Pricing Decisions of Two Products with Carbon Emissions Trading and Green Technology Investment

*Xiangchao Liu**
Sichuan Technology and Business University
Chengdu, China
375059733@qq.com*

Hua He
Tian Fu College of Southwestern University of Finance and Economics
Mianyang, China

Changsong Ma, Hongmei Zhang
Sichuan Technology and Business University
Chengdu, China

***Abstract*— In this paper, we study the monopoly market two products manufacturing enterprises in carbon cap and trade policy, respectively, for carbon emissions trading decisions, green technology investment decision, carbon emissions trading and green technology investment portfolio decision three cases the optimal pricing decision. The optimal pricing combination of two product manufacturing enterprises under three conditions is presented. The research results show that the government's carbon quota will have an important impact on the optimal pricing policy of manufacturing enterprises, carbon emissions trading and green technology investment can optimize and improve the pricing decisions of enterprises to a certain extent.**

Key words: carbon trading; green technology investment; two product; pricing decision

I. INTRODUCTION

With the global warming, as well as the increasingly serious environmental pollution, human life and work has brought serious challenges. In order to alleviate the problem of climate warming, reduce environmental pollution, Governments are in the introduction of relevant policies. The implementation of the carbon limit policy comes from the Kyoto Protocol, which aims to achieve effective emission reduction by means of control. The product pricing strategy under the carbon cap, carbon emissions trading and green technology investment can provide the reference and basis for the pricing policy of manufacturing enterprises under the policy of low carbon emission reduction.

Research on pricing strategy under carbon cap and trade policy, Hua analysis of the effect of carbon emission trading on Retailer's optimal order quantity, optimal pricing and maximum expected profit [1]; Zhu of B-S Option Pricing Model to analyze the pricing of decentralization of the carbon emissions [2]; Hou using game theory of carbon trading price of closed-loop supply chain pricing [3]. Zhang use newsboy model established manufacturing enterprises rely on the production and storage of carbon emissions trading mechanism under the optimal decision model, obtained the optimal pricing of products [4]. Choi based on the newsboy model analysis in carbon cap and trade policy under the constraint, product prices of retailer's procurement source selection effects [5].

Regarding to the research on green technology and its investment under the policy of carbon quota, Brawn and Wield pointed out that the green technology is a kind of reduction in the process of production and consumption in the process of the ecological environment of the transmission of the external technology [6]; Yu from the basis of green technology, innovation of green technology and ecological green technology three levels of the meaning of green technology and categories were defined [7]; Zhu analysis of the environmental factors that affect the enterprise green technology innovation, the establishment of a multi-level fuzzy comprehensive evaluation model of enterprise green technology innovation environment [8].

From the above analysis can be known, few scholars have studied the pricing decision of manufacturing enterprises from the perspective of carbon emissions trading and green technology investment. The pricing of enterprise products directly affect the enterprise product sales, income and enterprise competition and development, and under the new environment of the production of green technology investment and low carbon products, enterprise product pricing is bound to face new problems. To discuss the pricing decision of carbon emissions trading and green technology investment under the carbon cap and trade policy has become an urgent problem to be solved.

II. PROBLEM STATEMENT AND BASIC ASSUMPTION

In a monopoly market, there is a manufacturing enterprise and two products on the market. Sales at the end of the period, the remaining inventory will be processed according to the residual value. At the same time, manufacturing enterprises will face shortage loss. Under the restriction of carbon quota and trade policy, the government provides one of the biggest carbon emissions, namely the carbon quota K (>0). In order to express convenience, the meaning of the symbol in the model is as follows:

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TABLE 1 MEANING OF THE SYMBOL IN MODEL

Parameter	*Parameter implication*
Q_1 and Q_2	*Product 1 and product 2 yield*
$r_1$and r_2	*Out of stock opportunity cost per unit of product 1 and 2*
$v_1$and v_2	*Each unit of product 1 and 2 in the residual value at the end of sales*
K	*Maximum carbon emissions*
W	*Carbon trading volume*
w	*Per unit of carbon emission rights price*
z	*Risk free inventory factor*
$p_1$and p_2	*Price level of Product 1 and product 2*
T	*Manufacturing enterprise green technology investment level*
c_1 and c_2	*Did not carry out the green technology, the production cost per unit of product 1 and 2*
$c(T)_1$ and $c(T)_2$	*After the green technology investment, the production cost per unit of product 1 and 2*
k_1 and k_2	*Carbon emissions per unit of product 1 and 2 of the product without the green technology input*
$k(T)_1$ and $k(T)_2$	*Carbon emissions per unit of product 1 and 2 of the product with the green technology input*

In this paper, the above mentioned parameters must satisfy certain conditions:

(1)$p_i \geq c_i > v_i > 0,(i = 1,2)$ This condition indicates that every product sold in the consumer market will bring profit to the manufacturing enterprise. On the other hand, if a product is not sold, the manufacturing enterprise will suffer the loss of profit.

(2) The demand function of the model is $D_i(p_i,\ \varepsilon_i) = y(p_i) + \varepsilon_i$ （$a_i, b_i, \geq 0, D_i > 0$）， $y_i(p_i) = a_i - b_i p_i$（$a_i > 0$，$b_i > 0$）, D_i for market demand, $y_i(p_i)$to describe the demand is the price reduction function, a_i represents market potential demand. b_i for price sensitivity to demand, ε_i for demand deviation.

(3) Manufacturing companies will weigh the benefits and costs of carbon emissions trading and investment in green technology.

(4) Manufacturing companies can reduce their carbon emissions by investing in green technology.

Green technology investment cost $c(T)_i$， it is continuous and differentiable, with the rising of the level of the green technology investment and accelerate the rise of T, the value of T range of 0 to 1. $c_i'(T) > 0$， $c_i''(T) > 0, c_i(0) = c_i$

(5) Manufacturing enterprises to invest in green technology, make $Q_i = y(p_i, T_i) + z_i$, $D_i = y(p_i, T_i) + \varepsilon_i$, $y(p,T) = a_i - bp_i + \delta_i T_i$. δ_i for the impact of green technology investment on demand.

(6)Make $\theta_i(p_i) = -\dfrac{1}{b_i k_i(T_i)} \dfrac{d\pi(\mathbf{p},\mathbf{z})_{p_i}}{dp_i}$,

$p = (p_1, p_2), \mathbf{z} = (z_1, z_2)$

III. BASIC MODEL

At the beginning of the production period, the production capacities of the two products were Q_1 and Q_2. The rest of the product is treated with unit cost v_1 andv_2. Unit penalty costs were r_1 and r_2, when the government provides a maximum carbon emission, that is $K(>0)$, manufacturing enterprises in the production of carbon emissions cannot be more than the government's mandatory limits.

The expected profit function for manufacturing enterprises in this case is:

$$\begin{cases} \pi^K(\mathbf{p_K}, \mathbf{z_K}) = \\ \sum_{i=1}^{2} \begin{pmatrix} (p_i + r_i - c_i)(y(p_i) + z_i) - \\ (p_i + r_i - v_i)\int_0^{z_i} F_i(x)dx - r_i \mu_i \end{pmatrix} \\ s.t.\ \sum_{i=1}^{2} k_i (y(p_i) + z_i) \leq K \end{cases} \quad (1)$$

$\mathbf{p_K} = (p_1, p_2), \mathbf{z_K} = (z_1, z_2)$. Manufacturing enterprises in this case the decision goal is to maximize the expected profit.

Proposition 1: Under the carbon limitation, The optimal selling price of manufacturing enterprises $p_{1K}^* \geq p_1^*, p_{2K}^* \geq p_2^*$.

prove：Tectonic Lagrange factor $\varphi \geq 0$, According to the constraint conditions:

$$\begin{cases} k_1(a_1 - b_1 p_1 + z_1) + k_2(a_2 - b_2 p_2 + z_2) - K \leq 0 \\ \varphi \begin{pmatrix} k_1(a_1 - b_1 p_1 + z_1) + k_2(a_2 - b_2 p_2 + z_2) \\ -K \end{pmatrix} = 0 \\ a_1 - 2b_1 p_1 + z_1 - b_1(r_1 - c_1) - \\ \int_0^{z_1} F(x)dx - \varphi k_1 b_1 = 0 \\ a_2 - 2b_2 p_2 + z_2 - b_2(r_2 - c_2) - \\ \int_0^{z_2} F(x)dx - \varphi k_2 b_2 = 0 \end{cases}$$

When φ=0 , $k_1(a_1 - b_1 p_1 + z_1) + k_2(a_2 - b_2 p_2 + z_2) \leq K$, get

$$\frac{\partial \pi^n(\mathbf{p_K}, \mathbf{z_K})_{p_i}}{\partial p_1} = 0, \frac{\partial \pi^n(\mathbf{p_K}, \mathbf{z_K})_{p_i}}{\partial p_2} = 0$$

Then can get $p_{1K}^* = p_1^*, p_K^* = p^*$, here $K \leq \sum_{i=1}^{2} k_i Q_{iK}^*$,

When $\varphi \geq 0$, $k_1\left(a_1-b_1 p_1+z_1\right)+k_2\left(a_2-b_2 p_2+z_2\right)=K$, get

$$\frac{\partial \pi^n\left(\mathbf{p_K}, \mathbf{z_K}\right)_{p_i}}{\partial p_1}=a_1-2 b_1 p_1+z_1-$$

$$b_1\left(r_1-c_1\right)-\int_0^{z_1} F(x) dx=\varphi k_1 b_1>0$$

$$\frac{\partial \pi^n\left(\mathbf{p_K}, \mathbf{z_K}\right)_{p_i}}{\partial p_2}=a_2-2 b_2 p_2+z_2-$$

$$b_2\left(r_2-c_2\right)-\int_0^{z_2} F(x) dx=\varphi k_2 b_2>0$$

So $p_{1K}^*>p_1^*$, $p_K^*>p^*$ .Proof finished.

To sum up, under the constraint of carbon limitation, The optimal selling price of manufacturing enterprises $p_K^* \geq p^*$, it shows that the optimal selling price of manufacturing enterprise is not lower than the optimal selling price under the no carbon quota.

IV. DEVELOPMENT MODEL

Carbon cap and trade policy is a policy tool to regulate carbon emissions through the market. Government provides a maximum carbon emission, that is $K(>0)$, Carbon emissions produced by manufacturing enterprises cannot exceed the mandatory limits prescribed by the government, and manufacturing companies will seek the best pricing combination. This paper will be divided into three cases discussed:

(1) Under the constraint of carbon quota, the manufacturing enterprises will consider making carbon emission trading decisions;

(2) Under the constraint of carbon quota, the manufacturing enterprises will consider making green technology investment decisions;

(3) Under the constraint of carbon quota, manufacturing enterprises will consider the combination of carbon emissions trading and green technology investment decisions.

A. Situation One: Carbon Emissions Trading Decisions

Case one is under the carbon quota constraints, manufacturing enterprises only carbon emissions trading decisions. Among them, W is the amount of carbon emissions trading on the external carbon trading market. w as the unit price of carbon emission rights.

The expected profit function for manufacturing enterprises in this case is:

$$\begin{cases} \pi^e\left(\mathbf{p_e}, \mathbf{z_e}\right)= \\ \sum_{i=1}^2\left(\begin{array}{l}\left(p_i+r_i-c_i\right)\left(y\left(p_i\right)+z_i\right)- \\ \left(p_i+r_i-v_i\right)\int_0^{z_i} F_i(x) dx-r_i \mu_i\end{array}\right) \\ -wW \\ s.t. \ \sum_{i=1}^2 k_i\left(y\left(p_i\right)+z_i\right)=K+W \end{cases} \quad (2)$$

$\mathbf{p_e}=\left(Q_1, Q_2\right); \mathbf{z_e}=\left(z_1, z_2\right)$, Manufacturing enterprises in this case the decision goal is to maximize the expected profit.

$$\sum_{i=1}^2 k_i\left(y\left(p_i\right)+z_i\right)=K+W$$

Proposition 2: Decision making for carbon emissions trading in manufacturing enterprises, there is only the optimal selling price that makes the manufacturing enterprises expect to maximize the profit, Optimal selling price:

$p_{ie}^*\left(\mathbf{z}_e\right)=\frac{a_i-b_i\left(r_i-c_i\right)+z_i-\int_0^{z_i} F(x) dx+b_i k_i w_i}{2b}$; , and $i=1,2$

$\theta_1\left(p_1^*\right)=\theta_2\left(p_2^*\right)=w$.

prove：From the formula 2, $W=\sum_{i=1}^2 k_i\left(y\left(p_i\right)+z_i\right)-K$, therefore, the expected profit function becomes

$\pi^e\left(\mathbf{p_e}, \mathbf{z_e}\right)=$

$$\sum_{i=1}^2\left(\begin{array}{l}\left(p_i+r_i-c_i\right)\left(y\left(p_i\right)+z_i\right)- \\ \left(p_i+r_i-v_i\right)\int_0^{z_i} F_i(x) dx-r_i \mu_i\end{array}\right)-$$

$$w\left(\sum_{i=1}^2 k_i\left(y\left(p_i\right)+z_i\right)-K\right)$$

Further Hessian matrix:

$$\left|\begin{array}{ll}\frac{\partial^2 \pi^e\left(\mathbf{p_e}, \mathbf{z_e}\right)_{p_i}}{\partial p_1^2} & \frac{\partial^2 \pi^e\left(\mathbf{p_e}, \mathbf{z_e}\right)_{p_i}}{\partial p_1 \partial p_2} \\ \frac{\partial^2 \pi^e\left(\mathbf{p_e}, \mathbf{z_e}\right)_{p_i}}{\partial p_2 \partial p_1} & \frac{\partial^2 \pi^e\left(\mathbf{p_e}, \mathbf{z_e}\right)_{p_i}}{\partial p_2^2}\end{array}\right|=4 b_1 b_2>0$$

So $\pi^e\left(\mathbf{p_e}, \mathbf{z_e}\right)$ is a concave function of p_i , According to the first order optimal condition, there is only one optimal selling price p_{ie}^*.

Its satisfaction: $\left.\frac{\partial \pi^e\left(\mathbf{p_e^*}, \mathbf{z_e}\right)}{\partial p}\right|_{p_i^*}=0$ or

$$a_i - b_i\left(r_i - c_i\right) + z_i -$$

$$p_{ie}^*\left(\mathbf{z}_e\right) = \frac{\int_0^{z_i} F(x)\,dx + b_i k_i w_i}{2b}; i = 1,2 .$$

Summary of the manufacturing enterprises, the optimal selling price:

$$a_i - b_i\left(r_i - c_i\right) + z_i^* -$$

$$p_{ie}^*\left(\mathbf{z}_e^*\right) = \frac{\int_0^{z_i^*} F(x)\,dx + b_i k_i w_i}{2b}; i = 1,2 .$$ Proof finished.

B. Case Two: Making Green Technology Investment Decision

Case two is under the carbon limit, manufacturing enterprises to invest in green technology to obtain carbon emissions savings, access to additional carbon emissions. When the manufacturing enterprise carries on the green technology investment, make $Q_i = y\left(p_i, T_i\right) + z_i$, $D_i = y\left(p_i, T_i\right) + \varepsilon_i$, $y\left(p_i, T_i\right) = a_i - bp_i + \delta_i T_i$, ε_i random variables on the $[0, A]$, Its cumulative distribution function is $F(\cdot)$, δ_i indicates the impact of green technology investment on demand, then

$q_i - D_i = z_i - \varepsilon_i$, $\left(Q_i - D_i\right)^+ = \int_A^z F(x)dx$, at the same time, two kinds of products for green technology investment.

The expected profit function for manufacturing enterprises in this case is:

$$\begin{cases} \pi^t\left(\mathbf{p_t}, \mathbf{z_t}, \mathbf{T}\right) = \\ \sum_{i=1}^2 \left(p_i + r_i - c_i\left(T_i\right)\right)\left(y\left(p_i, T_i\right) + z_i\right) - \\ \left(p_i + r_i - v_i\right)\int_0^{z_i} F_i(x)dx - r_i\mu_i \\ s.t.\ \sum_{i=1}^2 k_i\left(T_i\right)\left(y\left(p_i, T_i\right) + z_i\right) \le K \end{cases} \tag{3}$$

$\mathbf{p_t} = \left(p_1, p_2\right)$, $\mathbf{z_t} = \left(z_1, z_2\right)$, $\mathbf{T_t} = \left(T_1, T_2\right)$, Manufacturing enterprises in this case the decision goal is to maximize the expected profit.

Proposition 3: Manufacturing enterprises to invest in green technology decisions, there is a profit maximization of the enterprise to maximize the sales price of $p_{it}^*; i = 1,2$, the investment level of green technology is $T_1^* \in (0,1)$ and $T_2^* \in (0,1)$, in accordance with the formula5.

prove：Tectonic Lagrange factor

$$\begin{gathered} \left(p_i + r_i - c_i\left(T_i\right)\right) \\ L^t\left(\mathbf{p_t}, \mathbf{z_t}, \mathbf{T}\right) = \sum_{i=1}^2 \left(y\left(p_i, T_i\right) + z_i\right) - \left(p_i + r_i - v_i\right) \\ \int_0^{z_i} F_i(x)dx - r_i\mu_i \\ + \lambda\left(K - \sum_{i=1}^2 k_i\left(T_i\right)\left(y\left(p_i, T_i\right) + z_i\right)\right) \end{gathered} \tag{1}$$

(1)By the terms of the $\lambda = 0$, above K-T condition is:

$$\begin{cases} y\left(p_1, T_1\right) + z_1 - b_1\left(p_1 + r_1 - c_1\left(T_1\right)\right) - \int_0^{z_1} F_1(x)dx = 0 \\ y\left(p_2, T_2\right) + z_2 - b_2\left(p_2 + r_2 - c_2\left(T_2\right)\right) - \int_0^{z_2} F_2(x)dx = 0 \\ p_1 + r_1 - c_1\left(T_1\right) - \left(p_1 + r_1 - v_1\right)F_1\left(z_1\right) = 0 \\ p_2 + r_2 - c_2\left(T_2\right) - \left(p_2 + r_2 - v_2\right)F_2\left(z_2\right) = 0 \\ -\frac{\partial c_1\left(T_1\right)}{\partial T_1}\left(y\left(p_1, T_1\right) + z_1\right) + \delta\left(p_1 + r_1 - c_1\left(T_1\right)\right) = 0 \\ -\frac{\partial c_2\left(T_2\right)}{\partial T_2}\left(y\left(p_2, T_2\right) + z_2\right) + \delta\left(p_2 + r_2 - c_2\left(T_2\right)\right) = 0 \end{cases} \tag{4}$$

Because the problem is concave planning, therefore the existence of p_{1t}^*、p_{2t}^*、T_{1t}^*、T_{2t}^*、z_{1t}^*、z_{2t}^* makes the above equations set up. The optimal selling price of manufacturing enterprises and the optimal green technology investment level of the product are given by the formula 4. After the green technology investment, the surplus amount of carbon emission right is

$W_t^* = K - k_1\left(T_{1t}^*\right)Q_{2t}^* - k_2\left(T_{2t}^*\right)Q_{2t}^*$, In this case, the production of carbon emissions from manufacturing enterprises is not the surplus and cannot be sold through the external carbon emissions trading market profits, Therefore, manufacturing enterprises will not be invested in green technology.

(2)by the terms of the $z_1 \neq 0$, $z_2 \neq 0$, $\lambda \neq 0$, above K-T condition is:

$$\begin{cases} y\left(p_i, T_i\right) + z_i - b_i\left(p_i + r_i - c_i\left(T_i\right)\right) - \\ \int_0^{z_i} F_i(x)dx + \lambda b_i k_i\left(T_i\right) = 0; i = 1,2 \\ p_i + r_i - c_i\left(T_i\right) - \left(p_i + r_i - v_i\right)F_i\left(z_i\right) - \\ \lambda k_i\left(T_i\right) = 0; i = 1,2 \\ -\frac{\partial c_i\left(T_i\right)}{\partial T_i}\left(y\left(p_i, T_i\right) + z_i\right) + \delta\begin{pmatrix} p_i + r_i - \\ c_i\left(T_i\right) \end{pmatrix} - \\ \lambda\left(\frac{\partial k_i\left(T_i\right)}{\partial T_i}\left(y\left(p_i, T_i\right) + z_i\right) + \delta k_i\left(T_i\right)\right) = 0; \\ i = 1,2 \\ K - \sum_{i=1}^2 k_i\left(T_i\right)\left(y\left(p_i, T_i\right) + z_i\right) = 0; \\ i = 1,2 \end{cases} \tag{5}$$

Because the problem is concave planning, therefore the existence of p_{1t}^*、p_{2t}^*、T_{1t}^*、T_{2t}^*、z_{1t}^*、z_{2t}^*、λ_t^*, the optimal selling price of manufacturing enterprises and the optimal green technology investment level of the product are given by the formula 5, manufacturing enterprises carbon emissions of the remaining amount is zero after carry out the green technology investment .

Therefore, under the constraint of carbon quota, the manufacturing enterprise carries on the green technology investment decision; there exists an optimal selling price $p_{it}^*; i=1,2$, optimal level of investment in green technology $T_1^* \in (0,1), T_2^* \in (0,1)$, in accordance with the formula5.

C. Case Three: Carbon Emissions Trading And Green Technology Investment Decisions

Case three is the combination of carbon emissions trading and green technology investment in manufacturing enterprises under the carbon quota constraints. When the two kinds of products are invested in green technology, $T_1 > 0$, $T_2 > 0$, In addition, p_1, p_2 respectively, said the sales price of products 1 and 2, and $p_1, p_2 > 0$.

From the proposition 3, when the manufacturing enterprises to invest in green technology, when

$K \geq \sum_{i=1}^{2} k_i \left(T_i\right) Q_i$, When the cost structure of the enterprise meets the formula 4, the enterprise has the residual carbon emission rights. However, due to the carbon limit, when unable to carry out carbon emission rights trading, manufacturing enterprises cannot sell carbon emission rights surplus profits, will not be invested in green technology. However, in the case of carbon cap and trade, due to the existence of the external carbon trading market, manufacturing enterprises have the potential to profit from the sale of carbon emission rights. We can get the following proposition:

Proposition 4: manufacturing enterprises to implement the combination of carbon emissions trading and green technology investment decisions, in the given parameters of the cost structure and the government to develop carbon limits. When $K \geq \sum_{i=1}^{2} k_i \left(T_{ic}^*\right)\left(y\left(p_{ic}^*, T_{ic}^*\right) + z_{ic}^*\right)$, there exists an optimal green technology investment level which makes the manufacturing enterprises expect to maximize profits $T_{ic}^* = T_{it}^*; i=1,2$, Optimal selling price $p_{ic}^* = p_{it}^*; i=1,2$, and meets the formula 4.

prove：From the proposition 3, we can see that in a given level of investment in green technology, the cost structure and the government to develop carbon limits. When

$K \geq \sum_{i=1}^{2} k_i \left(T_{ic}^*\right)\left(y\left(p_{ic}^*, T_{ic}^*\right) + z_{ic}^*\right)$, enterprises have the potential of carbon emission rights. According to proposition 3 conclusion, in this situation, the optimal green technology investment level is $T_{ic}^* = T_{it}^*; i=1,2$, the optimal sales price $p_{ic}^* = p_{it}^*; i=1,2$, and meet the formula 4. Proof finished.

V. CONCLUSIONS

In this paper, we study the pricing decisions of the two product manufacturing enterprises in the monopoly market under the restriction of the carbon cap and trade policy. The research shows that the optimal selling price of manufacturing enterprises is not lower than the optimal selling price under the constraint of carbon limitation; Decision making for carbon emissions trading in manufacturing enterprises, there is only the optimal selling price that makes the manufacturing enterprises expect to maximize the profit. In the case of the combination of product 1 and product 2 to implement carbon emission right trading and green technology investment, when the optimal production of carbon dioxide (CO_2) emissions from the enterprise is lower than the government's carbon quota, enterprises have the potential of carbon emission rights, companies can be the rest of the carbon emissions in the external carbon trading market for profit. When the optimal production of carbon dioxide (CO_2) emissions from the enterprise is higher than the government's carbon limit, the production and pricing decisions of the enterprises are influenced by the government's carbon quota, At this point, the enterprise will carry on the green technology investment; also will carry on the carbon emission right to purchase.

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