given that the new energy vehicle credit market operates as a realm of perfect competition, both traditional automobile manufacturers and new energy vehicle manufacturers assume the role of market price recipients. The order of the game is: (1) Manufacturer M1 and M2 determine the wholesale prices denoted as w_1 and w_2 respectively; (2) Dealer R, in turn, determines the selling prices for both fuel-powered and new energy vehicles, represented as p_1 and p_2 respectively.

$$\max_{w_1} \pi_{M1} = w_1 Q_1 - (s_1 + a) P Q_1 \quad (4)$$

$$\max_{w_2} \pi_{M2} = (w_2 - c)Q_2 + s_2PQ_2 \quad (5)$$

$$\text{s. t. } \pi_R = (p_1 - w_1)Q_1 + (p_2 - w_2)Q_2 \quad (3)$$

$$(s_1 + a)PQ_1 = s_2PQ_2 \quad (6)$$

Solving $\frac{\partial \pi_R}{\partial p_1} = 0$ and $\frac{\partial \pi_R}{\partial p_2} = 0$ simultaneously yields

$$p_1 = \frac{w_1 + \alpha}{2} \quad (7)$$

$$p_2 = \frac{w_2 + \alpha}{2} \quad (8)$$

Then, let $\frac{\partial \pi_{M1}}{\partial w_1} = 0$, $\frac{\partial \pi_{M2}}{\partial w_2} = 0$ and $(s_1 + a)PQ_1 = s_2PQ_2$, we have

$$w_1 = \frac{2\alpha s_1^2 + (c - \alpha)s_1s_2 + \alpha s_2^2}{2(s_1^2 + s_2^2)} \quad (9)$$

$$w_2 = \frac{(c + \alpha)s_1^2 - \alpha s_1s_2 + 2\alpha s_2^2}{2(s_1^2 + s_2^2)} \quad (10)$$

$$p_1 = \frac{4\alpha s_1^2 + (c - \alpha)s_1s_2 + 3\alpha s_2^2}{4(s_1^2 + s_2^2)} \quad (11)$$

$$p_2 = \alpha + \frac{s_1((c - \alpha)s_1 - \alpha s_2)}{4(s_1^2 + s_2^2)} \quad (12)$$

$$P = \frac{\alpha s_1 + (c - \alpha)s_2}{s_1^2 + s_2^2} \quad (13)$$

Furthermore,

$$Q_1 = \frac{s_2((-c + \alpha)s_1 + \alpha s_2)}{4(s_1^2 + s_2^2)} \quad (14)$$

$$Q_2 = \frac{s_1((-c + \alpha)s_1 + \alpha s_2)}{4(s_1^2 + s_2^2)} \quad (15)$$

$$\pi_{M1} = \frac{s_2^2((-c + \alpha)s_1 + \alpha s_2)^2}{8(s_1^2 + s_2^2)^2} \quad (16)$$

$$\pi_{M2} = \frac{s_1^2((-c + \alpha)s_1 + \alpha s_2)^2}{8(s_1^2 + s_2^2)^2} \quad (17)$$

$$\pi_R = \frac{((c - \alpha)s_1 - \alpha s_2)^2}{16(s_1^2 + s_2^2)} \quad (18)$$

3.2.2. Traditional car manufacturers dominate

In this situation, traditional fuel vehicle manufacturers, as buyers of credits, can dominate the pricing of credits. The order of the game is: (1) Manufacturer M1 first determines the wholesale price w_1 of fuel vehicles; (2) Then, M2 determines the wholesale price w_2 of new energy vehicles; (3) Dealer R determines the selling prices p_1 and p_2 for fuel powered and new energy vehicles.

$$\max_{w_1} \pi_{M1} = w_1Q_1 - (s_1 + a)PQ_1 \quad (4)$$

$$\text{s. t. } \pi_{M2} = (w_2 - c)Q_2 + s_2PQ_2 \quad (2)$$

$$\pi_R = (p_1 - w_1)Q_1 + (p_2 - w_2)Q_2 \quad (3)$$

$$(s_1 + a)PQ_1 = s_2PQ_2 \quad (6)$$

Let $\frac{\partial \pi_{M2}}{\partial w_2} = 0$ and $(s_1 + a)Q_1 = s_2Q_2$, we have

$$w_2 = \alpha + \frac{(w_1 - \alpha)(a + s_1)}{s_2} \quad (19)$$

$$P = \frac{-2(w_1 - \alpha)(a + s_1) + (c - \alpha)s_2}{s_2^2} \quad (20)$$

Let $\frac{\partial \pi_{M1}}{\partial w_1} = 0$, we have

$$w_1^T = \frac{4\alpha(a+s_1)^2+(c-\alpha)(a+s_1)s_2-\alpha s_2^2}{4(a+s_1)^2-2s_2^2} \tag{21}$$

Furthermore,

$$w_2^T = \frac{(c+3\alpha)(a+s_1)^2+\alpha(a+s_1)s_2-2\alpha s_2^2}{4(a+s_1)^2-2s_2^2} \tag{22}$$

$$p^T = \frac{(c-\alpha)(a+s_1)^2-\alpha(a+s_1)s_2+(-c+\alpha)s_2^2}{-2(a+s_1)^2s_2+s_2^3} \tag{23}$$

$$p_1^T = \frac{8\alpha(a+s_1)^2+(c-\alpha)(a+s_1)s_2-3\alpha s_2^2}{8(a+s_1)^2-4s_2^2} \tag{24}$$

$$p_2^T = \frac{(c+7\alpha)(a+s_1)^2+\alpha(a+s_1)s_2-4\alpha s_2^2}{8(a+s_1)^2-4s_2^2} \tag{25}$$

$$Q_1^T = \frac{s_2(-c-\alpha)(a+s_1)-\alpha s_2}{8(a+s_1)^2-4s_2^2} \tag{26}$$

$$Q_2^T = \frac{(a+s_1)(-c-\alpha)(a+s_1)-\alpha s_2}{8(a+s_1)^2-4s_2^2} \tag{27}$$

$$\pi_{M1}^T = -\frac{((c-\alpha)(a+s_1)+\alpha s_2)^2}{16(a+s_1)^2-8s_2^2} \tag{28}$$

$$\pi_{M2}^T = \frac{(a+s_1)(5(c-\alpha)^2(a+s_1)^3+2(c-\alpha)\alpha(a+s_1)^2s_2-(4c^2-8c\alpha+7\alpha^2)(a+s_1)s_2^2+4\alpha(-c+\alpha)s_2^3)}{8(-2(a+s_1)^2+s_2^2)^2} \tag{29}$$

$$\pi_R^T = \frac{((c-\alpha)(a+s_1)+\alpha s_2)^2((a+s_1)^2+s_2^2)}{16(-2(a+s_1)^2+s_2^2)^2} \tag{30}$$

3.2.3. New energy vehicle manufacturers dominate

In this case, as the seller of credits, new energy vehicle manufacturers affect the credit supply in the market, thereby affecting the transaction price of credits. The order of the game is: (1) M2 determines the wholesale price w_2 of new energy vehicles; (2) Traditional fuel vehicle manufacturer M1 determines the wholesale price of fuel vehicles w_1 ; (3) Dealer R determines the selling prices p_1 and p_2 for fuel powered and new energy vehicles.

$$\max_{w_1} \pi_{M2} = (w_2 - c)Q_2 + s_2PQ_2 \tag{5}$$

$$\text{s. t. } \pi_{M1} = w_1Q_1 - (s_1 + a)PQ_1 \tag{1}$$

$$\pi_R = (p_1 - w_1)Q_1 + (p_2 - w_2)Q_2 \tag{3}$$

$$(s_1 + a)PQ_1 = s_2PQ_2 \tag{6}$$

Similar to the previous situation, we can obtain

$$w_2^N = \frac{(c+\alpha)(a+s_1)^2-\alpha(a+s_1)s_2+4\alpha s_2^2}{2(a+s_1)^2+4s_2^2} \tag{31}$$

$$w_1^N = \frac{2\alpha(a+s_1)^2+(c-\alpha)(a+s_1)s_2+3\alpha s_2^2}{2(a+s_1)^2+4s_2^2} \tag{32}$$

$$p_1^N = \frac{4\alpha(a+s_1)^2+(c-\alpha)(a+s_1)s_2+7\alpha s_2^2}{4(a+s_1)^2+8s_2^2} \tag{33}$$

$$p_2^N = \frac{(c+3\alpha)(a+s_1)^2-\alpha(a+s_1)s_2+8\alpha s_2^2}{4(a+s_1)^2+8s_2^2} \tag{34}$$

$$p^N = \frac{\alpha(a+s_1)^2+(c-\alpha)(a+s_1)s_2+\alpha s_2^2}{(a+s_1)^3+2(a+s_1)s_2^2} \tag{35}$$

$$Q_1^N = \frac{s_2(-c-\alpha)(a+s_1)+\alpha s_2}{4(a+s_1)^2+8s_2^2} \tag{36}$$

$$Q_2^N = \frac{(a+s_1)(-(c-\alpha)(a+s_1)+\alpha s_2)}{4(a+s_1)^2+8s_2^2} \quad (37)$$

$$\pi_{M1}^N = \frac{s_2^2((c-\alpha)(a+s_1)-\alpha s_2)^2}{8((a+s_1)^2+2s_2^2)^2} \quad (38)$$

$$\pi_{M2}^N = \frac{((c-\alpha)(a+s_1)-\alpha s_2)^2}{8((a+s_1)^2+2s_2^2)} \quad (41)$$

$$\pi_R^N = \frac{((c-\alpha)(a+s_1)-\alpha s_2)^2((a+s_1)^2+s_2^2)}{16((a+s_1)^2+2s_2^2)^2} \quad (42)$$

4. Model Analysis

Proposition 1: $\pi_{M1} < \pi_{M2}$ if $s_2 > s_1$. Otherwise, $\pi_{M1} > \pi_{M2}$ if $s_2 < s_1$

In a scenario where neither traditional nor new energy vehicle manufacturers possess market power, the profitability outcome hinges on the relative values of positive credits associated with new energy vehicles versus the negative credits linked to fuel consumption. Should the positive credit value of new energy vehicles surpass the negative credit value of fuel consumption, it would yield higher profits for the new energy vehicle manufacturers. On the contrary, it will bring higher profits to traditional car manufacturers.

Proposition 2: When $0 < \alpha < \frac{c(a+s_1)}{a+s_1-s_2}$, $w_1^T > w_2^T, p_1^T > p_2^T, Q_1^T < Q_2^T$. And when $\alpha > \frac{c(a+s_1)}{a+s_1-s_2}$, $w_1^T < w_2^T, p_1^T < p_2^T, Q_1^T > Q_2^T$.

In a scenario where traditional cars hold have market power, the determination of wholesale prices by car manufacturers and the establishment of retail prices by dealers predominantly hinge upon the upper limit of price acceptance among consumers when it comes to purchasing passenger cars. Should consumers exhibit a lower tolerance for the highest price in acquiring passenger cars, traditional car manufacturers would opt for lower market prices. Conversely, new energy vehicle manufacturers would opt for higher market prices.

Proposition 3: When $0 < \alpha < \frac{c(a+s_1)}{a+s_1+s_2}$, $w_1^N > w_2^N, p_1^N > p_2^N, Q_1^N < Q_2^N$. And $\alpha > \frac{c(a+s_1)}{a+s_1+s_2}$, $w_1^N < w_2^N, p_1^N < p_2^N, Q_1^N > Q_2^N$.

Similar to the dominant position of traditional car manufacturers, should consumers exhibit a lesser tolerance for the highest price in acquiring passenger cars, traditional car manufacturers would opt for higher market prices. On the contrary, new energy vehicle manufacturers would opt for even higher market prices.

Proposition 4: When $0 < c < c_0, P^N < P^{M1}$

where c_0

$$= \frac{\alpha(s_1^2(a+s_1)^2 - s_1(a+s_1)(2a+s_1)s_2 + (3a^2 + 2s_1(3a+s_1))s_2^2 + (a+2s_1)s_2^3 - 2s_2^4)}{s_1^2(a+s_1)^2 + (3a^2 + 2s_1(3a+s_1))s_2^2 - 2s_2^4}$$

When traditional car manufacturers dominate, the clearing price of new energy vehicles is mainly influenced by their production costs. The lower the production cost, the lower the clearing price.

5. Numerical simulations

In order to present the previous research conclusions more intuitively, this chapter will analyze them through specific examples. Firstly, the basic parameters in the text were set.

Table 2. Parameters and corresponding values.

Parameter	a	c	s ₁	s ₂
Value	10	2	1	100

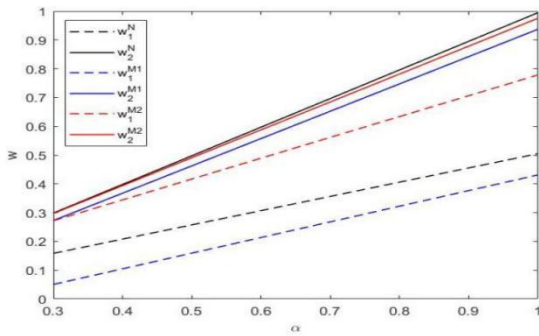


Fig 1. Wholesale price comparison.

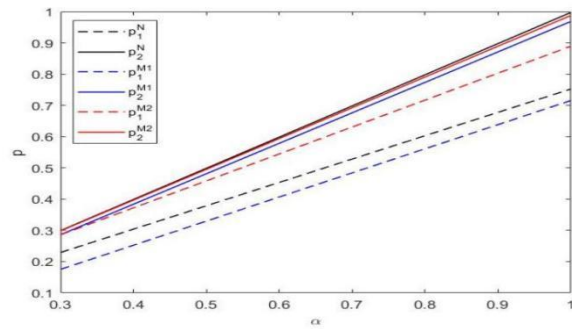


Fig 2. Retail price comparison.

Observing Fig.1, it becomes evident that as the demand for a higher proportion of new energy vehicle credits intensifies, both traditional and new energy vehicle manufacturers will establish elevated wholesale prices. Fig.2 further demonstrates that as the requirements for the new energy vehicle credit ratio escalate, dealers will correspondingly establish higher market retail prices for both fuel vehicles and new energy vehicles.

5.1. Comparative analysis of manufacturer profits

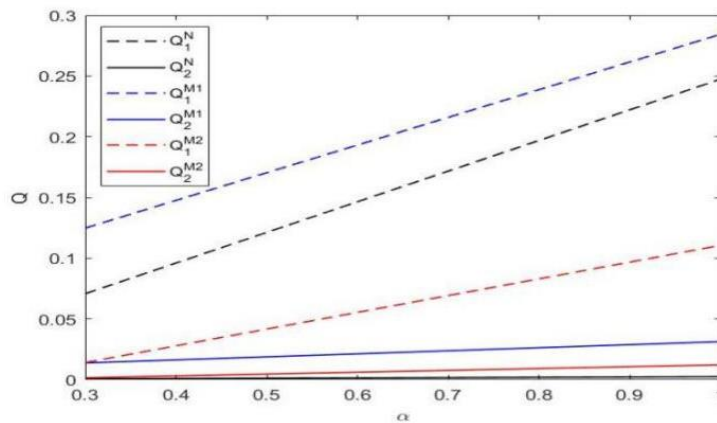


Fig 3. Comparative analysis of manufacturer profits.

It is apparent that as the demand for higher proportion of new energy vehicle credit increases, the profits of both types of manufacturers will surge. In a scenario where neither party possesses market power, the market profits of new energy vehicle manufacturers notably exceed those of traditional vehicle manufacturers. However, when traditional automobile manufacturers dominate, the magnitude of market profits depends on the level of requirement for the new energy vehicle credit ratio. If the ratio is low, traditional automobile manufacturers will secure higher market profits.

5.2. Market clearing price analysis of new energy vehicles

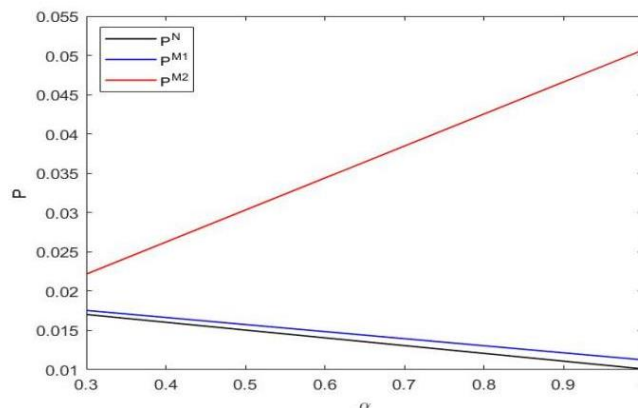


Fig 4. Market clearing price analysis of new energy vehicles.

It becomes evident that as the requirements for the proportion of new energy vehicle credits escalate, the market clearing price of new energy vehicles will witness an upturn when new energy vehicles hold market power. Conversely, the clearing price of new energy vehicles will decrease.

6. Summary

It has found that when the positive credit value of new energy vehicles is higher than the negative credit value of fuel consumption, new energy vehicle manufacturers will obtain higher profits. When the power structure is imbalanced, the wholesale and retail prices are largely determined by the highest price that consumers can accept for passenger cars. When new energy vehicle manufacturers dominate, the clearing price of new energy vehicle credits is mainly influenced by the production cost of new energy vehicles.

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References

- [1] Ministry of Industry and Information Technology Measures for Parallel Management of Average Fuel Consumption and New Energy Vehicle Points of Passenger Car Enterprises [EB/OL] [2018-04-30]
- [2] Shi L, Lin B. The dual-credit policy effectively replaces subsidy from the perspective of R&D intensity [J]. Environmental Impact Assessment Review, 2023, 102: 107160.
- [3] Jun S P, Yoo H S, Kim J H. A study on the effects of the CAFE standard on consumers [J]. Energy Policy, 2016, 91:148-160.
- [4] Wang Y, Zhao F, Yuan Y, et al. Analysis of typical automakers' strategies for meeting the dual-credit regulations regarding CAFC and NEVs [J]. Automotive Innovation, 2018, 1: 15-23.
- [5] Dongchang Z, Rujie Y, Huanhuan R, et al. A Power, Economy and Space Trade-off Analysis on Passenger Vehicles Controlled with China CAFC Requirement [J]. Energy Procedia, 2017,107.
- [6] Kong Y, Ma S J, Tang W C, et al. The policy effect on automobile industry considering the relationship between technology, market and production: The dual-credit policy as an example [J]. Transportation Letters, 2023, 15(3): 163-177.
- [7] Huo H, Luo D, Yan Z. Automaker's credits strategy considering fuel consumption and endurance capacity constraints under dual-credit policy in China [J]. Frontiers in Energy Research, 2023, 10: 963900.