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How Does Carbon Trading Affect the Pricing Strategy of Automobile Companies? A Balancing Act of Optimizing Vehicles Pricing and Production Structures

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Abstract. This paper studies the social-economic impacts of carbon trading on pricing management and the low-carbon behavior of automobile companies. We propose a game model between electric vehicles and gas-powered vehicles. Further, the influence of carbon trading on automobile selling price, sales volume, and sales profit are analyzed from the production mode of a certain company that only produces gas-powered vehicles. Our research contributes to the optimization of automotive companies' pricing, production management, and practices in the face of carbon emission quotas restrictions. The profit function was used to establish a game model for the single condition of producing only gas-powered vehicles, and the optimal sales price and profit of gas-powered vehicles were obtained by backward induction. (1) By adjusting the carbon limit, the government can promote the transformation of the automobile industry. (2) Carbon trading presents an opportunity for businesses with lower carbon emissions to mitigate the competitive disadvantage they face in the market.

Keywords. Carbon trading, competitive market, pricing decision, mechanism design

1. Introduction

The rapid growth of the global economy has brought energy shortages and environmental pollution to many countries. The production of electric vehicles (EVs) gives full play the role of the market mechanism in coping with climate change and stimulating low-carbon development, and promoting greenhouse gas emission reduction [1]. The carbon emission quotas restriction applies to the national carbon emission trading and related activities, including carbon emission quotas allocation and settlement, carbon emission registration, trading and settlement, greenhouse gas emission reporting and verification,

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etc. [2]. The government uses carbon emission quotas to limit the carbon emission of companies. We study the potential competition among different stakeholders, such as automobile companies and consumers, under the control of government-approved carbon emission credits.

Automobile companies that choose to produce are less affected by government carbon emission quotas. In fact, EVs Manufacture does not want to produce EVs [3]. On the one hand, the field of permanent magnet motor research and development technology is lacking. On the other hand, in terms of cost, a large number of motor and electronic control core parts are imported, the purchase price is relatively high, and the delivery cycle is completely subject to foreign companies [4].

Even if it is inconvenient for manufacturers to produce EVs, they have to produce EVs to achieve environmental transformation under the restriction of carbon emission quotas and carbon credit [5]. In order to achieve the transition from high dependence on oil to electricity consumption, automakers are playing a game between EVs and gas-powered vehicles (GVs) production. In the carbon emission quota restrictions vehicle companies have to change their energy structure, reduce exhaust emissions [6].

Carbon trading is facilitated to some extent by carbon allowances from manufacturers. When production requires more carbon emissions than the government's quotas, manufacturers need to buy the required carbon emissions to ensure production is successful [7]. Conversely, when manufacturers produce low-carbon products that emit less carbon than the government permits, they can increase profits by selling excess carbon emissions through carbon trading markets. But when manufacturers buy carbon allowances, they add to the cost of production, resulting in higher unit prices [8]. In other words, carbon trading indirectly affects market competition among manufacturers.

Our analytical results can be summarized as follows:

(1) Based on the production of the gasoline model only the game model is established.

(2) The government limits the carbon emission quotas of automobile companies, which will reduce the convenience of general transportation for users.

(3) Carbon emission quotas limit can promote the transformation of gas-powered vehicle companies.

2. Nomenclature

The nomenclature involved in this paper is shown in Table 1.

Table 1. Nomenclature.

Symbols		**Symbols**	
P_G	Companies' selling price for GVs	λ	Customer demand
P_E	Companies' selling price for EVs	λ_G	Consumer demand for GVs
C_G	Companies' production cost for GVs	λ_E	Consumer demand for EVs
C_E	Companies' production cost for EVs	Π	Profit of the manufacturer
Q_G	Total sales of GVs	K	Emission cap
Q_E	Total sales of EVs	k	The carbon emissions actually produced
U_1, U_2	Consumer utility	K_r	Carbon emissions for trading
v_1, v_2	Consumer valuation	r_G	Carbon emissions reduction level for GVs
ℓ	Consumer prefer	r_E	Carbon emissions reduction level for EVs
w	Carbon trading price	r_0	Initial unit carbon emissions

3. Model

Under Cap-and-trade Policy (CTP), companies are assigned a cap and can trade credits in a carbon market based on their circumstances.

3.1. Decisions

(1) Government regulations aimed at controlling carbon emission quotas for automobile companies. On January 22, 2016, the National Development and Reform Commission issued the Notice on the Key Work of Launching the National Carbon Emission Trading Market. At present, the carbon emission trading market is developing into a national market [9]. The main trading products in the carbon trading market are regulatory credits.

Carbon emission quotas refer to the annual carbon emission quotas allocated by the Ministry of Ecology and Environment according to the Key Emitting Entity in the region reported by each provincial environment department, according to the total greenhouse gas emission control and phased target of the year, and approved by The State Council [4]. We set the upper limit of carbon emission quotas of companies in a certain period as K_0.

(2) When companies reach the carbon emission quotas limit in the production process, companies can conduct carbon trading through the carbon market. Purchase the required carbon emission quotas at the carbon trading price of w. On the contrary, when the enterprise can meet its production conditions, the companies can obtain additional profits by selling the saved carbon quota.

(3) The selling price and the production cost for gas-powered vehicles are designed to harmonize automobile companies and consumers. Considering government restrictions on carbon emission quotas and market competition from electric vehicles against gas-powered vehicles, gas-powered vehicles will set their selling price P_G and the production cost for gas-powered vehicles C_G.

(4) Decision of purchasing intention of users to maximize user utility. To understand the heterogeneity of consumer travel choices, we employ a willingness to pay (WTF) model widely used in transportation and operations management literature.

3.2. Analysis of Willingness to Pay

Willingness to pay is refers to the consumers willing to pay for certain characteristics of a product or service. Specifically, it is the maximum amount of money a consumer is willing to pay for gas-powered vehicles or electric vehicles.

Therefore, in this paper, the price consumers willing to pay is taken into account and the actual sales price of the vehicle.

For the purposes of this article, we set the user utility as:

$$U_E = v_E - P_E \tag{1}$$

$$U_G = v_G - P_G \tag{2}$$

When $U_E > U_G$, consumers prefer electric vehicles.

3.3. Analysis of Potential Demand of Consumers

Next, we consider the potential demand of consumers to buy gas-powered vehicles and electric vehicles.

It is assumed that consumers' valuation of gas-powered vehicles follows a normal distribution, $v_E \sim N(\bar{v}, \sigma^2)$. Assume $\ell > 1$ to describe the extent to which GVs are more popular than EVs. At this point, it is reasonable to assume $\ell > 1$, because most consumers prefer to choose vehicles with long-running times and convenient charging times such as GVs. When $\ell > 1$, the consumer's valuation of the EVs $v_E \sim U[0,1]$, the consumer's valuation of the GVs $v_G = \ell v_E,\ v_G \sim U[0, \ell]$, and the total demand is λ.

From the above assumptions, given the valuation for GVs $v_G = \ell v_E$, the market share of GVs can be obtained as:

$$m_G = \text{Prob}\{\ell v_E \geq P_G, \ell v_E - P_G \geq v_E - P_E\} = \text{Prob}\left\{v_E \geq \max\left\{\frac{P_G}{\ell}, \frac{P_G - P_E}{\ell - 1}\right\}\right\} \quad (3)$$

In this case, we can get $P_G \leq \ell P_E$. At this time, the market demand for electric vehicles is small. Instead, when $P_G > \ell P_E$, we're going to get consumer demand λ. And the cumulative distribution function of v_E is $F(\cdot)$ [10].

Now the requirements of gas-powered vehicles can be obtained as follows:

$$\lambda_G = \lambda \cdot \left[1 - F\left(\frac{P_G - P_E}{\ell - 1}\right)\right]$$

Given the maximum consumer demand is λ.

When $P_G > \ell P_E$,

$$\lambda_G = \lambda \cdot \left(1 - \frac{P_G - P_E}{\ell - 1}\right) \quad (4)$$

4. Analysis of Profit

Now the profit model is set up. The profit function of companies can be divided into two parts, one is the income of the company from selling vehicles, and the other is the expenditure or income in the carbon trading market.

4.1. Optimal Decision-Making of Gas-Powered Vehicle Companies

This section establishes the case where only gas-powered vehicles are considered for production and sale respectively. Emission cap under CTP, we assume that $r_0 Q_G \geq K$, $K = K_r H(w, P_E, P_G) + k$. Assume that the sales price of gas-powered vehicles is greater than the production cost, and the production cost is greater than zero, $0 \leq C_G \leq P_G$.

Given the sales volume $Q_G = \min\{k_G, \lambda_G\}$ of gas-powered vehicles, we can define the optimal selling price of gas-powered vehicles and carbon trading price $({P_G}^*, w^*)$. The profit function is defined as follows:

When $k > K$,

$$\Omega = \max_{P_G,w} \Pi_G\{(P_G - C_G)Q_G - [(r_0 - r_G)Q_G - K]w\}^+$$

$$\text{s.t. } Q_G = \min\{k_G, \lambda_G\}$$

$$\lambda_G = \begin{cases} \lambda \cdot \left(1 - \frac{P_G - P_E}{\ell - 1}\right) & \text{if } P_G > \ell \cdot P_E \\ \lambda \cdot \left(1 - \frac{P_G}{\ell}\right) & o.w. \end{cases} \tag{5}$$

In equation (5), $(P_G - C_G)$ represents the profit from selling gas-powered vehicles,$(P_G - C_G)Q_G$ represents the total revenue from selling gas-powered vehicles, $(r_0 - r_G)Q_G$ represents the required carbon credits, $(r_0 - r_G)Q_G - K$ represents the carbon emission credits that the government needs to purchase when adopting carbon emission quota restrictions. $[(r_0 - r_G)Q_G - K$ represents the cost of purchasing additional carbon emission quotas and $[(r_0 - r_G)Q_G - K]w$ represents the profit from selling the rich carbon emission quotas. Then, although the company did not produce electric vehicles, there were other companies producing electric vehicles in the market [6].

If companies only consider the production of gas-powered vehicles, the selling price of vehicles will affect the overall profit of the enterprise. When the selling price of EVs produced by other companies increases, the optimal selling price of GVs also increases. For any given P_E, the optimal sales price of GVs P_G^* satisfies the following:

$$P_G^* = \frac{C_G + \ell - 1 + P_E - Kw + r_G w}{2}, P_G > \ell \cdot P_E \tag{6}$$

$$P_G^* = \frac{C_G + \ell - r_G w}{2}, P_G \leq \ell \cdot P_E \tag{7}$$

Proof of equations (6) and (7): The first partial derivative of price P_G can be obtained, and the second partial derivative of price can be further calculated as follows: $\frac{\partial^2 \Pi_G}{\partial^2 P_G} = \frac{-2\lambda}{\ell - 1}$. Then the equilibrium uniqueness is proved. By assuming $\ell > 1$, $\lambda > 0$, $\frac{\partial^2 \Pi_G}{\partial^2 P_G} = \frac{-2\lambda}{\ell - 1} < 0$.

The profit function of gas-powered vehicles is the quadratic function of the sold price P_G of gas-powered vehicles, and this function is a concave function with downward openings. It can be seen from the functional properties that the profit function only has a unique maximum point. When companies maximize profits at their own price points, the market also reaches a stable state, and this state is unique. When the market reaches the equilibrium state, the marginal profit margin of the enterprise is zero, $\frac{\partial \Pi_G}{\partial P_G}=0$, and the solution can be obtained.

Therefore, when the market reaches the equilibrium state, the enterprise will maximize its profit. On the premise that the demand function is linear, P_G^* is the optimal price response strategy of the enterprise. That is, given C_G, the optimal price of the company can be obtained by equation (5). P_G^* is the only equilibrium in this game. Then we can get the maximum profit by calculating.

4.2. Results

Through calculation, the optimal price of gas-powered vehicles and the optimal profit can be obtained as follows:

$$P_G^* = \frac{C_G + \ell - 1 + P_E - Kw + r_G w}{2}, P_G > \ell \cdot P_E$$

$$P_G^* = \frac{C_G + \ell - r_G w}{2}, P_G \leq \ell \cdot P_E$$

$$\Pi_G^* = \frac{\lambda}{2}\left(1 - \frac{P_G - P_E}{\ell - 1}\right)\left(\ell - 1 + P_E - C_G + w(2r_G - r_E - K)\right) + Kw$$

(1) $P_G > \ell \cdot P_E$, when consumers buy EVs or GVs based on price alone, there is strong competition in the market. When considering only the maximum profit of companies producing GVs, the unit selling price of GVs decreases with the increase of carbon emissions. When $r_G > K$, the unit selling price of GVs increases with the increase of carbon trading price, and conversely, the unit selling price of GVs decreases with the increase of carbon trading price. Moreover, the sales volume of GVs will increase with the increase of the price for EVs and carbon trading price.

(2) $P_G \leq \ell \cdot P_E$, at this point, the demand for EVs is minimal, and consumers tend to buy GVs instead of EVs. Therefore, in this demand case, the optimal pricing of GVs is not directly affected by carbon emission quota restrictions.

(3) $\lambda\left(1 - \frac{P_G - P_E}{\ell - 1}\right) = 2$, the maximum profits of companies will not be directly affected by carbon emission quotas and carbon trading prices. $\lambda\left(1 - \frac{P_G - P_E}{\ell - 1}\right) > 2$, when the carbon trading price is stable in the market, the higher limit of carbon emission quota, the lower optimal profit of companies. This shows that when the carbon emission quota restrictions are relatively loose, it is not always more favorable for automobile companies to obtain optimal profits. $\lambda\left(1 - \frac{P_G - P_E}{\ell - 1}\right) < 2$, companies are subject to carbon emission quotas, and the closer they are, the harder it is for them to make a profit.

5. Conclusion

Carbon emissions quotas for green emission is of great significance. The government limits the carbon emissions of various companies, however, there are few research on how carbon emission quotas affect the pricing strategy of automobile companies. Through exploring the activities among the government, automobile companies and consumers, we have the following findings.

(1) When government restricts the carbon emission quotas of automobile companies, the lower the upper limit of carbon emission quotas are, the higher the optimal price for GVs will be, and companies are more inclined to set a higher price. Nevertheless, the convenience that users generally enjoy when it comes to transportation will suffer as a result of the high prices.

(2) In a market environment that is highly competitive, carbon trading has the potential to raise the retail unit price for GVs. In this regard, businesses will also raise the unit price for EVs in order to obtain higher returns.

(3) Carbon trading can only promote the sales of trams when the emission reduction for GVs is greater than a certain threshold. The impact of carbon trading on profits is related to the carbon emission reduction of the two models. The carbon emission reduction of GVs is almost zero, so carbon trading is easier for EVs manufacturers to increase profits.

(4) When automobile companies only consider GVs production, carbon emission quotas are less restrictive, which does not always lead to better profits.

In addition, this paper also gives some management enlightenment as follows:

(i) By resetting the threshold for allowable levels of carbon dioxide emissions, the government can encourage the green transformation of the automotive sector. (ii) Carbon trading poses an opportunity for lower-emissions businesses to mitigate the competitive disadvantage. (iii) Businesses are only able to maximize their profits while simultaneously responding to lower carbon emissions if they adjust their pricing strategies and make responsible use of their carbon emission quotas.

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