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A green production strategies for carbon-sensitive products with a carbon cap policy

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ABSTRACT

This paper discusses the production strategies used by manufacturers of carbon-sensitive products that have a carbon cap Policy under both deterministic demand and stochastic demand. In this study, we examine green manufacturing strategies for carbon-sensitive products under carbon cap policy regulations. We primarily consider the two scenarios of deterministic demand and stochastic demand. When the carbon cap Policy regulation has no restriction to the production of the manufacturers, the higher the carbon sensitivity coefficient of the product, the lower the profit of the manufacturing enterprise. When carbon cap Policy regulation of manufacturing enterprise production is a constraint, for the deterministic demand, with the higher carbon sensitive coefficient, manufacturing enterprise profit is higher; for stochastic demand, With the increasingly high carbon sensitive coefficient, manufacturing enterprise profit is low. Through the above research, the conclusion of this paper has reference value and guiding role to carbon-sensitive products' green production strategies with a carbon cap policy.

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1. Introduction

Productivity has greatly improved since the Industrial Revolution. However, that production consumes a significant amount of energy and produces large quantities of carbon dioxide, which has triggered changes in the global climate. The International Energy Agency (IEA) estimates a world gross domestic product (GDP) of 70 trillion in 2011 and 3.4 percent average annual growth from 2008 to 2035. With economic development, energy consumption has greatly increased, and our country will soon be confronted by the serious issue of energy-resource shortages. If each 1 percent GDP increase results in a 0.47 percent energy-consumption increase, world economic development will primarily rely on fossil fuels. More importantly, a non-profit government consulting institute, the LMI Research Institute, has stated that commercial activity in all manufacturing sectors count for much in carbon emissions. The carbon emissions produced by the manufacturing industry are caused by the use of raw materials (the transportation of semiconductors, steel, energy resources), manufacturing processes (heating treatments, welding, pressing) and waste-disposal process (carbon emission from waste-disposal plants).

To mitigate global warming and reduce environmental pollution, governments worldwide are actively responding by publishing policies intended to solve this problem. The primary issue is how to transform human production and lifestyles to achieve a low-carbon economy and lifestyle. The Kyoto protocol provided a standard and direction for solving the global-warming problem. The implementation of a carbon quota has been derived from the Kyoto Protocol, which aims to achieve effective emissions reduction through a binding, legal requirement that greenhouse-gas emissions be maintained within a certain range. Furthermore, with an increase in environmental protection consciousness, consumers hope decrease carbon emissions as well as lower the prices, and enhance environmental protections. However, industrially manufactured products are carbon-sensitive products. With the establishment of a carbon quota mechanism, enterprises must consider the issue of carbon emissions. Simultaneously, because consumers are more likely to buy products with low carbon and environmental protections, a product's carbon sensitivity also has an impact on product demand.

In this context, production enterprises can both improve market demand and increase corporate profits by emphasizing the low-carbon , environmentally protective characteristics of carbon-sensitive products. Therefore, when an enterprise is required to adopt a carbon quota policy, the question of how it can realize sustainable development and social responsibility while growing its profits becomes a key aspect of both enterprise operation and enterprise development. Simultaneously, this issue has become the subject of major research both at home and abroad. Therefore, research on the production strategy of carbon-sensitive products under a carbon cap policy can provide the basis of and reference for an enterprise's production activities.

There have been relevant studies both at home and abroad on the production strategy associated with carbon quota policies. Hong et al. [1] considers retailer ordering and pricing decisions under carbon cap policies and discusses the impact of carbon emissions trading on retailer ordering, pricing and maximizing expected profit. Bouchery et al. [2] add carbon cap-and-trade to the inventory model, analyzing the effect of carbon quotas on the inventory model. Chaabane et al. [3] find that regarding carbon emissions trading, with the establishment of a relevant supply chain model, carbon limits can effectively reduce carbon emissions. Benjaafar et al. [4] study the impact of carbon limitation and transaction policies on enterprises' behavior associated with investment, production, inventory and ordering decisions. Enterprises can maximize profits by modifying order quantity. Zhang and Xu [5] investigate the multi-item production-planning issue associated with carbon cap-and-trade mechanisms where an enterprise produces vary products that fulfil independent stochastic demands with a common capacity and carbon emission quota; those authors use numerical analyses both to illustrate their findings and to identify managerial insights and policy implications. Using an economic order quantity (EOQ) model, Chen et al. [6] provide a situation where it is possible to lower emissions by altering the number of orders. They also provide the situations where the emissions reduction is comparatively greater than the cost increase. Moreover, they study the elements that influences differences in the magnitude of decrease in emission and rise in cost Ma et al. [7] demonstrates the effectiveness of the use of cap-and-trade policy as a mechanism to encourage manufacturers to reduce carbon emissions while obtaining expected profits through their use of green technology inputs. Qi et al. [8] stress the value of centralized management of value chain decisions and sharing of knowledge for Mass customization capability.

Regarding to economic benefit and emission reduction, a multi-goal optimization model has been set by Qu et al. to show their relationship; they show that when it compared with the original policy, the collection of diverse emission-reduction policies make greater-efficiency emission reduction and less economic loss. Mutingi [10] plays an important role in both academics and professionals in the field of green supply-chain management. First, Mutingi's study provides a great deal of information to construct a practical tool or framework for managers in the development of green supply-chain tactics given the certain industrial situations where those tactics are used. Second, Mutingi's taxonomic framework provides managerial view about the effects of the selection of certain strategies for a supply chain's operations policies.

Using a duopoly model, Wang and Wang [11] quantitatively explore the impact of a carbon offsetting scheme on both emission-trading participants' profits and industry output by drawing on the advanced experience of carbon-offsetting schemes in developed countries. A negative relationship between firms' carbon intensity and their equilibrium output in the product market is revealed from the outcomes. Furthermore, that study presents a commencement for the compared importance of duopoly enterprises' carbon intensity where their absolute output will differ dramatically.

Sengupta [12] considers that when consumers are aware of a product's green and environmental protections, they assume that green technology can both improve the production of green products and offer environmental protection; an appropriate increase in prices will generate additional profits. Koren et al. [13] analyses the effect of technical and organizational views on the product complexity and to identify where most incentives for innovation initiate, and the influence on the product complexity. Buchmeister et al. [14] think the implication of weak demand discrepancy and level constraints within the supply chain on the bullwhip effect was evident.

Liu et al. [15] use a Stackelberg model to study the problem of competition in the two stages of the supply chain, discussing not only product competition among suppliers but also competition among retailers. Those authors consider how suppliers and retailers can both obtain more benefits and improve their level of competitiveness. Xu and Zhao [16] show that supply chain cooperation can raise the emissions reduction level and increase the expected total profit. Finally, the effects of different parameters on the coordination of supply chain's performance are discussed. Li et al. [17] through the establishment of the Stackelberg game model, it is concluded that the optimal emission reduction level and the optimal proportion of the retail and supply, and the optimal profit value of the two in different contract forms. Huang and Zhao [18] study bargaining between manufacturers and retailers in the case of consumers' low carbon preferences, analysing both the influence of a manufacturer's pricing on the retailer and the function of the two parties.

Because of the relevant environmental protection policy and consumer awareness of both environmental protection and low carbon emissions, research on carbon-sensitive product manufacturers' production strategies under a Cap policy can provide manufacturers with valuable information.

2. Problem statements and basic assumptions

This paper studies a manufacturer in a monopoly market. The manufacturer produces only one product (for example, a smart phone); the remaining inventory is produced in accordance with residual value processing at the end of a sales period. The product's decision-making value is its production; the manufacturer's decision-making goal is profit maximization. The government has specified the largest carbon emissions E, under its carbon cap policy. To achieve carbon-emissions reduction targets, the carbon emissions of manufacturers' production activities cannot exceed the maximum level set by the government. At the same time, consumers demand low-carbon and environmental-protection features in their products; those features are associated with the products' carbon-sensitive coefficient k. Therefore, consumer demand influences production. This paper primarily studies the following two issues:

Under the deterministic demand condition, demand is equal to the economic order quantity (EOQ) and thus, to both a manufacturer's production strategy with a carbon cap policy and the influence of a carbon-sensitive coefficient on profits; and

Under the stochastic demand condition, requirements are related to price and a product's degree of carbon sensitivity and thus, to both a manufacturers' production strategy with a carbon cap policy and the influence of a carbon-sensitive coefficient on profits.

For convenience, the model's main variables are listed below:

k – Carbon-sensitive coefficient
e – Product's per-unit carbon emissions
E – Government limit on carbon emissions
a – Unit of time of potential market demand
D – Deterministic demand per unit of time
Q – Production
v – Residual value per unit product
A – Deterministic costs of each order at a particular time
h – Annual inventory holding cost per unit product
c – Cost of production per unit product
p – Unit price of the product
g – Shortage cost of one unit of the product

3. Deterministic demand model establishment and analysis

Under the deterministic demand condition, demand is equal to EOQ and the relationship between demand and the carbon-sensitive coefficient k is $D = a - ke(D, a, k, e > 0)$.

3.1. Basic model

In the case of no carbon constraints, take the related parameters into the EOQ formulae:

$$TC = cD + \frac{D}{Q}A + \frac{Q}{2}h \tag{1}$$

TC of Q derivative:

$$\frac{dTC}{dQ} = \frac{(a - ke)A}{Q^2} + \frac{h}{2}$$

Make $\frac{dTC}{dQ} = 0$, and obtain the optimal production:

$$Q^* = \sqrt{\frac{2(a - ke)A}{h}} \tag{2}$$

The optimal profit of the manufacturer is: $\pi^*(Q) = (p - c)Q^*$, that is,

$$\pi^*(Q) = (p - c)\sqrt{\frac{2(a - ke)A}{h}} \tag{3}$$

by Eq. 3

<u>*Proposition 1:*</u> In the absence of a carbon quota restriction, if other conditions remain unchanged, the optimal profit $\pi^*(Q)$ is a decreasing function of the carbon-sensitive coefficient k.
<u>*Proof:*</u>
$\pi^*(Q)$ of k derivative:

$$\frac{d\,\pi^*(Q)}{dk} = -\sqrt{\frac{2e^2A}{h(a - ke)}} < 0$$

The profit is a decreasing function $\pi^*(Q)$ of the carbon-sensitive coefficient k; with an increase in k, $\pi^*(Q)$ decreases, while with a decrease in $k, \pi^*(Q)$ increases.
<u>*End of proof.*</u>

3.2. Manufacturers' production strategy under a carbon cap policy

Under the carbon-limitation condition, the EOQ can be obtained:

$$TC = cD + \frac{D}{Q}A + \frac{Q}{2}h \tag{4}$$

$$s.t. eQ \leq E \tag{5}$$

The constraint condition means that the total carbon emissions in the enterprise's production activities shall not exceed the amount of carbon that is emitted by the government. By discussing the optimal production strategy in this case, the following theorems are obtained.

<u>*Theorem 1:*</u> Under the deterministic demand condition, manufacturers of carbon-sensitive products are subject to the carbon quota policy under the regulation of the optimal production $Q^a \leq Q^*$.
<u>*Proof:*</u>
Let $\varphi \geq 0$, the constraint conditions can be:

$$eQ - E \leq 0 \tag{6}$$

$$\varphi(eQ-E)=0 \tag{7}$$

$$\frac{(a-ke)A}{Q^2}+\frac{h}{2}-\varphi e=0 \tag{8}$$

When $\varphi=0$, by Eq. 8 $\frac{dTC}{dQ}=0$; therefore $Q^a \leq Q^*$, $eQ^* \leq E$.
When $\varphi>0$, by Eq. 8, $\frac{dTC}{dQ}=\frac{(a-ke)A}{Q^2}+\frac{h}{2}=\varphi e>0$; therefore $Q^a<Q^*$.
End of proof.

In summary, the optimal production of enterprises under carbon limitation $Q^a \leq Q^*$.

Theorem 1 shows that when demand is determined, the optimal production of manufacturing enterprises in the case of carbon limits is not greater than their production in the case of no carbon limits. Carbon-quota policies affect the production activities of manufacturing enterprises.

Corollary 1: Deterministic demand, the expected profit of carbon-sensitive product manufacturing enterprises with a Carbon cap Policy $\pi(Q^a) \leq \pi(Q^*)$.
Proof:
By Theorem 1
When $eQ^* \leq E$, then $Q^a=Q^*$, so we obtain $\pi(Q^a)=\pi(Q^*)$,
When $eQ^*>E$, then $Q^a<Q^*$, so we obtain $\pi(Q^a)<\pi(Q^*)$.
End of proof.

In summary, the expected profits of enterprises under carbon limitation $\pi(Q^a) \leq \pi(Q^*)$.

Corollary 1 shows that the expected profit of the manufacturing enterprises in the case of carbon limits is not greater than those enterprises' expected profits in the case of no carbon limits.

For manufacturing enterprises, there are two types of production activities:

1. When the carbon cap is far greater than an enterprise's total carbon emissions, the enterprise need not be concerned about production problems.
2. When a manufacturing enterprise's carbon emissions associated with increased production exceeds the carbon limits, the enterprise must adjust its production to remain within the limits, and the enterprise will be concerned about the cost of a shortage caused by its production adjustment. In that case, the enterprise's production is $Q=\frac{E}{e}$. For the enterprise to establish the expected profit model in the two cases, its expected profit in the event of a carbon quota policy is expected to be as follows:

$$\pi^a(Q^a)=\begin{cases}(p-c)Q^* & eQ^* \leq E\\ (p+g-c)\dfrac{E}{e}-Q^*g & eQ^*>E\end{cases} \tag{9}$$

Theorem 2:

1. When the $eQ^* \leq E$, the profit function of a manufacturer of carbon-sensitive products π^a is a decreasing function of the carbon-sensitive coefficient k, and with a decrease in k, π^a increases, while with an increase in k, π^a decreases.
2. When the $eQ^*>E$, the profit function of a manufacturer of carbon-sensitive products π^a is an increasing function of the carbon-sensitive coefficient k, and with a decrease in k, π^a decreases, while with an increase in k, π^a increases.

Proof:

1. Because $eQ^* \leq E$, equivalent to a non-carbon cap, with a proof of theorem 1.
2. When $eQ^*>E$, $\pi^a(Q^a)$ of k derivative:

$$\frac{d\pi^a(Q^a)}{dk}=g\sqrt{\frac{2Ae^2}{h(a-ke)}} \tag{10}$$

Because $g\sqrt{\frac{2Ae^2}{h(a-ke)}} > 0$, the profit function π^a is an increasing function of the carbon-sensitive coefficient k; with a decrease in k, π^a decreases, while with an increase in k, π^a increases.

End of proof.

In summary, the demand is determined, there is a carbon quota policy regulation, and the optimal production quantity of manufacturing enterprises for $Q^* = \sqrt{\frac{2(a-ke)A}{h}}$ if carbon emissions from manufacturing enterprises are far less than the carbon limits and will not exceed the carbon limits. With an increased carbon-sensitive coefficient k, manufacturing enterprises might consider it appropriate to reduce production and increase profits. With a decrease in the carbon-sensitive coefficient k, manufacturing enterprises might consider it appropriate to reduce production and increase profits. With a decrease in the carbon-sensitive coefficient, manufacturing enterprises can appropriately increase production and profits. If production increases, a manufacturing enterprise's carbon emissions will exceed the carbon quota and the enterprise needs to control production activities. With an increase in the carbon-sensitive coefficient k, manufacturing enterprises can appropriately increase production and then improve profits. With a decrease in the carbon-sensitive coefficient k, manufacturing enterprises can consider appropriately reducing production and increasing profits.

3.3. Numerical analysis

From the model solution, in a carbon-sensitive demand situation, the carbon-sensitive coefficient will affect the manufacturer's optimal production and maximum profit. To understand the influence of the carbon-sensitive coefficient and the carbon cap policy on the manufacturers' optimal production and the maximum profit, the following numerical analysis method was used to analyze the sensitivity of the parameters.

For the convenience of numerical analysis, let $a = 100$, $e = 10$, $A = 10$, $h = 20$, $p = 100$, $c = 50$, $g = 30$, $E = 80$, $e = 10$.

Making $k \in (1, 10)$, we can obtain Fig. 1 and Fig. 2. From Fig. 1 and Fig. 2, we can see that with the decrease in both the carbon-sensitive coefficient and production, manufacturer's profits first decrease and then increase, which means that when a carbon cap policy does not work, with the increase in the carbon-sensitive coefficient, profits decrease. When the carbon cap policy works, with the increase in the carbon-sensitive coefficient, profits increase. The optimal production at this time is $Q^* = \sqrt{\frac{2(a-ke)A}{h}} = 9.75$.

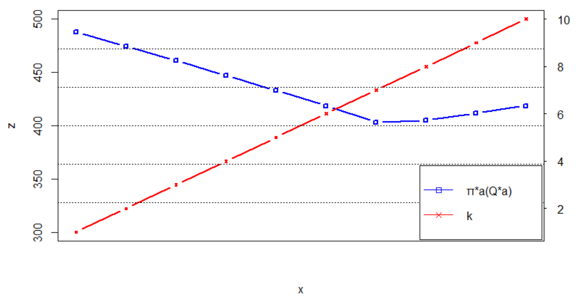

Fig. 1 Carbon-sensitive coefficient impact on profits

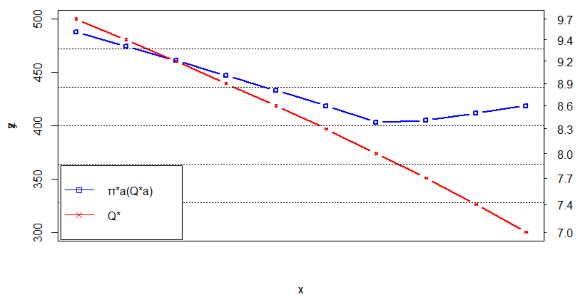

Fig. 2 Production impact on profits

4. The stochastic demand model establishment and analysis

With the stochastic demand, make x as a stochastic demand and obey follow the probability density function of the demand for $f(\cdot)$ distribution. According to the demand function and supply function, the price function for the relationship with the carbon-sensitive coefficient k is: $p = j - keQ$, ($j, k, e, Q > 0$, k as the carbon-sensitive coefficient)

4.1. Basic model

In the case of no carbon constraints, we construct the model according to the relationship of price and the carbon-sensitive coefficient function, combined with the newsboy structure of profit model for production Q:

$$\begin{aligned}\pi(Q) = \ & (j - keQ \\ & - v)\int_0^Q xf(x)dx \\ & - (c - v)\int_0^Q Qf(x)dx + (j - keQ + g \\ & - c)\int_Q^\infty Qf(x)dx - g\int_Q^\infty xf(x)dx\end{aligned} \tag{11}$$

If we make

$$\frac{d\pi(Q)}{dQ} = (j + g - c) - 2keQ + ke\int_0^Q F(x)dx = 0$$

we then obtain

$$j + g - c = \left(2Q - \int_0^Q F(x)dx\right)ke$$

For ease of calculation, make $G(Q) = 2Q - \int_0^Q F(x)dx$. The optimal production is as follows:

$$Q^* = G^{-1}\left(\frac{j + g - c}{ke}\right) \tag{12}$$

$\pi(Q)$ of k derivative allows us to obtain

$$\frac{d\pi(Q)}{dk} = -eQ[\int_0^Q xf(x)dx + \int_Q^\infty Qf(x)dx] < 0 \tag{13}$$

<u>*Proposition 2:*</u> When demand is stochastic, there is no carbon quota policy constraint and the profit of a manufacturer of carbon-sensitive products $\pi(Q)$ is a decreasing function of the carbon-sensitive coefficient k; with an increase in k, $\pi(Q)$ decreases, while with a decrease in k, $\pi(Q)$ increases.

<u>*Proof:*</u>

From (12), optimal production Q^* is a decreasing function of the carbon-sensitive coefficient k, The general model of the profit function is: $\pi = (p - c - v)\ Q^*$. Profit π is proportional to the carbon-sensitive coefficient Q^*, and profit π has an inverse relationship with the carbon-sensitive coefficientk; with an increase in k, π decreases, while with a decrease in k, π increases. In conclusion, the results are the same as for (13), and the proof is complete.

<u>*End of proof.*</u>

4.2. Manufacturers' production strategy under carbon cap policy

Under the carbon cap policy, carbon emissions in manufacturers' production activities must not exceed the government's largest carbon emissions. The largest production for manufacturers is $\frac{E}{e}$.

Through a discussion of the optimal production strategy in this case, the following theorems are obtained:

Theorem 3: Under conditions of stochastic demand, a manufacturer of carbon-sensitive products has a carbon cap policy of its optimal production $Q^a \leq Q^*$.
Proof:
Make $\varphi \geq 0$, can be obtained by constraint conditions:

$$eQ - E \leq 0 \tag{14}$$

$$\varphi(eQ - E) = 0 \tag{15}$$

$$(j + g - c) - 2(ke)Q + ke \int_0^Q F(x)dx - \varphi e = 0 \tag{16}$$

When $\varphi = 0$, using Eq. 16 we can obtain $\frac{d\pi(Q)}{dQ} = 0$, therefore, we can obtain $Q^a \leq Q^*$, $eQ^* \leq E$.
When $\varphi > 0$, using Eq. 16 we can obtain $\frac{d\pi(Q)}{dQ} = (j + g - c) - 2(ke)Q + ke \int_0^Q F(x)dx = \varphi e > 0$, therefore, we can obtain $Q^a < Q^*$.
End of proof.

In summary, the optimal production of enterprises under carbon limitation is $Q^a \leq Q^*$.

Theorem 3 shows that when the demand is stochastic, the optimal production of manufacturing enterprises in the case of carbon limits is not greater than the optimal production in the case of no carbon limits. The carbon quota policy has an effect on the production activities of manufacturing enterprises.

Corollary 2: Under conditions of stochastic demand, the expected profit of manufacturers of carbon-sensitive products with a carbon cap policy $\pi(Q^a) \leq \pi(Q^*)$.
Proof:
From theorem 3:
When $eQ^* \leq E$, then $Q^a = Q^*$, and we can obtain $\pi(Q^a) = \pi(Q^*)$.
When $eQ^* > E$, then $Q^a < Q^*$, and we can obtain $\pi(Q^a) < \pi(Q^*)$.
End of proof.

In summary, enterprises' expected profit under a carbon limitation is $\pi(Q^a) \leq \pi(Q^*)$.

Corollary 2 shows that manufacturers' expected profit in the case of carbon limits is not greater than in the case of no carbon limits. The carbon quota policy has an effect on manufacturers' profits.

For manufacturing enterprises, there are two types of production activities.

1. When the carbon cap is far greater than the manufacturer's total carbon emissions, the manufacturer need not be concerned about production problems.
2. When the manufacturer's carbon emissions under increased production exceeds carbon limits, it must adjust its production to comply with the carbon limits while considering the shortage cost caused by that production adjustment. At this time, the production of manufacturing enterprises is $Q = \frac{E}{e}$. For manufacturing enterprises to establish the expected profit model in two cases, we obtain the expected profit model for the manufacturing enterprises under a carbon quota policy.

When the carbon cap is far greater than a manufacturer's total carbon emissions, the manufacturer need not be concerned about a production problem; its profit model is the same as its profit model under the condition of no carbon limits, which is (11). From Proposition 2, manufacturers of carbon-sensitive products profit $\pi(Q)$ is a decreasing function of carbon-sensitive coefficient k, with the increase of k, $\pi(Q)$ decreased; with the decrease of k, $\pi(Q)$ increased.

When a manufacturer's carbon emissions increase with increased production, the production of a certain amount exceeds the carbon quota and the optimal profit model of the production of Q can be obtained by (11):

$$\pi^a(Q^a) = [j - (ke)Q - v]\int_0^{\frac{E}{e}} xf(x)dx - (c - v)\int_0^{\frac{E}{e}} \frac{E}{e}f(x)dx + [j - (ke)Q + g - c]\int_{\frac{E}{e}}^{\infty} \frac{E}{e}f(x)dx - g\int_{\frac{E}{e}}^{\infty} xf(x)dx \tag{17}$$

$$\text{s.t.}\, \mathrm{eQ} \leq \mathrm{E} \tag{18}$$

Bring $Q = \frac{E}{e}$ into (13), and obtain

$$\frac{d\pi^a(Q^a)}{dk} = -E[\int_0^Q xf(x)dx + \int_Q^{\infty} \frac{E}{e}f(x)dx] < 0 \tag{19}$$

The profit function π^a is a decreasing function of the carbon-sensitive coefficient k, with an increase in k, π^a decreases; with a decrease in k, π^a increases.

In summary, when the demand is stochastic, the optimal production $Q^* = G^{-1}\left(\frac{j+g-c}{ke}\right)$ at this time. If a manufacturer's carbon emissions are far less than the carbon limits and will not exceed those limits, with an increase in the carbon-sensitive coefficient k, manufacturing enterprises could consider it appropriate to reduce production and increase profits. With a decrease in the carbon-sensitive coefficient k, manufacturing enterprises can consider an appropriate increase in production and increase profits. If production increases, manufacturers' carbon emissions will exceed the carbon quota, and the enterprise needs to control its production activities. With an increase in the carbon-sensitive coefficient k, manufacturing enterprises might consider an appropriate reduction in production, thus improving their profits. With a decrease in the carbon-sensitive coefficient k, manufacturing enterprises can consider an appropriate production increase, thus increasing their profits.

4.3. Numerical analysis

Based on the model solution, in considering the carbon-sensitive demand situation, the carbon-sensitive coefficient will affect a manufacturer's optimal production and maximum profit. To more intuitively understand the influence of the carbon-sensitive coefficient and the carbon cap policy for manufacturers' optimal production and the maximum profit, below we demonstrate a numerical-analysis method of analysing the sensitivity of the parameters.

To conform to the general situation, assuming that market demand x satisfies normal distribution, make $x = max\ (\tilde{x}, 0)$, x satisfies a standard normal whose distribution average is 100 and variance is 10, that $\tilde{x} \sim N(100, 10^2)$. Because $p(\tilde{x} < 0)$ is small enough, it can be neglected. For ease of calculation, make $\tilde{x} = x$, and make $c = 30, v = 9, g = 10, e = 2, E = 150, j = 134.8$. We use MATLAB software (Math Works Corporation, Natick, U.S.A, Algorithm development; data visualization) to analyse the sensitivity of k and Q, resulting in Fig. 3 and Fig. 4.

As seen from Fig. 3, under the carbon cap policy regulation, there is a higher carbon-sensitive coefficient and lower profit. As seen Fig. 4, with increased production, the manufacturer's profits first increase and then decrease, which means that when the carbon cap policy does not work, with the increase of the carbon-sensitive coefficient, profits increase. When the carbon cap policy works, with the increase of the carbon-sensitive coefficient, profits decrease. Therefore, the optimal production is $Q^* = G^{-1}\left(\frac{j+g-c}{ke}\right) \approx 110$.

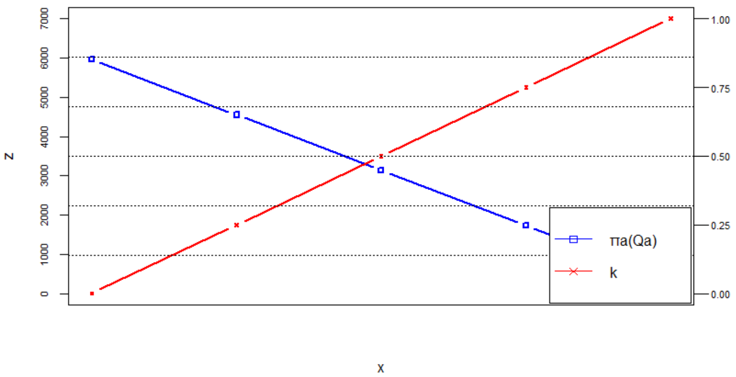

Fig. 3 Carbon-sensitive coefficient impact on profits

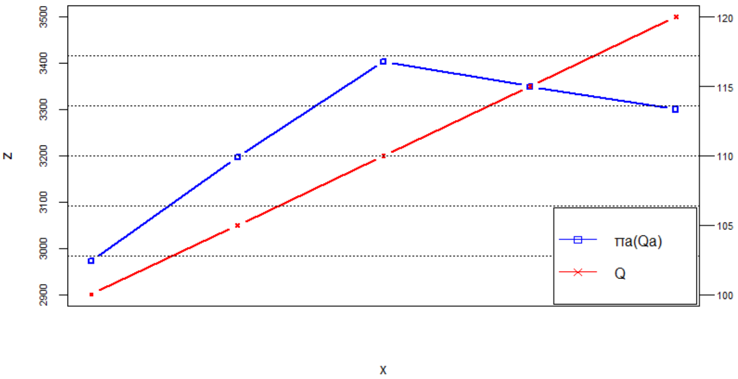

Fig. 4 Production impact on profits

5. Conclusion

This paper studied the production strategy of manufacturers of carbon-sensitive products that have a carbon cap policy. Using a reasonable assumption and example (for example, a smart phone manufacturer), it discussed the production strategy under both deterministic demand and stochastic demand, along with the influence of a carbon-sensitive coefficient on profits. The following conclusion can be drawn: If there is a carbon cap policy regulating manufacturers' production, whether under deterministic demand or stochastic demand, manufacturers will have higher carbon-sensitive coefficient products and lower profits. In this case, manufacturers engage in optimal production. When a carbon cap policy regulation plays a restrictive role in manufacturers' production, under deterministic demand, there will be a higher product carbon-sensitive coefficient and higher profits, and in this case, manufacturers engage in optimal production. Under stochastic demand, there are higher carbon-sensitive coefficient products and lower profits, in this case, manufacturers engage in optimal production. The results presented by the manufacturers studied in this paper can be applied to most industries with various probability density functions of demands, and optimality is easily obtained because the solution is expressed analytically.

This paper suffers from certain disadvantages. First, it only considers the existence of a carbon cap policy. Without simultaneously considering a Cap-and-trade, this article does not consider cost increases resulting from the use of green technology to reduce carbon emissions. These issues should be studied in the future. This paper, which is based on a reasonable hypothesis and an established model, can provide recommendations for sensitive product manufacturers' production strategies that are subject to carbon cap policy.

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