Research on Equilibrium Credit Price Based on Game Theory

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Abstract. Due to the lack of government guidance price and the particularity of the NEV credit, enterprises can not determine the price during the transaction, resulting in a waste of time, money and low transaction efficiency. The analysis shows that both the buyer and seller enterprises have ways to change the trading pattern and influence each other until the game equilibrium is reached, at which time the credit price will remain stable. Based on this point, this paper systematically analyzes the game process between the seller's enterprise and the buyer's enterprise, constructs an equilibrium credit price model, and takes the 2021 trading year as an example to analyze the trading price. This paper provides a reference for clarifying the credit trading process and also contributes ideas to credit price prediction.

Keywords: the Dual-Credit Policy, Game Theory, Equilibrium Credit Price

1 Introduction

1.1 Introduction to the Dual-Credit Policy

In order to improve the energy conservation level and electrification of automotive products and promote the automotive industry to achieve the carbon reduction goals, five departments including the Ministry of Industry and Information Technology issued The Passenger Cars Corporate Average Fuel Consumption and New Energy Vehicle Credit Regulation(hereinafter referred to as the "dual-credit policy") in 2017[1]. It aims at reducing the fuel consumption of traditional vehicles and promoting new energy vehicles, and introduces two corresponding types of credits: "CAFC credit" and NEV credit" . In addition, the dual-credit policy sets different compliance standards according to the production structures of different passenger vehicle enterprises. Positive credits will be generated if the standards are met, and negative credits will be generated if the standards are not met. Generally speaking, enterprises with positive credits which are up to standards have an early layout for new energy vehicles, high market acceptance and high penetration rate of new energy vehicles; enterprises with negative credits which are not up to standards do not have a complete layout for new energy vehicles, and their production of new energy vehicles has not yet become large-scale, with both the manufacturing cost and market acceptance inferior to those of enterprises with positive credits.

For enterprises with negative credits, the negative credits can be offset through the carry-over, transfer and trading of credits. In the process of offsetting, enterprises with negative credits

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pay considerable prices to purchase positive credits to achieve credit compliance, while enterprises with positive credits gain considerable benefits by selling credits.

1.2 Obstruction of the credit transaction

Credit offset involves a large time span and a complex decision-making process. Generally, it is based on the calendar year and divided into the accounting and trading stages. The accounting stage is the stage when credits are generated. The stage period involves January to December of the year when the credits are generated. During this period, the output of passenger vehicles continues to increase, and the credit status changes accordingly. The trading stage is the stage when negative credits are transferred and traded. The stage period is from January to September of the next year after the credits are generated. During this period, the output of passenger vehicles in the previous year will not change and the credit status will be fixed. The time span and credit status of credit accounting and credit trading stages are shown in **Figure 1.**

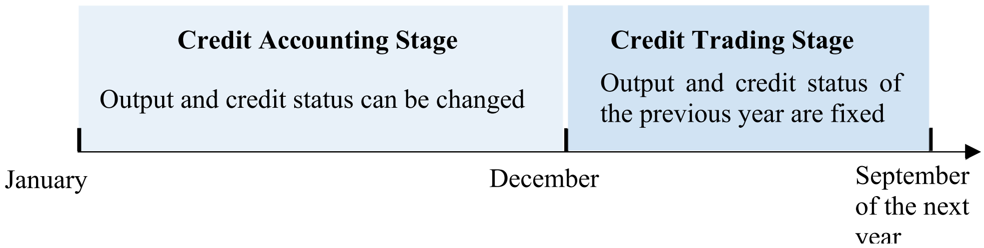

Fig. 1. Credit Accounting and Credit Trading Stages

In the two stages, enterprises with positive credits and enterprises with negative credits can carry out different activities respectively. In the credit accounting stage, some enterprises with negative credits start credit trading in advance, and enterprises with positive credits give quotations based on the credit market situation in the current year. Since the production schedule of enterprises with negative credits can still be adjusted at this time of year, enterprises with negative credits compare the credit quotations with the costs to gain positive credits through their own "production" and make a decision to achieve compliance: purchasing credits from enterprises with positive credits, or realizing self-compliance through their own production of new energy vehicles[2]. In the credit trading stage, enterprises with positive credits make a decision on the credits of the previous year: selling them to the enterprises with negative credits, carrying them over to subsequent years, or storing them in the credit pool. Among them, "carry-over waste" will occur when the credits are carried over to subsequent years. For example, the carry-over period is three years, 90% of the CAFC credits will be retained every year and carried over to the subsequent year, and 50% of the NEV credits will be retained every year and carried over to the subsequent year. The remaining 10% and 50% of the credits will be invalidated as carry-over waste. The credit pool[3] is a supply-demand regulating mechanism proposed by the competent departments in 2022 in regard to the dual-credit policy. It can collect and store surplus positive credits when the supply and demand of credits are loose, and release positive credits without loss in a year of tight supply. It has the advantage of dynamically regulating the supply and demand of credits and avoiding carry-over waste. Meanwhile, enterprises with negative credits must achieve compliance through credit trading at this stage.

Up to now, although four credit transactions have been completed, due to the lack of price prediction, the credit price has fluctuated significantly during the transaction, which has brought great risks and challenges to the implementation of policy management and enterprise product planning. In the process of transaction, due to the lack of government guidance price and the particularity of the NEV credit, enterprises can not determine the transaction price, resulting in a waste of time and low transaction efficiency. What's worse, limited by the imperfect trading mechanism, the industry does not have a reasonable credit price forecasting method, and a stable forecast price has become the common voice of industry and enterprises. Through sorting out the process of credit trading, this paper analyzes the decision-making considerations of credit buyers and sellers, and proposes a prediction method of credit price from the perspective of game theory.

2 Equilibrium Credit Price Model Based on the Buyer-Seller Game

In the process of credit offset, the buyer and the seller both have the approaches to actively regulate the credit status. For enterprises with negative credits, i.e. buyers, when the credit price is too high, increasing the output of their own energy-saving and new energy models in the credit accounting stage can effectively reduce their negative credits, and at the same time increase the credit supply-demand ratio to reduce the price and finally reduce the total compliance cost[4]. For enterprises with positive credits, i.e. sellers, when the market credit price is too low, they can take the initiative to store NEV credits in the credit pool or carry them over to subsequent years, so as to achieve the purpose of reducing the effective supply and increasing the price in the current year, and finally improve the total benefits.

To sum up, enterprises with negative credits regulate the industry's supply-demand pattern through compliance strategy adjustment, thus affecting the credit price and the income of enterprises with positive credits. Enterprises with positive credits can also regulate the supply and demand of credits by changing their planning of credit sale, affecting the credit price and further affecting the compliance strategy of enterprises with negative credits. Thus, a dynamic game comes into being until an equilibrium status is reached and an equilibrium credit price is set. The process is shown in **Figure 2.** below.

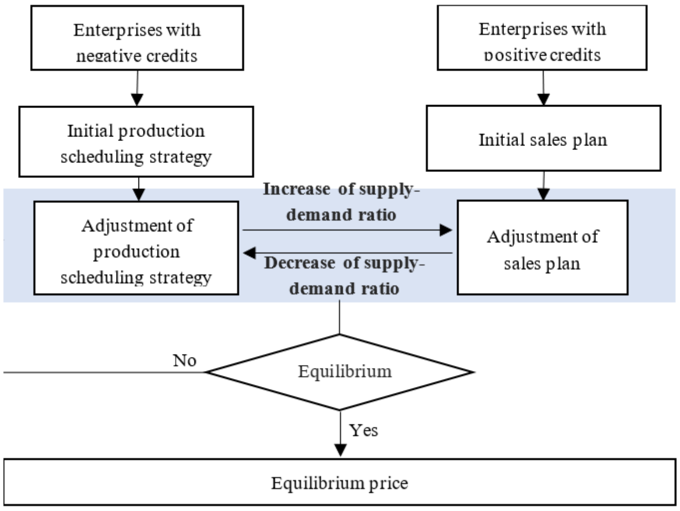

Fig. 2. Game Process of Enterprises with Positive and Negative Credits

2.1 Decision-making process of enterprises

2.1.1 Decision of enterprises with negative credits

Enterprises with negative credits pursue the minimum total cost, which is restricted by the total negative credits and the credit price. The optimization equation is shown in Equation (1).

$$Min\ C = p_1 \cdot q_1 + Sc \cdot q_2$$
$$s.t.\begin{cases} q_1 + q_2 = Q \\ p_1 = f(Sc, \alpha) \\ \alpha = \frac{s}{q} \\ q = q_1 \\ 0 \leq q_1, q_2 \leq Q \end{cases} \tag{1}$$

Where, C is the total cost of enterprises with negative credits, including the credit purchase cost ($p_1 \cdot q_1$) and the self-compliance cost ($Sc \cdot q_2$). p_1 is the credit trading price, q_1 is the number of credits traded, Sc is the unit credit cost in the self-compliance approach, in RMB/unit, and q_2 is the number of credits generated in the self-compliance approach.

The credit trading price is a function of self-compliance cost, Sc and supply-demand ratio, α, and is positively correlated with Sc and inversely correlated with α. The supply-demand ratio is the ratio of the total credit supply, s to the total credit demand, q.

2.1.2 Decision of enterprises with positive credits

Similarly, enterprises with positive credits pursue the maximum total income, which is restricted by the total supply of positive credits and the credit price. Under the hypothesis of enterprises with positive credits being short-sighted, the optimization equation is shown in Equation (2).

$$Max\ W = p_1 s_1$$

$$s.t.\begin{cases} p_1 = f(Sc, \alpha) \\ \alpha = \frac{s}{q} \\ s = s_1 \\ 0 \le s_1 \le S \end{cases} \tag{2}$$

Where, W is the total income of enterprises with positive credits, mainly including the income from the sale of credits in the current year. p_1 is the credit trading price, s_1 is the number of credits sold, and S is the maximum credit supply. Since enterprises with positive credits can actively choose to store the credits in the credit pool and carry them over, the number of credits sold is the actual effective supply, so for supply, $s = s_1$.

For enterprises with negative credits, q_1 and q_2 are taken as optimization variables, impacting enterprises with positive credits. For enterprises with positive credits, s_1 is taken as optimization variables, responding to the adjusted strategy of enterprises with negative credits and further affecting the compliance strategy of those enterprises. This process is iterated until game equilibrium is reached. At this moment, neither enterprises with positive credits nor enterprises with negative credits have the motivation to carry out readjustment, and the price becomes stable.

2.2 Solution of Equilibrium Price Model Based on the Buyer-Seller Game

With q_1 and s_1 taken as the optimization variables, the Lagrange multiplier method is used to solve the above optimization Equations (1) and (2), and the optimal solution can be obtained when q_1 and s_1 meet the following conditions, and the game reaches equilibrium.

Specifically, the constraint conditions of Equation (1) are substituted into the objective function, and we can reduce Equation (1) into Equation (3).

$$Min\ C = f(Sc, \frac{S}{q_1})q_1 + Sc(Q - q_1)$$

$$s.t.\begin{cases} q_1 \le Q \\ -q_1 \le 0 \end{cases} \tag{3}$$

For optimization Equation (3), according to value theory and credit trading law, the credit price increases with the increased number of positive credits purchased by enterprises with negative credits, and the price increase accelerates with the increase of purchase quantity. It can be proved that

$$\frac{dp_1}{dq_1} = \frac{f(Sc, \frac{S}{q_1})}{dq_1} \ge 0,$$

so the objective function is convex. The second derivative of the constraint condition in relation to q_1 is 0, which satisfies the negative semi-definite Hessian matrix, so (3) is a convex programming problem, and the Karush-Kuhn-Tucker Conditions (KKT conditions) are necessary and sufficient conditions for the optimal solution of (3)[5]. KKT conditions are shown in (4).

$$\begin{cases} \nabla_{q_1} C + \lambda_1 \cdot \nabla_{q_1}(q_1 - Q) + \lambda_2 \cdot \nabla_{q_1}(-q_1) = 0 \\ \lambda_1(q_1 - Q) = 0 \\ \lambda_2(-q_1) = 0 \\ \lambda_1, \lambda_2 \geq 0 \end{cases} \tag{4}$$

By solving Equation (4), the optimal solution q_1^* can be obtained, which shall meet Equation (5).

$$\begin{cases} -\frac{s}{q_1^*} \cdot \nabla_{q_1} f(SC, \frac{s}{q_1^*}) + f(SC, \frac{s}{q_1^*}) - SC + \lambda_1 - \lambda_2 = 0 \\ \lambda_1(q_1 - Q) = 0 \\ \lambda_2(-q_1) = 0 \\ \lambda_1, \lambda_2 \geq 0 \end{cases} \tag{5}$$

We reduce Equation (2) to obtain Equation (6).

$$Max\ W = f(Sc, \frac{s_1}{q_1^*}) s_1$$

$$s.t. \begin{cases} s_1 \leq S \\ -s_1 \leq 0 \end{cases} \tag{6}$$

The optimal solution s_1^* can be obtained by explicating Equation (5) as an explicit function $q_1^* = g(SC, s_1)$ in relation to q_1^* and substituting it into (6).

3 Equilibrium Price of Buyer-Seller Credit Game Based on Reality

With the credit trading in 2021 taken as an example, we analyze the equilibrium credit price in the buyer-seller game. According to the Annual Report on the Dual Credits Policy Implementation issued by the Ministry of Industry and Information Technology, in the trading year of 2021, the total supply of positive credits for new energy vehicles in the industry was 6.29 million credits, and the deficits of negative credits was 5.24 million. It is estimated that the compliance cost was about RMB 3,000/unit. The credit price is negatively correlated with the supply-demand ratio and positively correlated with the compliance cost, but there is no industry consensus on the quantitative relationship. In order to explain the game process, we might as well assume that the credit price has a linear relationship with the above influencing factors, i.e.

$$p_1 = f(Sc, \alpha) = m \cdot SC + n \cdot \frac{s_1}{q_1} + \varepsilon \tag{7}$$

According to the public data, the credit price expression is as follows

$$p_1 = 1.03 \cdot SC - 525.96 \cdot \frac{s_1}{q_1} - 371.68 \tag{8}$$

We substitute (8) into (5) to obtain the optimal solution q_1^* for buyers

$$q_1^* = 5.24 \times 10^6 \tag{9}$$

We further obtain the optimal solution s_1^* for sellers

$$s_1^* = 6.29 \times 10^6 \tag{10}$$

It can be found that the optimal decision of the buyer is to maintain the original production scheduling plan, and the deficits of all negative credits is offset by purchasing NEV credits; the optimal decision of the seller is to sell all NEV credits. In this case, the credit price reaches equilibrium and is fixed at around RMB 2,000. The theoretical optimization decision is consistent with the actual behavior of the enterprise, and the above analysis is effective.

4 Conclusions

Focusing on the full cycle of the credit market, this paper systematically analyzes the game behavior of buyers and sellers in the process of credit trading, and discovers a set of methods to determine the equilibrium credit price. The rationality of equilibrium decision-making and equilibrium price is further verified through the empirical analysis of the annual trading data in 2021.

Based on the mutually exclusive regulation effects of enterprises with positive and negative credits on the credit market, this paper uses the research idea of game theory to analyze in detail the decision-making adjustment behavior of enterprises on both sides of the game for the purpose of achieving objective optimization, and thus summarizes the method of determining the equilibrium price of the credit trading game, which can provide ideas and support for the credit price prediction and other analysis.

It is worth noting that the equilibrium credit price obtained is highly correlated with the expression form of the price model. The form shown in this paper is only one way of thinking, while in other forms, the final results may vary, but the research idea described in this paper still applies.

References

[1] Ministry of Industry and Information Technology, Ministry of Finance, Ministry of Commerce, et c.: Measures for the Parallel Administration of the Average Fuel Consumption and New Energy Vehi cle Credits of Passenger Vehicle Enterprises. http://www.gov.cn/xinwen/2017-09/28/content_522821 7.html

[2] Chai Qiangfei, Xiao Zhongdong, Zhou Guanghui: Strategy Selection for Traditional Car Manufact urers under the Dual-credit Policy. Journal of Industrial Engineering and Engineering Management. P p. 124-133 (2022)

[3] Ministry of Industry and Information Technology: Public Solicitation for Comments on the Decisi on on Amending the Measures for the Parallel Administration of the Average Fuel Consumption and New Energy Vehicle Credits of Passenger Vehicle Enterprises (Draft for Comments). https://www.mi it.gov.cn/gzcy/yjzj/art/2022/art_584bce0d78fe4819aa7cf46e8c4094e8.html

[4] Chen Chuan, Su Hui, Liu Yutong, Research on Credit Price Trend of New Energy Vehicle Based on Multi-Factor Analysis, China Auto, pp. 55-58 (2022)

[5] Karush W, Tucker W: Nonlinear Programming: Proceedings of the 2nd Berkeley symposium on mathematics, statistics and probability, Berkeley: University of California Press, pp. 481–492 (1951)