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Pricing and Investment Decision Issues of an Automobile Manufacturer for Different Types of Vehicles

XIAOLIANG ZHANG[1], ZHENKAI LOU[2], ZHONGYUAN SUN[3], AND XIAOZHEN DAI[4]

[1]School of Economics and Management, Beijing University of Posts and Telecommunications, Beijing 100876, China
[2]School of Management and Economics, Beijing Institute of Technology, Beijing 100081, China
[3]School of Economics and Management, Xi'an University of Posts and Telecommunications, Xi'an 710061, China
[4]School of Management, Wenzhou Business College, Zhejiang 325035, China

Corresponding author: Xiaozhen Dai (daixz81@126.com)

ABSTRACT With the raise of consumers' environmental awareness, automobile manufacturers try to add production lines of new energy vehicles. This paper deals with pricing and investment decision issues of an automobile manufacturer for different types of cars. The consumers' purchase preference for the new energy vehicle is formulated as a function of the manufacturer's investment on facility and advertisement. Aiming to maximize the total profit of the manufacturer, we construct a decision model. By solving a differential equation, a necessary condition is proposed for guaranteeing that the manufacturer produces and sells both of the two types of vehicles. It is shown that both the consumers' preference and the carbon tax affect the decisions of the manufacturer. For the possible scenarios in which the manufacturer only sells one kind of product, we present two simplified models. By comparing different achieved solutions, the optimal decision strategy is achieved. Finally, we show a numerical illustration to examine different decisions of the manufacturer under different sensitivity coefficients with regard to the investment. The main contribution of this paper is providing a jointly pricing and investment decision model under changeable consumers' purchase preference, and revealing the influence factors of the automobile manufacturer's transformation.

INDEX TERMS New energy vehicle, consumers' purchase preference, carbon tax, a necessary condition, simplified model.

I. INTRODUCTION

With the development of economics, environmental concerns attract more and more attentions. Many countries and regions like China and the European Union, make policies of the carbon tax to encourage production and sales of new energy vehicle. Moreover, the consumers' environmental awareness is growing rapidly. Given these reasons, many automobile manufacturers redesign their traditional products by engaging in production lines of new energy vehicles. Furthermore, some manufacturers like Tesla only focus on the new energy vehicle, which they firmly believe is the only choice for humans in the future.

Traditional vehicles use gasoline as their fuel, which incurs serious environmental pollution. Hence, the government always charges a carbon tax from traditional automobile manufacturers. Some models are implemented to examine the possible economic and environmental trade-offs for various carbon-pricing and fuel-pricing scenarios in actual cases [1]. Different from traditional vehicles, electric vehicles are friendly to the environment. However, manufacturers need to pay cost on facility and advertisement so as to enhance consumers' purchase preference on the new energy vehicle.

To encourage the production and sales of the new energy vehicle, some governments have provided subsidy policies for automobile manufacturers [2], [3]. For instance, [4] analyzed a traditional automobile supply chain and an electric-and-fuel automobile supply chain in a duopoly setting under a government's subsidy incentive scheme. Specifically, [5] proposed a subsidy and pricing model for electric vehicle sharing based on the two-stage Stackelberg game according to the current situation in China. As a supplement, the promotion of the government subsidy on the sales quantity of the new energy vehicle had also been deeply discussed [6]. Moreover,

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both the linear subsidy model and the fixed subsidy model were proposed to explore the optimal subsidy policy for the government [7].

However, the subsidy scheme of the government in practice is always varying, depending on the government's financial budget. Some other points are relatively easy to control for automobile manufacturers. [8] constructed a utility model of ordinary and green consumers by considering consumers' willingness to pay different prices for new energy vehicles and traditional vehicles. [9] examined different strategies to incentivize 'green' vehicle choice by exempting some of these vehicles from road user charges. In addition, green technology investments are also important topics for automobile manufacturers who considering production lines of new energy vehicles [10]. For example, [11] proposed a tri-level programming model involving a government, a new energy vehicle manufacturer and customers to investigate the manufacturer's investment strategies, the government's purchase subsidy policies and customers' purchasing decisions.

Despite the abundant literatures with regard to new energy vehicles, few considered how the automobile manufacturer transforms its product type for maximizing its expected profit. Obviously, this is a practical and significant issue for an automobile manufacturer. Actually, whether the manufacturer transforms or not mainly depends on the consumers' purchase preference and the carbon tax. Till now, the consumers' purchase preference on the new energy vehicle also lacks enough investigation [12]. This paper discusses pricing and investment decision issues of an automobile manufacturer who possesses two types of production lines, i.e., traditional vehicle line and new energy vehicle line. The consumers' purchase preference for the new energy vehicle is considered during formulating the demand functions of the two products. The aim of the manufacturer is to determine the optimal investment and pricing strategies. Similar to [13], the object of the manufacturer is to maximize the total profit of the two products.

This research covers some gaps for the existing literature. Firstly, both pricing and investment strategies for two different types of automobiles are considered, and a jointly pricing and investment decision model is proposed. Secondly, the influence factors of the automobile manufacturer's transformation are revealed by examining the solution of the decision model. We demonstrate that the production cost cannot be higher than the sum of the single traditional vehicle's production cost and the carbon tax so as to guarantee a positive sales volume. According to the obtained results, manufacturers could make decisions for pricing and investment accordingly before sales begins.

II. ASSUMPTION AND NOTATIONS

In this paper, pricing and investment decision issues of an automobile manufacturer for different types of vehicles are discussed in the presence of carbon tax. Because of the long range and mature technology, the fuel vehicle is easily to be adopted by consumers than the new energy vehicle. With the raise of consumers' environmental awareness, automobile manufacturers tend to invest on facility and advertisement to enhance the purchase preference for the new energy vehicle. The aim of the manufacturer is to determine the multiple decision variables.

TABLE 1. Notation definition.

Symbol	Description
a	potential demands of the market for this brand of product
c	production cost of a single fuel vehicle
d	production cost of a new energy vehicle
e	carbon tax of a fuel vehicle
ε	sensitivity coefficient of consumers' purchase preference with regard to the investment
$\lambda(i)$	consumers' purchase preference for the new energy vehicle
$1-\lambda(i)$	consumers' purchase preference for the fuel vehicle
δ	expected marginal demand with respect to the sales price
θ	promotion coefficient incurred by one sales price to the other sale quantity
i	investment on facility and advertisement for the new energy vehicle
p_t	sales price of the traditional vehicle
p_e	sales price of the new energy vehicle
Q_t^m	sales quantity of the traditional vehicle, $Q_t^m = (1-\lambda(i))a -\delta p_t +\theta p_e$
Q_e^m	sales quantity of the new energy vehicle, $Q_e^m =\lambda(i)a -\delta p_e +\theta p_t$
π_t^m	profit gained by selling traditional vehicles
π_e^m	profit gained by selling new energy vehicles
π^m	total profit of the manufacturer

Consider both fuel vehicles and new energy vehicles for a certain brand of automobile manufacturer. The notations used throughout the paper are given as follows:

We next make some explanations for the above setting.

Firstly, we consider the sensitivity coefficient of consumers' purchase preference ε. It is a positive value, depending on consumers' environmental awareness and the investment of the manufacturer. When the consumers' environmental awareness is relatively high, ε is large accordingly. Actually, ε is a parameter of function $\lambda(i)$.

Secondly, we analyze the properties of consumers' purchase preference for the new energy vehicle $\lambda(i)$. Similar to [14], we think that the manufacturer's investment on the new energy vehicle affects the consumers' purchase preference. The more investment for the new energy vehicle, the more widely known and convenient for consumers. In other words, $\lambda(i)$ is a function of i. Further, we assume that $\lambda(0) = 0$, $\lambda^{/}(i) > 0$ and $\lambda^{//}(i) < 0$, which is widely used in practice. Besides, for any i, $\lambda(i) < 1$. Given the above, $\lambda(i)$ is a monotonic increasing function, which implies $\lambda^{-1}(\lambda)$ exists, and $\lambda^{-1}(0) = 0$.

Thirdly, $\delta > \theta$ is widely adopted when involving different products or dual channels [15], [16]. This setting suggests that the impact brought by one's own price is always greater than the impact brought by another product's price.

In order to further discussion, we give the following assumptions:

1) This paper only considers this brand of cars, without paying attention to the impact incurred by other brands of vehicle.

2) Because the considered model is deterministic, this paper doesn't consider stock out and over production issues.

3) Under some strategy of the manufacturer, the sales quantity of one kind vehicle may be zero. Nevertheless, the price of this vehicle still promotes the demand of the other vehicle in our model.

4) In practice, the process of producing new energy vehicle may also generate carbon emissions, similar to traditional vehicles. In this research, the carbon emission for the production process of the two types of vehicles is overlooked.

III. THE PRICING AND INVESTMENT MODEL

This section concerns pricing and investment decision issues of an automobile manufacturer for different types of cars. Similar to [17], the manufacturer produces and sells products by himself. The decision variables are investment volume i, sales price of the traditional vehicle p_t, and sales price of the new energy vehicle p_e.

According to the notations given in the previous section, the profit gaining by selling traditional vehicles is given as follows:

$$\pi_t^m = (p_t - c - e)[(1 - \lambda(i))a - \delta p_t + \theta p_e]. \qquad (1)$$

And the profit of selling new energy vehicles is

$$\pi_e^m = (p_e - d)[\lambda(i)a - \delta p_e + \theta p_t] - i. \qquad (2)$$

We denote by $\pi^m = \pi_t^m + \pi_e^m$ the total profit of the manufacturer. The decision model is constructed as follows:

$$\begin{aligned} &\max\ \pi^m = \pi_t^m + \pi_e^m \\ &s.t.\ p_t \geq c + e, \\ &\quad p_e \geq d, \\ &\quad (1 - \lambda(i))a - \delta p_t + \theta p_e \geq 0, \\ &\quad \lambda(i)a - \delta p_e + \theta p_t \geq 0. \end{aligned} \qquad (3)$$

Before solving (3), we first demonstrate that the feasible region of model (3) is a bounded closed region.

We denote by R_1 the feasible region of model (3). According to the sign-preserving property of inequalities, we combine the two inequalities with regard to sales quantities and have

$$a - (\delta - \theta)(p_t + p_e) \geq 0,$$

i.e.,

$$p_t + p_e \leq \frac{a}{\delta - \theta}.$$

Obviously, R_1 is contained in a bounded closed region R_2 that is determined by the following inequality set:

$$\begin{cases} p_t \geq c + e \\ p_t + p_e \leq \dfrac{a}{\delta - \theta} \\ p_e \geq d \end{cases}$$

Given the above, R_1 is also a bounded closed region.

First, we analyze the objective function of model (3) without considering the constraints. According to the known conditions, the objective function is transformed to

$$\begin{aligned} \pi^m = &-\delta p_t^2 + [(1 - \lambda(i))a + \delta(c + e)]p_t - \theta(c + e)p_e \\ &- (1 - \lambda(i))a(c + e) - \delta p_e^2 + [\lambda(i)a + \delta d]p_e \\ &+ 2\theta p_e p_t - \theta d p_t - \lambda a d - i. \end{aligned} \qquad (4)$$

The following equation set is obtained by letting all the first-order partial derivative of π^m be zero:

$$\begin{cases} \dfrac{\partial \pi^m}{\partial p_t} = -2\delta p_t + 2\theta p_e + (1 - \lambda(i))a + \delta(c + e) - \theta d = 0 \\ \dfrac{\partial \pi^m}{\partial p_e} = -2\delta p_e + 2\theta p_t + \lambda(i)a + \delta d - \theta(c + e) = 0 \\ \dfrac{\partial \pi^m}{\partial i} = -a p_t \lambda'(i) + a p_e \lambda'(i) + a(c + e)\lambda'(i) \\ \qquad - a d \lambda'(i) - 1 = 0. \end{cases} \qquad (5)$$

According to the elimination method, expressions of p_t and p_e are obtained by the first two equations:

$$\begin{cases} p_t = \dfrac{(1 - \lambda(i))\delta a + \lambda(i)\theta a + (\delta^2 - \theta^2)(c + e)}{2(\delta^2 - \theta^2)} \\ p_e = \dfrac{\lambda(i)\delta a + (1 - \lambda(i))\theta a + (\delta^2 - \theta^2)d}{2(\delta^2 - \theta^2)}. \end{cases} \qquad (6)$$

It is easy to tell that the sales price of the fuel vehicle is linear increasing with the carbon tax.

$$\lambda'(i)a[(2\lambda(i) - 1)(\delta - \theta)a + (\delta^2 - \theta^2)(c + e) - (\delta^2 - \theta^2)d] = 2(\delta^2 - \theta^2).$$

Substituting (6) into the third equation of (5), we have

Because $\delta > \theta$, the above equation can be transformed to

$$\lambda'(i)a[(2\lambda(i) - 1)a + (\delta + \theta)(c + e) - (\delta + \theta)d] = 2(\delta + \theta). \qquad (7)$$

We next turn to solve differential equation (7). By analyzing the construction of (7), we know that it is a one-order non-linear equation and there is no existing formula for solving it directly.

Using differential form, (7) converts into

$$2a^2\lambda(i)d\lambda(i) + [(\delta + \theta)(c + e - d) - a]a d\lambda(i) = 2(\delta + \theta)di,$$

i.e.,

$$\frac{di}{d\lambda} = \frac{a^2}{\delta + \theta}\lambda + \frac{[(\delta + \theta)(c + e - d) - a]a}{2(\delta + \theta)}. \qquad (8)$$

In (8), λ is an abridged notation of $\lambda(i)$.

The solution of (8) is acquired as follows:

$$i = \frac{a^2}{2(\delta + \theta)}\lambda^2 + \frac{[(\delta + \theta)(c + e - d) - a]a}{2(\delta + \theta)}\lambda + k,$$

in which k is a constant item. According to $\lambda^{-1}(0) = 0$, we know that $k = 0$.

We regard λ as an unknown number, and regard i as a parameter. Consider the following quadratic equation with one unknown:

$$\frac{a^2}{2(\delta+\theta)}\lambda^2+\frac{[(\delta+\theta)(c+e-d)-a]a}{2(\delta+\theta)}\lambda-i=0.$$

Under the premise that λ and i are both positive, we obtain the unique solution of the quadratic equation as (9), as shown at the bottom of the page.

Given that $\lambda=\lambda(i)$ is determined, we consider the following equation set under $i\geq 0$ (10), as shown at the bottom of the page.

If equation set (10) has no solution in the set of real numbers, π^m has no extreme value in the bounded closed region R_1, which implies that the solution of model (3) realizes at one boundary of R_1.

If equation set (10) has one or more than one solution, we should first verify whether the solution meets the constraints of model (3). After that, the Hessian matrix of π^m is used to verify whether the solution is the extreme value or not.

Before presenting the Hessian matrix of π^m, we show the following conclusion:

Proposition 1: If equation set (10) has no solution, there must be $Q_t^m=0$ or $Q_e^m=0$ for the solution of model (3).

When equation set (10) has no solution, the optimal strategy of the manufacturer is to price the two types of vehicles properly and let the sales quantity of a certain product be zero. Some explanations are given for this scenario.

When the sensitivity coefficient of consumers' purchase preference with regard to the investment is relatively low, the curve of $\lambda(i)$ is always below the curve of the function determined by (9). Apparently, the optimal strategy of the manufacturer is to low the sales quantity of the new energy vehicle to zero.

Moreover, we draw the following conclusion with regard to production costs and the carbon tax:

Proposition 2: If the production cost of a new energy vehicle is higher than the sum of the single traditional vehicle's production cost and the carbon tax, the optimal strategy of the manufacturer is lowing Q_e^m to zero.

In practice, the above conclusion is of significance for a manufacturer to judge whether it is worth producing new energy vehicles.

Further, we present the Hessian matrix of π^m as follows:

$$H=\begin{bmatrix}-2\delta & 2\theta & -a\lambda^{/}\\ 2\theta & -2\delta & a\lambda^{/}\\ -a\lambda^{/} & a\lambda^{/} & (p_e-p_t+c+e-d)a\lambda^{//}\end{bmatrix}.$$

Apparently, $-2\delta<0$ and

$$\begin{vmatrix}-2\delta & 2\theta\\ 2\theta & -2\delta\end{vmatrix}=4\delta^2-4\theta^2>0.$$

By expansion of the determinant, we acquire the determinant of H as follows:

$$\begin{aligned}&\begin{vmatrix}-2\delta & 2\theta & -a\lambda^{/}\\ 2\theta & -2\delta & a\lambda^{/}\\ -a\lambda^{/} & a\lambda^{/} & (p_e-p_t+c+e-d)a\lambda^{//}\end{vmatrix}\\ &=4a^2\lambda^{/2}(\delta-\theta)+a\lambda^{//}(4\delta^2-4\theta^2)(p_e-p_t+c+e-d)\\ &=a(\delta-\theta)[4a\lambda^{/2}+2(\delta+\theta)\lambda^{//}(d-c-e)+2\lambda^{//}(2\lambda-1)a].\end{aligned}$$

The determinant of H can be use to verify the solution of equation set (10). If equation set (10) has only one solution which lets the determinant of H be negative, this is the optimal investment of the manufacturer. For other situations, we should examine both extreme points and boundaries of the feasible region of model (3) to find out the optimal strategy of the manufacturer.

When the solution(s) of equation set (10) meets the constraints of model (3), by (6) we obtain the total profit as (11), as shown at the bottom of the page.

For other situations, we need to examine the value of π^m at one boundary of $Q_t^m=0$ and $Q_e^m=0$.

We adopt the elimination method to deal with π^m. The specific calculation steps are as follows:

$$\lambda=\frac{[a-(\delta+\theta)(c+e-d)]+\sqrt{[(\delta+\theta)(c+e-d)-a]^2+8(\delta+\theta)i}}{2a} \tag{9}$$

$$\begin{cases}\lambda=\dfrac{[a-(\delta+\theta)(c+e-d)]+\sqrt{[(\delta+\theta)(c+e-d)-a]^2+8(\delta+\theta)i}}{2a}\\ \lambda=\lambda(i)\end{cases} \tag{10}$$

$$\begin{aligned}\pi^m=&\frac{[\lambda(i^*)\delta a+(1-\lambda(i^*))\theta a-(\delta^2-\theta^2)d][\lambda(i^*)a-\delta d+\theta(c+e)]}{4(\delta^2-\theta^2)}\\ &+\frac{[(1-\lambda(i^*))\delta a+\lambda(i^*)\theta a-(\delta^2-\theta^2)(c+e)][(1-\lambda(i^*))a-\delta(c+e)+\theta d]}{4(\delta^2-\theta^2)}\end{aligned} \tag{11}$$

1) Let $Q_t^m = (1-\lambda(i))a - \delta p_t + \theta p_e = 0$. The sales price of the fuel vehicle is acquired:

$$p_t = \frac{(1-\lambda(i))a + \theta p_e}{\delta}.$$

Thus, the decision model of the manufacturer is transformed to

$$\begin{aligned} &\max\ \pi^m = (p_e - d)[\lambda(i)a + \frac{\theta}{\delta}(1-\lambda(i))a - \delta p_e + \frac{\theta^2}{\delta}p_e] - i \\ &s.t.\ p_e \geq d, \\ &\quad \lambda(i)a + \frac{\theta}{\delta}(1-\lambda(i))a - (\delta - \frac{\theta^2}{\delta})p_e \geq 0. \end{aligned} \tag{12}$$

Given $\delta > \theta$, we know that the feasible region of model (12) is a closed interval of p_e for $i \geq 0$. The necessary condition for guaranteeing that the manufacturer gains positive profits is the objective function of model (12) has at least one extreme point within the feasible region.

Based on the above analysis, we show the following equation set by differentiating π^m:

$$\begin{cases} \dfrac{\partial \pi^m}{\partial p_e} = -2(\delta - \dfrac{\theta^2}{\delta})p_e + \lambda(i)a + \dfrac{\theta}{\delta}(1-\lambda(i))a \\ \qquad + (\delta - \dfrac{\theta^2}{\delta})d = 0 \\ \dfrac{\partial \pi^m}{\partial i} = (a - \dfrac{\theta}{\delta}a)\lambda^{/}(i)(p_e - d) - 1 = 0. \end{cases} \tag{13}$$

Besides, setting $i = 0$, we consider the maximum value of

$$(p_e - d)[\frac{\theta}{\delta}a - \delta p_e + \frac{\theta^2}{\delta}p_e]$$

on the closed interval of p_e determined by the feasible region of model (12). By comparing the maximum value of this one-variable function and the extreme value acquired by substituting the solution of (13) into the objective function, we obtain the maximum profit and corresponding strategies of the manufacturer under $Q_t^m = 0$.

2) Let $Q_e^m = \lambda(i)a - \delta p_e + \theta p_t = 0$. The sales price of the new energy vehicle is acquired:

$$p_e = \frac{\lambda(i)a + \theta p_t}{\delta}.$$

Thus, we obtain the decision model as follows:

$$\begin{aligned} &\max\ \pi^m = (p_t - c - e)[(1-\lambda(i))a + \frac{\theta}{\delta}\lambda(i)a - (\delta - \frac{\theta^2}{\delta})p_t] - i \\ &s.t.\ p_t \geq c + e, \\ &\quad (1-\lambda(i))a + \frac{\theta}{\delta}\lambda(i)a - (\delta - \frac{\theta^2}{\delta})p_t \geq 0. \end{aligned} \tag{14}$$

Similarly, the feasible region of model (14) is a closed interval of p_t for $i \geq 0$.

By analyzing the objective function of model (14), we find that the optimal investment strategy of the manufacturer in this situation is $i = 0$. Hence, the objective function can be simplified as

$$\pi^m = (p_t - c - e)[a - (\delta - \frac{\theta^2}{\delta})p_t]. \tag{15}$$

The necessary condition for guaranteeing that the manufacturer gains positive profits is function (15) has at least one extreme point on the closed interval of p_t.

Comparing solutions obtained by 1) and 2), the optimal strategy of the manufacturer is acquired.

Some explanations are given for different decisions of the manufacturer. When the sensitivity coefficient of consumers' purchase preference with regard to the investment is low or the production cost of a new energy vehicle is high, the manufacturer will certainly low the production quantity and the investment volume of the new energy vehicle, which coincides with the fact.

IV. A NUMERICAL EXAMPLE

This section provides a numerical illustration to examine different decisions of the manufacturer under different sensitivity coefficients with regard to the investment. Consider the following scenario: $a = 2000$, $c = d = 500$, $e = 50$, $\delta = 2$, $\theta = 1$, and $\lambda(i) = 1 - 2^{-\varepsilon i}$.

First, given that equation set (10) is crucial for analyzing the optimal strategy, we concentrate on whether it has solutions under different sensitivity coefficients. Given $\varepsilon = 1 \times 10^{-4}$ and $\varepsilon = 8 \times 10^{-4}$, we show the curve of $\lambda(i)$ and the curve determined by function (9) as follows:

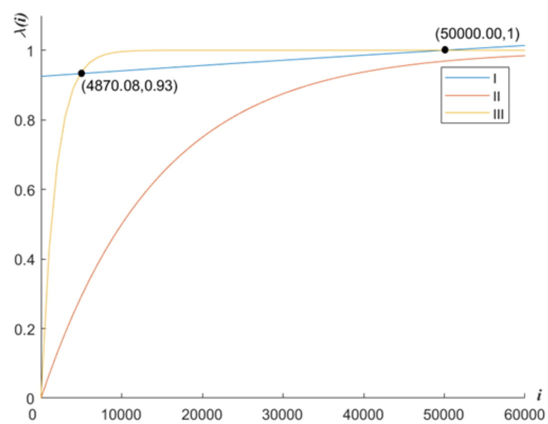

FIGURE 1. Curves of the two functions.

In figure 1, I represents the curve of function (9), II represents the curve of $\lambda(i)$ under $\varepsilon = 1 \times 10^{-4}$, and III represents the curve of $\lambda(i)$ under $\varepsilon = 8 \times 10^{-4}$.

Firstly, we examine the optimal decisions when $\varepsilon = 1 \times 10^{-4}$. A we can see, curve I and curve II have no intersection point, which implies that the corresponding equation set (10) has no solution. The optimal strategy of the manufacturer must lie on one boundary of $Q_t^m = 0$ and $Q_e^m = 0$.

Let $Q_e^m = 0$. In this situation, the optimal investment $i = 0$. According to (15), the objective function of the manufacturer is

$$\pi^m = -1.5p_t^2 + 2825p_t - 1100000.$$

It is easy to obtain that the maximum value of the above quadratic function is $\pi^m = 230104$, and the corresponding solution is $p_t = 941.7$.

Let $Q_t^m = 0$. The objective function is

$$\pi^m = (p_e - 500)[1000(1 - 2^{-10^{-4}i}) - 1.5p_e + 1000] - i.$$

By dealing with the corresponding equation set according to (13), we get $\pi^m = 197675$, and corresponding decisions are $i = 48103.2$ and $p_e = 904.8$. Besides, $\pi^m = 10417$ when $i = 0$.

Given the above, the optimal strategy is $p_t = 941.7$ and $i = 0$ under $\varepsilon = 1 \times 10^{-4}$.

Next, we examine the optimal decisions when $\varepsilon = 8 \times 10^{-4}$. As we can see, curve I and curve III have two intersection points. Hence, we should calculate the extreme values and the values on the boundaries.

Using (6), pricing decisions under $i = 4870.08$ and $i = 50000$ are acquired as follows: (631.7,893.3); (608.3,916.7). Examining the two pairs of solutions, we find that neither of them meets the constraints of model (3). According to the analysis in the previous section, the optimal strategy of the manufacturer is still lowing the sales quantity of one product to zero.

Let $Q_e^m = 0$. The optimal profit of the manufacturer is still $\pi^m = 230104$, and the corresponding solution is $p_t = 941.7$.

Let $Q_t^m = 0$. The objective function is

$$\pi^m = (p_e - 500)[1000(1 - 2^{-8\times10^{-4}i}) - 1.5p_e + 1000] - i.$$

By mathematical software, we obtain the optimal strategy as follows: $i = 9808.8$, $p_e = 915.2$. And the maximum profit is $\pi^m = 248801$. In addition, $\pi^m = 10417$ when $i = 0$.

Given the above, the optimal strategy is $p_e = 915.2$ and $i = 9808.8$ under $\varepsilon = 8 \times 10^{-4}$.

As it is shown in this example, the optimal strategies of the manufacturer are seriously affected by the sensitivity coefficients of consumers' purchase preference. When the consumers' purchase preference on the new energy vehicle is high enough, the manufacturer tends to transform its product type thoroughly. In practice, the change of the consumers' purchase preference is also affected by the government's policy. In this research, this factor is not discussed.

The performance of the proposed method is analyzed. By the numerical example, it is shown that we can easily tell when the manufacturer only produces and sells only one type of automobile by the curve figure. When the two curves have at least one intersection point, maximum values of three functions need to be calculated to find the optimal strategy of the manufacturer.

V. CONCLUSION

In this paper, we investigate pricing and investment decision issues of an automobile manufacturer for different types of vehicles. The consumers' purchase preference for the new energy vehicle is formulated as a strictly increasing function of the manufacturer's investment on facility and advertisement. Moreover, the change of the manufacturer's decision is examined under different degrees of consumers' purchase preference.

The contributions of this research are summarized as follows. Firstly, we show a criterion for judging whether the manufacturer decides to produce and sell the two types of vehicles simultaneously. It is recommended that the new energy automobile should not be produced and sold when the production cost of a new energy vehicle is higher than the sum of the single traditional vehicle's production cost and the carbon tax. Secondly, the influence factors of the automobile manufacturer's transformation are revealed. With the change of the sensitivity coefficient of consumers' purchase preference, the automobile manufacturer should make transformation decisions accordingly.

There are some shortcomings in this research. The competition between different brands of vehicles is not considered. Uncertain factors are also not taken into consideration. In addition, the government's subsidy for the new energy vehicle also needs to be considered.

APPENDIX

A. PROOF OF PROPOSITION 1

We adopt reductio ad absurdum by assuming that $Q_t^m > 0$ and $Q_e^m > 0$ for the solution of model (3). Because the solution of model (3) realizes at one boundary of R_1, then there must be at least one equality with regard to the constraints of sales prices.

If $p_t = c+e$ and $p_e > d$ in the solution of model (3), we can enhance p_t properly and meanwhile guarantee that $Q_t^m > 0$ and $Q_e^m > 0$. Thus, the total profit will be increased, which means $p_t = c + e$ and $p_e > d$ cannot happen in the solution of model (3). Similarly, $p_t > c+e$ and $p_e = d$ cannot happen as well.

Given the above, $Q_t^m = 0$ or $Q_e^m = 0$ when equation set (10) has no solution. □

B. PROOF OF PROPOSITION 2

Proof: When $c + e < d$, we have

$$a - (\delta + \theta)(c + e - d) > a.$$

$$\begin{aligned}\lambda &= \frac{[a - (\delta+\theta)(c+e-d)] + \sqrt{[(\delta+\theta)(c+e-d) - a]^2 + 8(\delta+\theta)i}}{2a} \\ &> \frac{2[a - (\delta+\theta)(c+e-d)]}{2a} \\ &> 1\end{aligned}$$

Thus, for the value of function (9), we have λ, as shown at the bottom of the page, for any $i > 0$. Given that $\lambda(i) < 1$, we know equation set (10) has no solution in this situation. For the manufacturer, investment on facility and advertisement for the new energy vehicle with a high production cost is apparently not cost-effective.

Hence, the conclusion is drawn by briefly analyzing the total profit function. □

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XIAOLIANG ZHANG is currently pursuing the Ph.D. degree with the School of Economics and Management, Beijing University of Posts and Telecommunications, Beijing. His research interests include e-commerce platform pricing and supply chain management.

ZHENKAI LOU is currently pursuing the Ph.D. degree with the School of Management and Economics, Beijing Institute of Technology, Beijing. His research interests include e-commerce platform pricing and supply chain management.

ZHONGYUAN SUN received the Ph.D. degree from the School of Economics and Management, Beijing University of Posts and Telecommunications. He is currently a Lecturer with the Xi'an University of Posts and Telecommunications. His research interests include technical innovation and e-commerce platform economics.

XIAOZHEN DAI received the master's degree from the School of Transportation and Logistics, Southwest Jiaotong University, Chengdu, in 2008. He is currently an Associate Professor with Wenzhou Business College. His research interests include supply chain management and logistics.