CSCanada
Management Science and Engineering
Vol. 9, No. 1, 2015, pp. 30-35
DOI: 10.3968/6324

ISSN 1913-0341 [Print]
ISSN 1913-035X [Online]
www.cscanada.net
www.cscanada.org

Manufacture's Production and Pricing Strategies With Carbon Tax Policy and Strategic Customer Behavior

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Supported by National Natural Science Foundation of China (71272128); the National Soft Science Research Program (2013GXS4D145); Youth Foundation for Humanities and Social Sciences of Ministry of Education of China (11YJC630022); the Fundamental Research Funds for the Central Universities (ZYGX2009X020); Sichuan Province Key Technology R&D Program (2012FZ0003).

Received 27 November 2014; accepted 14 February 2015
Published online 26 March 2015

Abstract

This paper investigates the manufacture's production and pricing strategies with carbon tax policy and strategic customer behavior, and analyze the impact of carbon tax policy and its parameter on the manufacturer's optimal strategies and maximum expected profit. We derive the optimal production, pricing strategies and maximum expected profit under the rational expectations equilibrium. The results show that the manufacturer's optimal production quantity and maximum expected profit are decreasing in carbon tax rate, and the manufacturer's optimal price is increasing in the carbon tax rate. Compared with the no carbon emission policy scenario, we prove that the manufacturer's optimal production quantity decreases, the manufacturer's optimal price increases, the manufacturer's maximum expected profit decreases, and the carbon tax policy effectively reduces the manufacturer's carbon emissions.

Key words: Carbon tax; Strategic customer behavior; Production strategy; Pricing strategy; Manufacturer

Jiang, W., & Chen, X. (2015). Manufacture's Production and Pricing Strategies With Carbon Tax Policy and Strategic Customer Behavior. *Management Science and Engineering*, *9*(1), 30-35. Available from: URL: http://www.cscanada.net/index.php/mse/article/view/6324
DOI: http://dx.doi.org/10.3968/6324

INTRODUCTION

Climate change and global warming are a serious threat to human survival and development. Excessive carbon dioxide emissions are considered as the main cause of global warming (Song & Leng, 2012). For environmental protection, governments around the world are required to implement carbon emission policy to reduce carbon emissions. Considered to be cost-effective emission reduction policy, carbon tax has accepted and adopted by many countries, such as Italy, Finland and the Netherlands and so on (Baranzini, Goldemberg, & Speck, 2000). In this context, the impact of the implementation of Carbon tax policy on enterprise operational decisions is concerned by the majority of scholars. Song and Leng (2012) examined the classical single-cycle problem with carbon tax policy, derived the optimal production quantity and maximum expected profit and draw the corresponding managerial implications. They show that, in order to reduce carbon emissions by a certain percentage, the tax rate imposed on the high-margin firm should be less than that on the low-margin firm for the high-profit perishable products, whereas the high-margin firm should absorb a high tax than the low-margin firm for the low-profit products. Choi (2013a) analytically studies how a properly designed carbon footprint taxation scheme can be imposed on a quick response (QR) system that enhance environmental sustainability via employing a local manufacturer to offset the probable higher total logistics and production costs. By examining both the single-ordering and the dual-QR ordering systems, it illustrates how the carbon footprint taxation scheme affects the optimal choice of the sourcing decision. Choi (2013b) studies an optimal supplier selection problem in the fashion apparel supply chain in the presence of carbon emission tax and analyzes the impact of linear and quadratic carbon emission tax scheme on supplier selection strategies. Shi et al. (2013) analyze the emission reduction effect, economic effect and emission reduction cost of single carbon tax policy, single cap and trade, and mixed carbon tax and cap and trade policy. All the studies above laid the foundation for our research, but they did not consider strategic customer behavior. In fact, strategic customer behavior has become a common phenomenon in perishable products sale process (Su & Zhang, 2008). Strategic customer behavior refers to that customers anticipate future sales and choose purchase timing to maximize their expected surplus. Many scholars have studied the impact of strategic customer behavior on corporate operational decisions. Su and Zhang (2009) studies the impact of strategic customer behavior on supply chain performance and derive the optimal price, the optimal order quantity and the maximum expected profit of rational expectations equilibrium. Levin et al. (2010) formulate a dynamic pricing model for a monopolistic company selling a perishable product to a finite population of strategic consumers. They prove the existence of a unique subgame-perfect equilibrium pricing policy and provide equilibrium optimality conditions for both customer and seller. Yang (2012) investigates the impact of discounting and retailer competition on decentralized channel performance with strategic customers. They show that a decentralized channel may have higher profit than that of a centralized channel with strategic customers. Huang et al. (2011) examine the multi-product newsvendor problem with the budget constraint and strategic customers. They obtain the rational expectation equilibrium solution to the static game between the newsvendor and the strategic customers and analyze the impact of quantity commitment on the equilibrium quantity and equilibrium price. Jiang and Chen (2012) investigate the manufacturer's production and pricing policy with both cap policy and strategic customer behavior. They derive the manufacturer's optimal production and pricing policy. Researches above in-depth analyzed the impact of strategic customer behavior on business operations decisions, but they did not combine with the carbon tax policy.

The paper integrates the carbon tax policy and strategic customer behavior into a model to examine the manufacturer's operational decisions. The paper address three issues: (a) what is the manufacturer's optimal decisions; (b) How does the carbon tax policy and its parameter impact on the manufacturer's optimal decisions, the maximum expected profit and the carbon emissions; (c) the impact of strategic customer behavior on the manufacturer's optimal decisions and the maximum expected profit.

1. MODEL DESCRIPTIONS AND ASSUMPTION

We consider monopoly manufacturer facing homogeneous strategic customers decide the production quantity and price simultaneously with carbon tax policy. We divide the whole sales period into two phases i.e. phase I and II. The manufacturer sells the products to customers at full price in phase I and sells the leftover products to the customers at salvage price in phase II.In order to maximum the expected surplus, customers decide purchase immediate or waiting the price markdown. We don't consider the shortage costs.

We denote our parameters and variables for model development as the following notations in Table 1.

Table 1
Parameters and Variables

Notation	Descriptions
D	*The random demand of customer,* $D\geq 0$.
$F(x)$	Distribution function of random demand D. Denote $\overline{F}$=1-F.
$f(x)$	Probability density function of random demand D.we assume that $f(x)$ is continuous and the demand distribution has an increasing failure rate i.e. $f(x)/1-F(x)$increasing in x.
c	Unit produce cost of the product.
p	Unit retail selling price of the product, which is observed by the customers.
q	Produce quantities for the product, which is customers' private information and cannot be observed by the customers.
s	Unit salvage price of the product.
v	The value of unit product to the customer i.e. the customers' utility from consuming the product.
r	Customers' reservation price, which is customers' private information and cannot be observed by the manufacturer.
ξ_r	The beliefs of the manufacturer over the customer' reservation price.
ξ_{prob}	The beliefs of customers over their chances of obtaining the product on the salvage market.
τ	Tax rate of carbon tax policy i.e. the cost per unit carbon emission.

The parameters must satisfy certain conditions for the model to make "sense", so we assume:

(a) $p \le r$. Only when the retail selling price not more than the customer reservation price, the customer may purchase the product at full price.

(b) $v>p>c>s>0$. This condition states that there is a positive profit margin for the manufacturer and customers when a product is sold to customers. In addition, the production cost is greater than the salvage price, which indicates that the manufacturer will lose money when the product failed to sell at full price. This prompted the manufacturer to arrange the production plan according to the customers' demand, because the excess inventories generate losses.

(c) $\tau<v-c$. It shows that the manufacturer is profitable from production. Otherwise, the manufacturer will be out of the market without production.

The sequence of events is as follows: First, the manufacturer forms the belief of customers' reservation price ξ_r and then decides the retail selling price, product quantity and carbon trading volume; second, the customers form the beliefs ξ_{prob} of probability of the product selling at salvage price s according to the information of market price and then form the reservation price r; third, the customers' demand is satisfied and the products are sold at full price p; finally, all remaining products are sold to the external market at salvage price s.

2. THE MANUFACTURER'S OPTIMAL STRATEGY

In this paper, the rational expectations equilibrium problem between the manufacturer and the customers is examined with rational expectations equilibrium method. Rational expectations hypothesis first proposed by Muth (1961) and then introduced into operations management by Su and Zhang (2008) to analyze the enterprises' decision problems in the presence of strategic customer behavior. Rational expectations equilibrium refers to there is no systematic bias between the result of economics and the people's expectation.

First, we examine the decision-making behavior of strategic customers. The customers choose purchase immediately at full price or wait for markdown to maximize their expected surplus. The consumer's expected surplus is v-p((v-s)ξ_{prob}) when the customer purchases the product at full price (salvage price). Then we can obtain the customer's expected surplus $\max\{v-p,(v-s)\xi_{\text{prob}}\}$. If and only if $v-p \ge (v-s)\xi_{\text{prob}}$, the customer will buy at full price. So given ξ_{prob}, we can obtain the customer's reservation price $r(\xi_{\text{prob}})=v-(v-s)\xi_{\text{prob}}$.

Second, we examine the manufacturer's decision problem. The manufacturer decides the production quantity q and full price p to maximize his expected profit. When $D>q$, the manufacturer's profit is $(p-c-\tau)q$. When $D\le q$, the manufacturer's profit is $pD+s(q-D)-(c+\tau)q$. By rearranging we obtain the manufacturer's expected profit function with carbon tax:

$$\Pi_t(q,p)=(p-s)E(q-\int_0^q F(x)\mathrm{d}x)-(c+\tau-s)q\,. \quad (1)$$

The beliefs of the manufacturer over the customer' reservation price is ξ_r. Obviously, the manufacturer will set $p=\xi_r$ and $q(p)=\arg\max_q \Pi_t(q,p)$. According to the definition of rational expectations equilibrium in Su and Zhang (2008), the solution of rational expectations equilibrium ($p,q,r,\xi_r,\xi_{\text{prob}}$) must meet the following conditions:

$$r=v-(v-s)\xi_{\text{prob}}\,, \quad (2)$$

$$p=\xi_r\,, \quad (3)$$

$$q=\arg\max_q \Pi_t(q,p)\,, \quad (4)$$

$$\xi_{\text{prob}}=F(q)\,, \quad (5)$$

$$\xi_r=r\,. \quad (6)$$

Conditions (2) (3), and (4) indicate, and indicate that the manufacturer and customers will choose the action to maximize their own utility. Conditions (5) and (6) can ensure the solution meets rational expectations hypothesis i.e. the actual situation of economic in line with people's expectations.

The rational expectations equilibrium makes:

$$p=v-(v-s)F(q)\,. \quad (7)$$

As to the manufacturer's optimal production and pricing strategies with carbon tax policy, we get the following proposition.

Proposition 1 the manufacturer's optimal production quantity and optimal price with carbon tax policy exist and are unique. The manufacturer's optimal production quantity (q^*) is:

$$q^*=\bar{F}^{-1}\left(\sqrt{\frac{c+\tau-s}{v-s}}\right). \quad (8)$$

The manufacturer's optimal price (p^*) is:

$$p^*=s+\sqrt{(c+\tau-s)(v-s)} \quad (9)$$

Proof: From (1), we can obtain $\frac{\mathrm{d}^2\Pi_t(q,p)}{\mathrm{d}q^2}=-(p-s)f(q)<0$. Combined with (7), we can prove the manufacturer's optimal production quantity and optimal price exist and are unique.

Set $\frac{\mathrm{d}\Pi_t(q,p)}{\mathrm{d}q}=0$, then $(p-s)\bar{F}(q)=c+\tau-s$. Combined with (7), we can obtain equations with respect to p and q. Solve the equations, we have $q^*=\bar{F}^{-1}\left(\sqrt{\frac{c+\tau-s}{v-s}}\right)$, $p^*=s+\sqrt{(c+\tau-s)(v-s)}$. This completes the proof.

This proposition means that the manufacturer's optimal production quantity and optimal price with strategic customer behavior and carbon tax policy exist and are unique.

(8), (9) are substituted in the manufacturer's profit function, we get the manufacturer's maximum expected profit with strategic customer behavior and carbon tax policy. That is $\Pi_t(q^*, p^*) = (p^* - s)(q^* - \int_0^{q^*} F(x)\mathrm{d}x) - (c + \tau - s)q^*$.

3. SENSITIVITY ANALYSIS

In order to understand the impact of carbon tax policy parameter i.e. τ on the manufacturer's optimal strategies and the maximum expected profit, we analyze the changes in q^*, p^* and $\Pi_t(q^*, p^*)$ on τ.

By analyzing changes in q^* and p^* on τ, we get the following proposition:

Proposition 2 q^* is decreasing in τ, p^* is increasing in τ.

Proof: the derivative of q^* and p^* to τ:

$$\frac{\mathrm{d}q^*}{\mathrm{d}\tau} = -\frac{1}{2f(q^*)\sqrt{(c+\tau-s)(v-s)}} < 0 \quad , \quad \frac{\mathrm{d}p^*}{\mathrm{d}\tau} = \frac{1}{2}\sqrt{\frac{v-s}{c+\tau-s}} > 0 \quad .$$

Then we can obtain that q^* is decreasing in τ, p^* is increasing in τ. This completes the proof.

Proposition 2 shows that the manufacturer's optimal production quantity and optimal price are affected by the carbon tax set by the government. As the carbon tax increases, the manufacturer's optimal production quantity decreases and optimal price increases. When the manufacturer's optimal production quantity equals to q^*, the manufacturer's margin profit under the Rational Expectations Equilibrium (production decision and pricing decision satisfy (7)) is $\frac{\partial \Pi_t(q,p)}{\partial q}\Big|_{q=q^*, p=p^*} = 0$. In microeconomics, the manufacturer's optimal production quantity follows the condition that the margin profit equal to zero. The conclusion of this paper is consistent with the above rule.

When the government charges a higher carbon tax, it makes a higher marginal production quantity cost of manufacturers. To make the margin profit equal to zero, manufacturers must continue to reduce production quantity, by improving the buying willingness at the full price the customer to make the price continuous increase.

By analyzing changes in τ on $\Pi_t(q^*, p^*)$, we get the following proposition:

Proposition 3 $\Pi_t(q^*, p^*)$ is decreasing in τ.

Proof: put $p^* = s + \sqrt{(c+\tau-s)(v-s)}$ into the manufacturer's maximum expected profit function, we get $\Pi_t(q^*) = \sqrt{(c+\tau-s)(v-s)}(q^* - \int_0^{q^*} F(x)\mathrm{d}x) - (c+\tau-s)q^*$.

According to Envelope Theorem, we get:

$$\frac{\mathrm{d}\Pi_t(q^*)}{\mathrm{d}\tau} = \frac{1}{2}\sqrt{\frac{v-s}{c+\tau-s}}(q^* - \int_0^{q^*} F(x)\mathrm{d}x) - q^*$$

$$= \frac{1}{2\bar{F}(q^*)}(q^* - \int_0^{q^*} F(x)\mathrm{d}x) - q^* .$$

Take the derivative of q^*, $\frac{\mathrm{d}}{\mathrm{d}q^*}(\frac{\mathrm{d}\Pi_t(q^*)}{\mathrm{d}\tau}) = \frac{f(q^*)}{2(\bar{F}(q^*))^2}(q^* - \int_0^{q^*} F(x)\mathrm{d}x) - \frac{1}{2}$, then we obtain:

$$\frac{\mathrm{d}^2\Pi_t(q^*)}{\mathrm{d}\tau^2} = \frac{\mathrm{d}}{\mathrm{d}q^*}(\frac{\mathrm{d}\Pi_t(q^*)}{\mathrm{d}\tau}) \cdot \frac{\mathrm{d}q^*}{\mathrm{d}\tau}$$

$$= (\frac{f(q^*)}{2(\bar{F}(q^*))^2}(q^* - \int_0^{q^*} F(x)\mathrm{d}x) - \frac{1}{2}) \cdot \frac{\mathrm{d}q^*}{\mathrm{d}\tau} .$$

As F satisfies the IFR, and $\frac{f(q^*)}{2(\bar{F}(q^*))^2}(q^* - \int_0^{q^*} F(x)\mathrm{d}x)$ is increasing in q^*, there obviously exist $\tilde{q}^*$: when $q^* \le \tilde{q}^*$, $\frac{\mathrm{d}}{\mathrm{d}q^*}(\frac{\mathrm{d}\Pi_t(q^*)}{\mathrm{d}\tau}) \le 0$: when $q^* \ge \tilde{q}^*$, $\frac{\mathrm{d}}{\mathrm{d}q^*}(\frac{\mathrm{d}\Pi_t(q^*)}{\mathrm{d}\tau}) \ge 0$. As q^* is decreasing in τ, we get $\frac{\mathrm{d}q^*}{\mathrm{d}\tau} < 0$, and there certainly exist $\tilde{\tau}$ satisfied, when $\tau \ge \tilde{\tau}$, $\frac{\mathrm{d}^2\Pi_t(q^*)}{\mathrm{d}\tau^2} \ge 0$; when $\tau \le \tilde{\tau}$, $\frac{\mathrm{d}^2\Pi_t(q^*)}{\mathrm{d}\tau^2} \le 0$. Obviously, $\frac{\mathrm{d}\Pi_t(q^*)}{\mathrm{d}\tau}\Big|_{\tau+c=v} = 0$. When $\tau \in [\tilde{\tau}, v\text{-}c]$, $\frac{\mathrm{d}\Pi_t(q^*)}{\mathrm{d}\tau}$ is increasing in τ, then $\frac{\mathrm{d}\Pi_t(q^*)}{\mathrm{d}\tau} < 0$, we obtain $\Pi_t(q^*, p^*)$ is decreasing in τ. When $\tau \le \tilde{\tau}$, $\frac{\mathrm{d}\Pi_t(q^*)}{\mathrm{d}\tau}$ is decreasing in τ, and $\frac{\mathrm{d}\Pi_t(q^*)}{\mathrm{d}\tau}\Big|_{\tau+c=s} < 0$, we obtain that $\Pi_t(q^*, p^*)$ is decreasing in carbon tax rate. This completes the proof.

Proposition 3 indicates that the manufacturer's maximum expected profit decreases with the increasing of carbon tax rate. Carbon tax rate increases the manufacturer's production costs, in order to avoid the loss of profit, the manufacturer has to reduce the production quantity and increase the sales price. However, among the factors that affect profit, cost rising lead to the loss of profit is dominated. As a result, when the carbon tax rate increases, the production cost continuously rises, and the manufacturer's maximum expected profit decreases.

4. THE IMPACT OF CARBON TAX POLICY ANALYSIS

In this part, comparing with the scenario without carbon policy, we analyze the impact of carbon tax policy on manufacturer's optimal production quantity, price and maximum expected profit. When τ=0, that is the scenario without carbon policy. Put τ=0 into q^*, p^* and $\Pi_t(q, p)$, we get manufacturer's optimal production quantity (q_n), price

(p_n) and maximum expected profit ($\Pi_n(q_n, p_n)$) without carbon policy.

$$q_n = \bar{F}^{-1}(\sqrt{\frac{c-s}{v-s}}), \tag{10}$$

$$p_n = s + \sqrt{(c-s)(v-s)}, \tag{11}$$

$$\Pi_n(q_n, p_n) = (p_n - s)(q_n - \int_0^{q_n} F(x)\,\mathrm{d}x) - (c-s)q_n. \tag{12}$$

Compare the manufacturer's optimal production quantity and price with carbon tax policy and without carbon policy, we obtain the propositions as follows.

Proposition 4 $q^*<q_n$; $p^*>p_n$.

Proof: As $q^* = \bar{F}^{-1}(\sqrt{\frac{c+\tau-s}{v-s}}) < \bar{F}^{-1}(\sqrt{\frac{c-s}{v-s}}) = q_n$, we get $q^*<q_n$. According to formula (7), p is decreasing in q, and as $q^*<q_n$, we get $p^*>p_n$.This completes the proof.

Proposition 4 shows that compared with the scenario without carbon policy, the manufacturer's optimal production quantity decreased but the optimal price increased under carbon tax policy. The lower the manufacturer's production quantity is, the lower the probability of customers buying the products in phase II is, and the higher the customer's reservation optimal price is. Manufacturers would make the price equals to customer's reservation price, so manufacturer's production quantity decreases, the product price increases, and the manufacturer's marginal revenue increases. Under the carbon tax policy, the manufacturer's marginal produce cost increase. If keeps the original production quantity level, the manufacturer's marginal cost is greater than marginal revenue. To maximize the profit, the manufacturer has to reduce the production quantity, improve customer's buying willingness, so as to improve product price and marginal revenue, and makes the marginal revenue equal to the marginal cost of production.

Comparing with the scenario of no carbon emission policy, the the manufacturer's optimal production quantity decreases under carbon tax policy. According to the hypothesis of this paper, that is producing every unit of the product would produce a unit of carbon emission. It shows that manufacturer's optimal carbon emission under carbon tax policy is lower than that of no carbon emission policy. Therefore, the implementation of carbon tax policy effectively reduces the manufacturer's carbon emissions. The degree of carbon emissions reduction is positive correlation with the carbon tax rate (because the manufacturer's optimal production quantity is negative correlation with the carbon tax rate), that is, the higher the carbon tax rate is, and the effect of carbon tax policy is more obvious.

Comparing the manufacturer's maximum expected profit under carbon tax policy and no carbon emission policy, we obtain the following propositions:

Proposition 5 $\Pi_t(q^*, p^*)<\Pi_n(q_n, p_n)$

Proof: when τ=0，that is the scenario under no carbon policy, $\Pi_t(q^*, p^*)=\Pi_n(q_n, p_n)$. According to proposition 3, we know that $\Pi_t(q^*, p^*)$ is decreasing in τ，that is, when τ>0, $\Pi_t(q^*, p^*)<\Pi_n(q_n, p_n)$.This completes the proof.

Proposition 5 shows that manufacturer's maximum expected profit under Carbon tax policy is less than that under no carbon policy. When government charges the carbon tax, it could strictly reduce the manufacturer's maximum expected profit. Compared with the scenario of no carbon policy, Carbon tax policy increases the manufacturer's produce cost directly. The manufacturer can adjust the product production quantity and price to offset part of the loss of profit, but he cannot save all. As a result, the manufacturer's maximum expected profit under carbon tax policy is less than that under no carbon policy.

5. CONCLUSION AND FUTURE RESEARCH

This paper studied how a manufacturer facing the strategic customer behavior made the joint production quantity and pricing decisions under carbon tax policy, and analyzed the impact of carbon tax policy and its parameter on manufacturer's optimal decisions and maximum expected profit. First, we obtained manufacturer's optimal production quantity, price and maximum expected profit under carbon tax policy and strategic customer behavior; Secondly, we found that manufacturer's optimal production quantity is decreasing in carbon tax rate, manufacturer's optimal price is increasing in carbon tax rate, and manufacturer's maximum expected profit is decreasing in carbon tax rate; Finally, compared with the scenario of no carbon policy, we found that the manufacturer's optimal production quantity is decreasing, optimal price is increasing and maximum expected profit was decreasing under carbon tax policy.

This paper studied the operating decision problem from the perspective of manufacturer under carbon tax policy and strategic customer behavior. However, in real society, the supply chain environment is more common, so studying from the perspective of the supply chain will be more valuable. If considering manufacturer's production quantity decisions and retailer's pricing decisions, we can expand our research from a single manufacturer to a supply chain environment. Therefore, the further research direction of this paper is corporate operational decision-making problem from the perspective of the supply chain under carbon tax policies and strategic customer behavior.

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