ISSN 2616-5902 Vol. 5, Issue 1: 20-27, DOI: 10.25236/AJBM.2023.050104

Research on Production Mode and Eco-Label Strategy Selection Considering Consumers' Environmental Awareness

Mengting Lin[1,a,*]

[1]*College of Management, Shanghai University, Shanghai, 200444, China*
[a]*287474990@qq.com*
**Corresponding author*

Abstract: *This paper studies the enterprise's selection of production mode and eco-label strategy. Using optimization methods, we find the optimal decisions of the enterprise, NGO, and government under different circumstances. We can obtain the following conclusions by analyzing and comparing the optimal decisions. No matter what kind of eco-label the enterprise adds, the mixed production mode is the best choice for the enterprise. When consumers' environmental awareness is high, the production mode of only ordinary products is the worst choice. For the NGO and the government, the enterprise's production mode of only eco-labeled products can bring the highest environmental benefits and social welfare. And the government label has a lower standard than the NGO label. By applying the government label, the enterprise can provide eco-label products at a lower price, thus gaining higher market share and profits.*

Keywords: *Eco-label standards, Production mode, Product pricing*

1. Introduction

The improvement of consumers' environmental awareness has prompted enterprises to pay attention to upgrade the greenness of their products. To achieve green upgrading of products, enterprises need to spend more on production costs to reduce pollution emissions. Therefore, enterprises may produce only ordinary products, or only eco-labeled products, or both two products. Applying for eco-label certification is a common mean for enterprises to realize green products upgrading. Eco-labels are common to be issued by NGOs or governments, such as the FSC launched by environmental NGOs and the Energy Star logo launched by the US government. The standards of eco-labels issued by different label issuers vary.

A large number of empirical studies have shown that eco-label has a positive impact on consumers' purchasing behaviours [1-3]. Regarding the study on the pricing of green products, Sedjo and Swallow [4] take wood products as an example to explore the impact of eco-label on the pricing of labeled and unlabeled products. Zhang et al. [5] study the pricing of green products in a dual-channel supply chain consisting of a manufacturer and a retailer under both decentralized and centralized decision-making scenarios. Liu et al. [6] study the pricing and coordination of green products based on consumer behaviour. Ling et al. [7] study the competition between two enterprises with different green technologies on the pricing and greenness of green products under a government-led scenario with a set subsidy rate. In research on the choice of enterprise production modes, Fadavi et al. [8] study the manufacturer's choice of green product production mode in the supply chain consisting of a manufacturer and a retailer. Awaga et al. [9] construct an evolutionary game model between the government and enterprises to explore the influence of different reward and punishment mechanisms implemented by the government on enterprises' choice of green production mode. Zhang et al. [10] construct a supply chain consisting of two competing manufacturers and a single retailer and study the influence of the retailer's subsidy scheme on the choice of green production mode of the two competing manufacturers. In the studies of the competition of eco-label issuers, Fischer and Lyon [11-12] explore the environmental impact of the eco-label strategic competition between two kinds of label issuers with different objectives (trade associations and NGOs), and expand the types of eco-labels from binary labels to multi-layer labels in the further study. Heyes and Martin [13] study the design of eco-label and competition of several NGOs. Youssef and Lahmandi-Ayed [3] construct a game model between label issuers and two competing enterprises, the research shows that labels do not always improve the environment. To sum up, this paper is carried out

ISSN 2616-5902 Vol. 5, Issue 1: 20-27, DOI: 10.25236/AJBM.2023.050104

on the basis of the above studies, but there are some differences. This paper not only considers enterprises' choice of production mode, but also studies the strategy of eco-label selection. The research questions of this paper are as follows: What is the impact of the consumers' environmental awareness, environment quality costs, etc. on the optimal decision making? Which production mode and eco-label should the enterprise choose?

2. Problem Description and Hypothesis

We study the production mode and eco-label selection of the enterprise in an oligopoly monopoly market. In the market, there are the eco-label provided by the NGO seeking maximum environmental improvement, and the eco-label provided by the government seeking maximum social welfare. The enterprise can choose to apply for one of the eco-label certifications. Based on the realistic background and the study of literature [1]-[4], consumers are considered to have environmental awareness and are willing to pay a premium for eco-labeled products. Enterprise M has three production modes to choose. Suppose that the price of ordinary products is p_O^{ij}, market demand is d_O^{ij}, and production cost is c, where $i = N, G$ represents NGO label and government label, $j = 1, 2, 3$ represents the strategy of producing only ordinary products, the strategy of producing only eco-labeled products and the mixed production mode. Suppose that the pricing of the eco-labeled product is p_E^{ij}, the market demand is d_E^{ij}, and the production cost is $c + \sigma s^{ij}$. The higher the eco-label standard, the higher the production cost of the eco-labeled product. Eco-labeled products and ordinary products differ from each other in terms of environment quality attributes and can be replaced in terms of function. Related notations and definitions are shown in Table 1.

Table 1: Notations and definitions.

Notations	Definitions
Subscript n	$n = M, N, G, O, E$, *represent the firm, NGO, government, ordinary products and eco-labeled products respectively*
c	*Production cost of an ordinary product,* $c > 0$
V	*Consumer valuation of ordinary products,* $0 < V < 1$
θ	*Environmental awareness of consumers,* $\theta > 1$
σ	*Environment quality cost per unit,* $\sigma > 0$
g	*Environmental improvement factors,* $g > 0$
d_n^{ij}	*Under label* i*, market demand of product* n *in production mode* j
π_n^{ij}	*Under label* i*, the objective function of* n *in production mode* j
p_n^{ij}	*Under label* i*, the price of product* n *in production mode* j*,* $p_{ij} > 0$
s^{ij}	*Under the label* i*, the eco-label standard in production mode* j*,* $s^{ij} > 0$

3. Choice of Production Mode under the NGO Label

3.1. Production Mode of Only Ordinary Products

The consumer's utility of buying ordinary products is only affected by the price of products and the valuation of function, and the expression is $U_O^{N1} = V - p_O^{N1}$. The market size is assumed to be 1. If $U_O^{N1} > 0$, consumers will buy ordinary products. Equation (1) is the demand function. Equation (2) refers to the enterprise's profit, that is, the income from the production and sales of ordinary products. The enterprise determines the price of ordinary products based on the profit maximization.

$$d_O^{N1} = 1 - p_O^{N1} \tag{1}$$

$$max\, \pi_M^{N1}(p_O^{N1}) = (p_O^{N1} - c) d_O^{N1} \tag{2}$$

Lemma 1. The enterprise's optimal pricing of ordinary products and the equilibrium demand and profit are $p_O^{N1} = \frac{1+c}{2}$, $\pi_M^{N1} = \frac{(1-c)^2}{4}$, $d_O^{N1} = \frac{1-c}{2}$.

Proposition 1. π_M^{N1} and d_O^{N1} decrease as c increases; p_O^{N1} increases as c increases.

Proposition 1 suggests that with the increase in production cost, the enterprise will raise the price, but the demand and profits will decrease.

ISSN 2616-5902 Vol. 5, Issue 1: 20-27, DOI: 10.25236/AJBM.2023.050104

3.2. Production Mode of Only Eco-labeled Products

The consumer's utility of buying eco-labeled products is also influenced by consumers' environmental awareness and is given by the expression $U_E^{N2} = \theta V - p_E^{N2}$. If $U_E^{N2} > 0$, consumers will buy the eco-labeled products, the demand function is shown in equation (3). The profit of the enterprise consists of the sale of eco-labeled products, as expressed in equation (4). The NGO seeks to maximize environmental benefits, as expressed in equation (5). First, the NGO decides on the eco-label standard; then, the enterprise sets the price.

$$d_E^{N2} = 1 - \frac{p_E^{N2}}{\theta} \tag{3}$$

$$max\, \pi_M^{N2}(p_E^{N2}) = (p_E^{N2} - c - \sigma s^{N2}) d_E^{N2} \tag{4}$$

$$max\, \pi_N^{N2}(s^{N2}) = g s^{N2} d_E^{N2} \tag{5}$$

Lemma 2. The optimal price of the eco-labeled products and the NGO eco-label standard are $p_E^{N2} = \frac{3\theta + c}{4}$, $s^{N2} = \frac{\theta}{2\sigma}$. The equilibrium demand and profit of the enterprise are $d_E^{N2} = \frac{\theta - c}{4\theta}$ and $\pi_M^{N2} = \frac{(c-\theta)^2}{16\theta}$. The environmental benefit of the NGO is $\pi_N^{N2} = \frac{g(c-\theta)^2}{8\theta\sigma}$.

Proposition 2**.** (1) d_E^{N2}, p_E^{N2}, π_M^{N2}, π_N^{N2}, s^{N2} increase as θ increases. (2) π_N^{N2}, s^{N2} decrease as σ increases. (3) π_N^{N2} increases as g increases. (4) d_E^{N2}, π_M^{N2}, π_N^{N2}, s^{N2} decrease as c increases; p_E^{N2} increases as c increases.

Proposition 2 shows that improving consumers' environmental awareness can increase market demand, improve the enterprise's profits and the environmental benefits. The environmental benefits and the eco-label standard will decrease as the environment quality cost increases. Environmental benefits will increase with the increase of environmental improvement factors. As production costs increase, the eco-label standard, environmental improvements, demand and profits of enterprises will decrease.

3.3. Mixed Production Mode

In the mixed production mode, the market offers both ordinary and eco-labeled products, and the consumer's utility of buying each of the two products is $U_O^{N3} = V - p_O^{N3}$ and $U_H^{N3} = \theta V - p_E^{N3}$. If $0 < U_O^{N3} < U_E^{N3}$, consumers will buy the regular product, while if $U_E^{N3} > U_O^{N3}$, consumers will buy the eco-labeled product. The demand for the two products is respectively shown in equation (6), (7). The profit of the enterprise consists of the sale of two products, as expressed in equation (8). The NGO pursues to maximize the environmental benefits, as expressed in equation (9). The game sequence is as follows: first, the NGO decides the eco-label standard; then, the enterprise decides the price of both products.

$$d_O^{N3} = \frac{p_E^{N3} - p_O^{N3}}{\theta - 1} - p_O^{N3} \tag{6}$$

$$d_E^{N3} = 1 - \frac{p_E^{N3} - p_O^{N3}}{\theta - 1} \tag{7}$$

$$\pi_M^{N3}(p_O^{N3}, p_E^{N3}) = (p_O^{N3} - c) d_O^{N3} + (p_E^{N3} - c - \sigma s^{N3}) d_E^{N3} \tag{8}$$

$$\pi_N^{N3}(s^{N3}) = g s^{N3} d_E^{N3} \tag{9}$$

Lemma 3. If $c < \frac{1}{2}$, the optimal prices of the two products and the eco-label standard are $p_O^{N3} = \frac{1+c}{2}$, $p_E^{N3} = \frac{1}{4}(2c - 1 + 3\theta)$, $s^{N3} = \frac{\theta - 1}{2\sigma}$. The demand and profit of the enterprise are $d_O^{N3} = \frac{1-2c}{4}$, $d_E^{N3} = \frac{1}{4}$, $\pi_M^{N3} = \frac{1}{16}(3 + 4(-2 + c)c + \theta)$. The environmental improvement is $\pi_N^{N3} = \frac{g(\theta - 1)}{8\sigma}$.

Proposition 3. (1) p_E^{N3}, π_M^{N3}, π_N^{N3}, s^{N3} increase as θ increases. (2) π_N^{N3}, s^{N3} decrease as σ increases. (3) π_N^{N3} increases as g increases. (4) d_O^{N3}, π_M^{N3} decrease as c increases; p_O^{N3}, p_E^{N3} increase as c increases.

Under the mixed production mode, the effect of each parameter on the optimal decision is similar to Proposition 2. The difference is that the pricing and demand of ordinary products are only affected by the production cost. However, the environmental benefits and the eco-label standard are not affected by the production cost.

ISSN 2616-5902 Vol. 5, Issue 1: 20-27, DOI: 10.25236/AJBM.2023.050104

4. Choice of Production Mode for the Enterprise under the Government Label

4.1. Production Mode of Only Ordinary Products

The consumer's utility of purchasing the ordinary products is $U_O^{G1} = V - p_O^{G1}$. Similar to the above, the demand function can be obtained as equation (10). Equation (11) is the enterprise's profit. Equation (12) is the government's objective function which consists of the enterprise's profit and consumer surplus. Then, the enterprise sets the price.

$$d_O^{G1} = 1 - p_O^{G1} \tag{10}$$

$$max\, \pi_M^{G1}(p_O^{G1}) = (p_O^{G1} - c)d_O^{G1} \tag{11}$$

$$\pi_G^{G1} = \int_{p_O^{G2}}^{1} (V - p_O^{G2})\, dV + \pi_M^{G1} \tag{12}$$

Lemma 4. If $c < 1$, the optimal price of ordinary products and the equilibrium demand and profit of the enterprise are $p_O^{G1} = \frac{1+c}{2}$, $d_O^{G1} = \frac{1-c}{2}$, $\pi_M^{G1} = \frac{(1-c)^2}{4}$. The social welfare is $\pi_G^{G1} = \frac{(1-c)^2}{8}$.

Proposition 4. π_G^{G1}, π_M^{G1} *and* d_O^{G1} decrease as c increases; p_O^{G1} increases as c increases.

Proposition 4 suggests that increasing production costs are detrimental to the enterprise and government, as they reduce the demand for and profitability of ordinary goods and social welfare.

4.2. Production Mode of Only Eco-labeled Products

The consumer's utility of purchasing the eco-labeled products is $U_H^{G2} = \theta V - p_E^{G2}$. Similar to the above, the demand function can be obtained as equation (13). Equation (14) is the enterprise's profit. Equation (15) is the government objective function consisting of consumer surplus, enterprise's profit, and environmental improvement. The game sequence is as follows: first, the government decides the eco-label standard; second, the enterprise sets the price.

$$d_E^{G2} = 1 - \frac{p_E^{G2}}{\theta} \tag{13}$$

$$\pi_M^{G2}(p_E^{G2}) = (p_E^{G2} - c - \sigma s^{G2})d_E^{G2} \tag{14}$$

$$\pi_G^{G2}(s^{G2}) = \int_{\frac{p_E^{G2}}{\theta}}^{1} (\theta V - p_E^{G2})\, dV + \pi_M^{G2} + g s^{G2} d_E^{G2} \tag{15}$$

Lemma 5. If $g > \frac{3}{2}\sigma$ and $\theta > c$, the optimal price of eco-labeled products and the eco-label standard are $p_E^{G2} = \theta + \frac{g(c-\theta)}{4g-3\sigma}$, $s^{G2} = \frac{(\theta-c)(2g-3\sigma)}{(4g-3\sigma)\sigma}$. The demand and profit of the enterprise and the social welfare are $d_E^{G2} = \frac{g(\theta-c)}{\theta(4g-3\sigma)}$, $\pi_M^{G2} = \frac{g^2(c-\theta)^2}{\theta(4g-3\sigma)^2}$, $\pi_G^{G2} = \frac{g^2(c-\theta)^2}{2\theta(4g-3\sigma)\sigma}$.

Proposition 5. (1) d_E^{G2}, p_E^{G2}, π_M^{G2}, π_G^{G2}, s^{G2} increase as θ increases. (2) d_E^{G2}, π_M^{G2} increase as σ increases; p_E^{G2}, π_G^{G2}, s^{G2} decrease as σ increases. (3) d_E^{G2}, π_M^{G2} decrease as g increases; p_E^{G2}, π_G^{G2}, s^{G2} increase as g increases. (4) d_E^{G2}, π_M^{G2}, π_G^{G2}, s^{G2} decrease as c increases; p_E^{G2} increases as c increases.

Proposition 5 shows that the higher the environmental awareness of consumers, the more beneficial it is for the enterprise and government. As the cost of environment quality increases, the eco-label standard and social welfare decrease, and the price of labeled products decreases, thus increasing product demand and the enterprise's profits. As the environmental improvement factor increases, the eco-label standard and social welfare increase, which raises the price of eco-labeled products, leading to a decrease in both the market share and profits of the enterprise. The enterprise will ease the pressure of the increasing production costs by raising the price of products, but the increase in production costs is detrimental to both the enterprise and the government.

4.3. Mixed Production Mode

The utility of the consumer to purchase ordinary and eco-labeled products are $U_L^{G3} = V - p_O^{G3}$, $U_L^{G3} = V - p_O^{G3}$. Similar to the above, the demand function can be obtained as equation (16) and (17). Equation (18) is the enterprise's profit. Equation (19) is the government's objective function, i.e.,

ISSN 2616-5902 Vol. 5, Issue 1: 20-27, DOI: 10.25236/AJBM.2023.050104

to maximize social welfare. First, the government decides the eco-label standard; second, the enterprise determines the prices of two kinds of products.

$$d_O^{G3} = \frac{p_E^{G3} - p_O^{G3}}{\theta - 1} - p_O^{G3} \tag{16}$$

$$d_E^{G3} = 1 - \frac{p_E^{G3} - p_O^{G3}}{\theta - 1} \tag{17}$$

$$\pi_M^{G3}(p_O^{G3}, p_E^{G3}) = (p_O^{G3} - c)d_O^{G3} + (p_E^{G3} - c - \sigma s^{G3})d_E^{G3} \tag{18}$$

$$\pi_G^{G3}(s^{G3}) = \int_{p_O^{G3}}^{\frac{p_E^{G3} - p_O^{G3}}{\theta - 1}} (V - p_O^{G3})\, dV + \int_{\frac{p_E^{G3} - p_O^{G3}}{\theta - 1}}^{1} (\theta V - p_E^{G3})\, dV + \pi_M^{G3} + g s^{G3} d_E^{G3} \tag{19}$$

Lemma 6. If $g > \frac{3(1-c)\sigma}{2-4c}$ and $c < \frac{1}{2}$, the optimal prices of ordinary and eco-labeled products are $p_O^{G3} = \frac{1+c}{2}$, $p_E^{G3} = \frac{c-1+2\theta}{2} + \frac{g(\theta-1)}{3\sigma-4g}$. The government eco-label standard is $s^{G3} = \frac{(\theta-1)(2g-3\sigma)}{(4g-3\sigma)\sigma}$. The enterprise's demand and profit are $d_E^{G3} = \frac{g}{4g-3\sigma}$, $d_O^{G3} = \frac{1-c}{2} - \frac{g}{4g-3\sigma}$, $\pi_M^{G3} = \frac{(1-c)^2}{4} + \frac{g^2(\theta-1)}{(4g-3\sigma)^2}$. The social welfare is $\pi_G^{G3} = \frac{1}{8}\left(3 + 3(-2+c)c + \frac{4g^2(-1+\theta)}{(4g-3\sigma)\sigma}\right)$.

Proposition 6. (1) p_E^{G3}, π_G^{G3}, s^{G3} increase as θ increases. (2) d_E^{G3}, π_M^{G3} increase as σ increases; d_O^{G3}, p_E^{G3}, π_G^{G3}, s^{G3} decrease as σ increases. (3) π_M^{G3}, d_E^{G3} decrease as g increases; d_O^{G3}, p_E^{G3}, π_G^{G3}, s^{G3} increase as g increases. (4) d_O^{G3}, π_M^{G3}, π_M^{G3} decrease as c increases; p_O^{G3}, p_E^{G3} increase as c increases.

Proposition 6 shows that the increase in consumers' environmental awareness benefits both the enterprise and the government. With the increase of environment quality cost, for the enterprise, the price of eco-labeled products and the demand for ordinary products decrease, and the demand for eco-labeled products and the profits increase; and for the government, social welfare and the eco-label standard will decrease as the environment quality cost increases. As the environmental improvement factor increases, for the enterprise, the demand for labeled products and the profits decrease, and the demand for ordinary products and the price of eco-labeled products increase; and for the government, social welfare and the eco-label standard increase. The increase in production costs is detrimental to both the government and the enterprise.

5. Model Comparison

5.1. Comparison of Three Production Mode

Proposition 7. (1) $p_E^{N2} > p_E^{N3} > p_O^{N3} = p_O^{N1}$; (2) $d_O^{N1} = (d_O^{N3} + d_E^{N3}) > d_E^{N2}$, $d_O^{N1} > d_E^{N2} > d_E^{N3} > d_O^{N3}$; (3) If $\theta < \theta_1$, $\pi_M^{N3} > \pi_M^{N1} > \pi_M^{N2}$; if $\theta > \theta_1$, $\pi_M^{N3} > \pi_M^{N2} > \pi_M^{N1}$, $\theta_1 = 2 - 3c + 2c^2 + 2(1-c)\sqrt{(1+(c-1)c)}$.

Proposition 8. (1) $p_E^{G2} > p_E^{G3} > p_O^{G3} = p_O^{G1}$; (2) $d_O^{G1} = (d_O^{G3} + d_E^{G3}) > d_E^{G2}$, $d_O^{G1} > d_E^{G2} > d_E^{G3} > d_O^{G3}$; (3) If $\theta < \theta_2$, $\pi_M^{G3} > \pi_M^{G1} > \pi_M^{G2}$; if $\theta > \theta_2$, $\pi_M^{G3} > \pi_M^{G2} > \pi_M^{G1}$, where θ_2 is the larger positive root of $F_3 = 0$,$F_3 = 4g^2\left(-6c\theta - (\theta-4)\theta + c^2(-1+4\theta)\right) - 24(1-c)^2 g\theta\sigma + 9(1-c)^2\theta$.

Proposition 7 and Proposition 8 show that no matter what kind of eco-label the enterprise joins, eco-labeled products are priced higher than ordinary products. The optimal price of ordinary products is not influenced by the enterprise's production mode, and the price is highest in the production mode of only eco-labeled products. The demand under the production mode of only eco-labeled products is lower than the other modes. The eco-labeled products demand under the production mode of only eco-labeled products is higher than the demand for eco-labeled products under the mixed production mode. For the enterprise, mixed production mode is the optimal choice; when consumers' environmental awareness is low, producing only eco-labeled products is the worst choice, and when consumers' environmental awareness is high, producing only ordinary products is the worst choice.

Proposition 9. (1) $s^{N3} < s^{N2}$, $\pi_N^{N3} < \pi_N^{N2}$; (2) $s^{G2} > s^{G3}$, $\pi_G^{G2} > \pi_G^{G3} > \pi_G^{G1}$.

Proposition 9 suggests that the government and NGO will establish higher eco-label standard when the enterprise only produces eco-labeled products. For the government and NGO, the enterprise's

ISSN 2616-5902 Vol. 5, Issue 1: 20-27, DOI: 10.25236/AJBM.2023.050104

production mode of only eco-labeled products can bring more environmental improvement and social welfare. Figure 1 shows the numerical validation of Proposition 9 (1), where the parameters are given as $c = 0.1,\ \sigma = 0.6,\ g = \{1.1,1.3\}$. Comparing the numerical groups (1) and (2), it shows that the profit difference between the two production modes increases with the increase of the environmental improvement factor. Figure 2 shows the numerical verification of Proposition 9 (2), where the parameters are given as $= 0.2,\ \sigma = 0.5$. Comparing the numerical groups (1) and (2), it shows that the increase of the environmental improvement factor improves the social welfare of the production mode of only eco-labeled products and the mixed production mode.

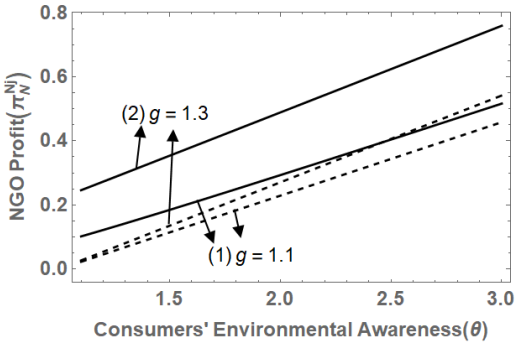

Figure 1: Comparison of NGO profit.

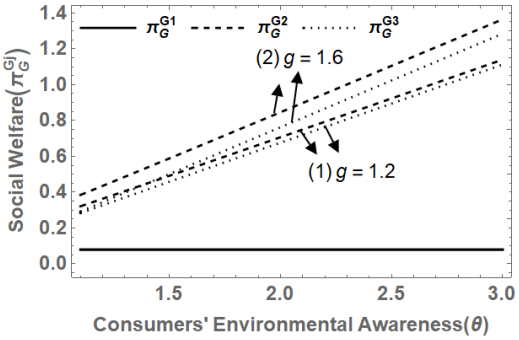

Figure 2: Comparison of social welfare.

5.2. Comparison of Two Eco-label Strategies

Proposition 10. (1) $\pi_M^{G2} > \pi_M^{N2},\ d_E^{G2} > d_E^{N2},\ p_E^{G2} < p_E^{N2}$; (2) $s^{G2} < s^{N2}$.

Proposition 10 suggests that in the mode of producing only eco-labeled products, it is better for the enterprise to obtain an eco-label approved by the government. Compared to the NGO eco-label, government eco-label has lower standard, hence the enterprise can capture more market demand and profit.

Proposition 11. (1) $\pi_M^{G3} > \pi_M^{N3},\ d_E^{G3} > d_E^{N3},\ p_E^{G3} < p_E^{N3}$; (2) $d_O^{G3} = d_O^{N3},\ p_O^{G3} = p_O^{N3}$; (3) $s^{N2} > s^{G2}$.

Proposition 11 shows that in a mixed production mode, when the enterprise chooses to obtain the government eco-label, the price of eco-labeled products is lower, and the enterprise can achieve more market share and profit. The price and demand for ordinary products are not affected by the type of eco-label. The standard for the eco-label set by the NGO is higher.

6. Conclusion

This paper studies the production mode and eco-label selection strategy of enterprises. By analyzing and comparing the optimal decisions under different models, the following conclusions are obtained. (1) Raising the environmental awareness of consumers can improve environmental benefits, social welfare and the enterprise's profits, benefiting all three parties. The environmental benefits, social welfare, and eco-label standard all decrease with the increase of environment quality cost. As the environmental improvement factor increases, environmental benefits and social welfare will increase and the

ISSN 2616-5902 Vol. 5, Issue 1: 20-27, DOI: 10.25236/AJBM.2023.050104

enterprise's profits will decrease. (2) For the enterprise, the mixed production mode is optimal. For the government, the enterprise's production mode of only eco-labeled products always brings the highest environmental benefits or social welfare. (3) The eco-label standard set by the NGO is higher. Therefore, the enterprise can always gain more market share and profit by choosing to join the eco-label approved by the government.

References

[1] Vanclay J K, Shortiss J, Aulsebrook S, et al. Customer response to carbon labelling of groceries[J]. Journal of Consumer Policy, 2011, 34(1): 153-160.
[2] Amacher G S, Koskela E, Ollikainen M. Environment quality competition and eco-labeling[J]. Journal of Environmental Economics and Management, 2004, 47(2): 284-306.
[3] Youssef A B, Lahmandi-Ayed R. Eco-labelling, competition and environment: Endogenization of labelling criteria[J]. Environmental and Resource Economics, 2008, 41(2): 133-154.
[4] Sedjo R A, Swallow S K. Voluntary eco-labeling and the price premium[J]. Land economics, 2002, 78(2): 272-284.
[5] Zhang C, Liu Y, Han G. Two-stage pricing strategies of a dual-channel supply chain considering public green preference[J]. Computers & Industrial Engineering, 2021, 151: 106988.
[6] Liu K, Li W, Jia F, et al. Optimal strategies of green product supply chains based on behaviour-based pricing[J]. Journal of Cleaner Production, 2022, 335: 130288.
[7] Ling Y, Xu J, Ülkü M A. A game-theoretic analysis of the impact of government subsidy on optimal product greening and pricing decisions in a duopolistic market[J]. Journal of Cleaner Production, 2022, 338: 130028.
[8] Fadavi A, Jolai F, Taleizadeh A A. Green product design in a supply chain with considering marketing under competition and coordination[J]. Environment, Development and Sustainability, 2022, 24(10): 11721-11759.
[9] Awaga A L, Xu W, Liu L, et al. Evolutionary game of green manufacturing mode of enterprises under the influence of government reward and punishment[J]. Advances in Production Engineering & Management, 2020, 15(4): 416-430.
[10] Zhang X, Jin Y, Shen C. Manufacturers' green investment in a competitive market with a ordinary retailer[J]. Journal of Cleaner Production, 2020, 276: 123164.
[11] Fischer C, Lyon T P. Competing environmental labels[J]. Journal of Economics & Management Strategy, 2014, 23(3): 692-716.
[12] Fischer C, Lyon T P. A theory of multitier ecolabel competition[J]. Journal of the Association of Environmental and Resource Economists, 2019, 6(3): 461-501.
[13] Heyes A, Martin S. Social labeling by competing NGOs: A model with multiple issues and entry[J]. Management Science, 2017, 63(6): 1800-1813.

Appendix

Since the proof methods of the Proposition and Lemma of the two label policies are similar, the appendix only shows the proof of the model under the NGO label.

Proof of Lemma 1. First, from $\frac{\partial^2 \pi_M^{N1}}{\partial (p_O^{N1})^2} = -2$, we can obtain that $\pi_M^{N1}$is concave with respect to p_O^{N1}. Second, from $\frac{\partial \pi_M^{N1}}{\partial p_O^{N1}} = 0$， we can obtain $p_O^{N1} = \frac{1+c}{2}$.

Proof of Proposition 1. $\frac{\partial p_O^{N1}}{\partial c} = \frac{1}{2}$, $\frac{\partial d_O^{N1}}{\partial c} = -\frac{1}{2}$, $\frac{\partial \pi_M^{N1}}{\partial \theta} = \frac{1}{2}(-1 + c)$.

Proof of Lemma 2. First, $\pi_M^{N2}(\frac{\partial^2 \pi_M^{N2}}{\partial (p_E^{N2})^2} = -\frac{2}{\theta} < 0)$ is concave with respect to p_E^{N2}. Second, from $\frac{\partial \pi_M^{N2}}{\partial p_E^{N2}} = 0$, we can obtain $p_E^{N2} = \frac{1}{2}(c + \theta + \sigma s^{N2})$. Further, substituting p_E^{N2}in π_N^{N2}. From $\frac{\partial^2 \pi_N^{N2}}{\partial (s^{N2})^2} = -\frac{g\sigma}{\theta} < 0$, so $\pi_N^{N2}$is concave with respect to s^{N2}. Finally, solving $\frac{\partial \pi_N^{N2}}{\partial s^{N2}} = 0$, we can obtain $s^{N2} = \frac{\theta}{2\sigma}$.

Proof of Proposition 2. (1) $\frac{\partial d_E^{N2}}{\partial \theta} = \frac{c}{4\theta^2}$, $\frac{\partial p_E^{N2}}{\partial \theta} = \frac{3}{4}$, $\frac{\partial \pi_M^{N2}}{\partial \theta} = \frac{1}{16}\left(1 - \frac{c^2}{\theta^2}\right)$, $\frac{\partial \pi_N^{N2}}{\partial \theta} = \frac{g(\theta - c)(c + \theta)}{8\theta^2 \sigma}$, $\frac{\partial s^{N2}}{\partial \theta} = \frac{1}{2\sigma}$. (2) $\frac{\partial \pi_N^{N2}}{\partial \sigma} = -\frac{g(c-\theta)^2}{8\theta\sigma^2}$, $\frac{\partial s^{N2}}{\partial \sigma} = \frac{c-\theta}{2\sigma^2}$. (3) $\frac{\partial \pi_N^{N2}}{\partial g} = \frac{(c-\theta)^2}{8\theta\sigma}$. (4) $\frac{\partial d_E^{N2}}{\partial c} = -\frac{1}{4\theta}$, $\frac{\partial p_E^{N2}}{\partial c} = \frac{1}{4}$, $\frac{\partial \pi_M^{N2}}{\partial c} = \frac{1}{8}\left(-1 + \frac{c}{\theta}\right)$, $\frac{\partial \pi_N^{N2}}{\partial \theta} = \frac{g(c-\theta)}{4\theta\sigma}$, $\frac{\partial s^{N2}}{\partial \theta} = \frac{1}{2\sigma}$.

ISSN 2616-5902 Vol. 5, Issue 1: 20-27, DOI: 10.25236/AJBM.2023.050104

Proof of Lemma 3. First, solving the Hessian matrix $H^N = \begin{pmatrix} \frac{2\theta}{1-\theta} & \frac{2\theta}{\theta-1} \\ \frac{2}{\theta-1} & \frac{2\theta}{1-\theta} \end{pmatrix}$ of π_M^{N3} with respect to $p_E^{N3}\ and\ p_O^{N3}$, where $|H_1^N| = \frac{2\theta}{1-\theta} < 0$, $|H_2^N| = \frac{4}{\theta-1} > 0$. Therefore, the Hessian is negative definite, Next, solving $\frac{\partial \pi_M^{N3}}{\partial p_E^{N3}} = 0\ and\ \frac{\partial \pi_M^{N3}}{\partial p_O^{N3}} = 0$, we obtain $p_E^{N3} = \frac{1}{2}(\theta + \sigma s^{N3})\ and\ p_O^{N3} = \frac{1}{2}$. Then, substituting $p_E^{N3}\ and\ p_O^{N3}$ into π_N^{N3}, we get $\frac{\partial^2 \pi_N^{N3}}{\partial (s^{N3})^2} = \frac{g\sigma}{1-\theta} < 0$, $so\ \pi_N^{N3}$ is concave with respect to s^{N3}. Finally, solving $\frac{\partial \pi_N^{N3}}{\partial s^{N3}} = 0$, we can obtain $s^{N3} = \frac{\theta-1}{2\sigma}$.

Proof of Proposition 3. (1) $\frac{\partial p_E^{N3}}{\partial \theta} = \frac{3}{4}$, $\frac{\partial \pi_M^{N3}}{\partial \theta} = \frac{1}{16}$, $\frac{\partial \pi_N^{N3}}{\partial \theta} = \frac{g}{8\sigma}$, $\frac{\partial s^{N3}}{\partial \theta} = \frac{1}{2\sigma}$. (2) $\frac{\partial \pi_N^{N3}}{\partial \sigma} = \frac{g(1-\theta)}{8\sigma^2}$, $\frac{\partial s^{N3}}{\partial \sigma} = \frac{1-\theta}{2\sigma^2}$. (3) $\frac{\partial \pi_N^{N3}}{\partial g} = \frac{\theta-1}{8\sigma}$. (4) $\frac{\partial p_E^{N3}}{\partial c} = \frac{\partial p_O^{N3}}{\partial c} = \frac{1}{2}$, $\frac{\partial d_O^{N3}}{\partial c} = -\frac{1}{2}$, $\frac{\partial \pi_M^{N3}}{\partial c} = \frac{1}{2}(-1 + c)$.

Proof of Proposition 7. (1) The conclusion is derived from the conditions $p_E^{N2} - p_E^{N3} = \frac{1-c}{4}$ and $p_E^{N3} - p_O^{N3} = \frac{1}{4}(3\theta - 2 - c)$. (2) The conclusion is derived from the conditions $d_O^{N1} - (d_O^{N3} + d_E^{N3}) = 0$, $d_O^{N1} - d_E^{N2} = \frac{c+\theta-2c\theta}{4\theta}$, $d_E^{N3} - d_E^{N2} = \frac{c}{4\theta}$, $d_O^{N3} - d_E^{N2} = \frac{c(1-2\theta)}{4\theta}$. (3) $\pi_M^{N3} - \pi_M^{N1} = \frac{\theta-1}{16}$, $\pi_M^{N3} - \pi_M^{N2} = \frac{3\theta(1-2c)+c^2(4\theta-1)}{16\theta}$, $\pi_M^{N2} - \pi_M^{N1} = \frac{F_1}{16\theta}$, where $F_1 = \theta^2 - 2\big(2 + c(-3 + 2c)\big)\theta + c^2$, substituting $\theta = 1$, we obtain $F_1 = -3(1-c)^2$. $\theta_1 = 2 - 3c + 2c^2 + 2(1-c)\sqrt{(1 + (c-1)c)}$ is the positive point of intersection with the axis. So if $\theta < \theta_1$, $\pi_M^{N1} > \pi_M^{N2}$; if $\theta > \theta_1$, $\pi_M^{N2} > \pi_M^{N1}$.

Proof of Proposition 9. (1) $s^{N3} - s^{N2} = \frac{c-1}{2\sigma} < 0$, $\pi_N^{N3} - \pi_N^{N2} = -\frac{g(c^2+\theta-2c\theta)}{8\theta\sigma} < 0$. Similarly, (2) can be proved.

Proof of Proposition 10. (1) $\pi_M^{G2} - \pi_M^{N2} = \frac{3(c-\theta)^2(8g-3\sigma)\sigma}{16\theta(4g-3\sigma)^2} > 0$, $d_E^{G2} - d_E^{N2} = \frac{3\sigma(\theta-c)}{4(4g-3\sigma)} > 0$, $p_E^{G2} - p_E^{N2} = \frac{3(c-\theta)\sigma}{4(4g-3\sigma)} < 0$. (2) $s^{N2} - s^{G2} = \frac{3(\theta-c)}{8g-6\sigma} > 0$.