Optimal Subsidy and Tax Policies for Green Product with Consumer Environmental Awareness

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Abstract

This paper investigates the government's optimal subsidy and tax policies in response to consumer environmental awareness (CEA) and the manufacturers' product selection (generic, green or both) plus quality and pricing decisions. We derive the equilibria under different policy combinations and derived the analytical and numerical solutions. We find that (1) subsidizing and taxing consumers is more social beneficial when the potential market share of green products is small and environmental technology is high; (2) subsidizing green-product consumers and taxing manufacturers who produce ordinary products can yield higher social welfare; (3) subsidizing and taxing manufacturers may be more social optimal when either CEA or consumer awareness of traditional quality is high.

1. Introduction

Subsidy and tax policies are important instruments adopted by governments to stimulate green technology development. For example, the U.S. government passed the American Recovery and Reinvestment Act (ARRA) of 2009, which granted a tax credit to consumers who purchased electric vehicles [8]. Feed-In-Tariff is a policy instrument to attract investments in renewable energy by offering long-term guaranteed purchase agreements to green power producers to sell their electricity into the grid [2, 12, 15]. Gasoline taxes and carbon tax are added in the fuel price considering that greenhouse gas emissions from human activities in particular carbon dioxide (CO_2) are responsible for the current observed global warming [1].

However, no policy is completely efficient. Diamond & David (2009) concluded that there is a strong relationship between gasoline price and hybrid adoption, but a much weaker relationship between incentive policies and hybrid adoption. Gallagher & Muehlegger (2011) showed that conditional on value, sales tax waivers are associated with more than a ten-fold increase in hybrid sales relative to income tax credits. Lobel & Perakis (2011) examined that the current policies in Germany for the adoption of solar photovoltaic technology are not efficient. Therefore, in this paper, we focus on comparing the efficiency government policies (tax and subsidy) in stimulating the demand and supply of green products, and discuss the optimal polices with different environmental level product.

Consumer environmental awareness (*CEA*) is another important factor affect green product demand. The rise of consumer environmental awareness (*CEA*) has changed consumer behavior. The BBMG Conscious Consumer Report shows that 67% of Americans agree that it is important to buy products with environmental benefits and 51% are willing to pay more for products with high environmental quality [3]. Considering the impact of *CEA*, researchers started to introduce environmental quality as a demand enhancement factor in the product demand function [14].

In response to the government's policy and rising CEA, manufacturers adapt their strategies by adjusting product prices and green product quality [7,20]. For example, in 2012, Honda Fit EV model was quickly sold out in Southern California after offering sizable leasing discounts [11]. Feed-In-Tariffs attracts a wide range of manufacturers to invest in renewable energy (such as PV) [2]. Manufacturer will introduce green product based on the ordinary product line with stricter environmental emission standard, given the green product subsidy or ordinary tax set out by the government [7, 18, 20]. The manufacturer decides how to set green product's environmental quality and price with policy instruments and CEA are need to solve for the manufacturers.

In this paper, we assume the manufacturer can choose to produce the variety of products: ordinary product or green product, consumers with different CEA will determine which product to purchase; government will provide subsidy or tax in order to

URI: http://hdl.handle.net/10125/41780
ISBN: 978-0-9981331-0-2

improve social welfare. We mainly investigate the following questions:

1. How instruments policies affect social welfare with manufacturer's product strategy and *CEA*?
2. How environmental quality and price of green product change with *CEA* and instruments policies?
3. What are the optimal policies with different *CEA* and environmental level of green product?

We incorporate *CEA* and the quality of the green product into the demand function. This study compares two scenarios: (i) subsidy to green consumer and tax to ordinary consumer, (ii) subsidy to manufacturer who produces green product and tax to manufacturer who produces ordinary product. We derive the closed-form expressions of price with quality. Then we present the changes of optimal subsidy and tax by using numerical examples and further give the zone division with different *CEA*.

Our paper differs from the literature in the following ways: (1) we compare the effectiveness of the government's subsidizing and tax policies regarding green products when the policies instrument to different objects while previous studies only focused on one particular object [7,17,1]; (2) we incorporate environmental quality and *CEA* into demand function to observe the change of manufacturer's strategy change, while other demand models assume that green demand is fixed [7,18,20,12]; (3) we present the optimal policies with different CEA and green products, while other literature with fixed green product and CEA [2,6,9,10].

There are four main findings: (1) subsidizing and taxing to consumer is more beneficial when the potential market share of green products is small and environmental technology is high; (2) whenever government implements policy to consumer or manufacturer, the social welfare in concave with government subsidy and tax; (3) subsidy to green consumer and taxing to manufacturer who produces ordinary product could obtain high social welfare and environment quality; (4) government should subsidize manufacturer when green product has the low marginal profit; then, government should transfer from subsiding the manufacturer to consumers when the price of green product increases.

This paper is organized as follows. Section 2 presents the model description. Section 3 and 4 present manufacturer's product strategy when the government implements policy to consumer and manufacturer, respectively. Section 5 describes numerical examples. Section 7 summarizes our main findings and concludes the paper by providing some directions for future research. All proofs are relegated to Appendix A.

2. Model

We start by explaining the different components of the environmental products, consumer utility, and social welfare.

2.1. Products

We assume that a monopolist offers a specific class of durable products with two competing attributes, the traditional and environmental attributes, over which individuals may express quantifiable preferences. Given the assumption that both attributes behave like "qualities" (i.e., consumers who value each attribute prefer higher levels to lower levels on the attribute), we will from now on call them traditional and environmental qualities (denoted by q_t and q_e). For example, q_t and q_e can represent the levels of safety rating and fuel economy of a vehicle, which usually conflict with each other [7,18]. Additionally, q_t and q_e can represent the specified levels of any competing traditional and environmental qualities, such as the material consistency and recycled content of a durable product. In order to capture the relationship between traditional and environmental qualities, we assume $q_t + rq_e = 1, r \geq 1$, because the technology of environmental quality improvement is costly, so the one unit improvement of environmental quality is always accompany with more units of traditional quality decrease, which is different from [7].

The monopolist intends to supply all the customers in the market with either an ordinary product or multiple product type(s). The cost of supplying a product increases as a quadratic function with respect to the levels of its two qualities. That is, the unit cost of a product with qualities q_t and q_e is $c_t q_t^2 + c_e q_e^2$, where c_t and c_e are positive cost coefficients. Assume that there is a fixed cost *F* associated with introducing any product type (for R&D and other relevant expenses). Assume further that there are no economies of scale so that unit cost is independent of the number of units produced.

2.2. Demand

We assume that demand of each product is impacted by its price and quality. When manufacturer provides two substitutable products, one product's demand is also affected by another product's price and quality. With the considerations of price competition and the demand enhancement due to ecofriendly improvement, we give demand functions for green product and ordinary product, denoted by

$$D_g = a_g - b_g p_g + \theta_g p_o + k_{gt} q_t^g + k_{ge} q_e^g - l_{gt} q_t^o - l_{ge} q_e^o$$

$$D_o = a_o - b_o p_o + \theta_o p_g + k_{\mathrm{ot}} q_t^o + k_{oe} q_e^o - l_{ot} q_t^g - l_{oe} q_e^g$$

where a_i is initial market potential of product *i*, *i=o* or *g*, where represent ordinary product or green product, respectively; b_i is product *i*'s demand sensitivity to price of product *i*, θ_i is product *i*'s demand sensitivity to price of product *j(j=o* or *g* and $j \neq i$ *)*, k_{gt}, k_{ge} represent green consumer's sensitivity to the traditional quality and environmental quality of environmental product, k_{ot}, k_{oe} represent ordinary consumer's sensitivity to the traditional quality and environmental quality of ordinary product, l_{gt}, l_{ge} are green consumers' sensitivity to the traditional quality and environmental quality of ordinary product and l_{ot}, l_{oe} are ordinary consumers' sensitivity to the traditional quality and environmental quality of green product, respectively. Notice that $b_i > \theta_i$, $k_{it} > l_{it}$ and $k_{ie} > l_{ie}$, because product *i*'s price and quality has more influence than his competitor's price and quality. We assume that $a_i - b_i p_i + \theta_i p_j > 0$ and $D_i > 0$.

Our demand model is a linear stochastic model with substitution: (i) the expected demand of a product decreases with its price; however how the improvement of environmental quality impacts demand depends on consumers' emphasis on environmental quality and traditional quality; (ii) the price of one product increases the mean demand of the other product; however, whether the environmental quality of one product increases or decreases the mean demand of the other product still depends consumers' preference. Our demand model is inspired by [5,15]. We assume that there is no repeat purchase, i.e., customers will leave the market forever after they have bought a unit of the product, regardless of the product type.

2.3. Government policy

We use $t \geq 0$ and $s \geq 0$ to denote the tax rate and the subsidy rate, respectively. The government aims at maximizing the weighted aggregate social welfare

$$W = \alpha_1 \pi + \alpha_2 U + \alpha_3 \mathrm{D(E)} + \alpha_4 (tQ_t - sQ_e) \quad (1)$$

Similar to [19], the government's objective (1) can be decomposed into industry welfare, consumer welfare, environmental welfare caused by environmental improvement, and the government income. The third item is sometime included in the second item, for example [4], however, we separate it in order to observe the effect of the environment change obviously. The value of the weight reflects the government emphasis on one party. For example, $\alpha_1 = 2/5, \alpha_2 = \alpha_3 = \alpha_4 = 1/5,$ then we refer to a government as industry-friendly. The borderline case $\alpha_n = 1/4, n = 1, 2, 3, 4$ constitutes the benchmark. In this case, we label the government as neutral.

2.4. Timing

Decisions take place in four stages.

Stage I, the government chooses the object of subsidy and tax policy: consumer or manufacturer.

Stage II, the government decides the tax rate *t* or subsidy rate *s*.

Stage III, the monopolist manufacturer decides to produce traditional product or environmental product, and determine the product environmental quality and price.

Stage IV, consumer decides to purchase the traditional product or green product.

3. Subsidy and tax to consumer

In this subsection, government subsidize to consumer who purchase environmental product and tax to consumer who purchase ordinary product. Manufacturer could choose to produce one product-environmental product or traditional product, two products-environmental product and traditional product.

We assume that price of traditional product is fixed because of full market competition, then manufacturer focuses on determine price and quality of environmental product given government policy.

In this section, consumer who purchases green product will obtain subsidy *s*, the subsidy may be price subsidy or other discount policy (e.g. the Electric Vehicle could obtain free license in Shanghai, China), hence subsiding to consumer increases total demand. Consumers who purchases ordinary product will be taxed *t*; when the manufacturer produces two products, there is product substitution; therefore, the demand functions with subsidy and tax are as follows:

$$D_g = a_g - b_g (p_g - s) + \theta_g (p_o + t) + k_{gt} q_t^g + k_{ge} q_e^g - l_{gt} q_t^o - l_{ge} q_e^o$$

$$D_o = a_o - b_o (p_o + t) + \theta_o (p_g - s) + k_{\mathrm{ot}} q_t^o + k_{oe} q_e^o - l_{ot} q_t^g - l_{oe} q_e^g$$

Manufacturer may produce traditional product, green product or both of them. We will present three scenarios, then give manufacturer's optimal strategy with government policy.

3.1. One product-ordinary product

In this scenario, manufacturer only produces ordinary product, then demand function of ordinary product is

$$D_o = a_o - b_o(p_o + t) + k_{ot}q_t^o + k_{oe}q_e^o ,$$

Then we can give manufacturer's profit as follows,

$$\pi_1^o = [a_o - b_o(p_o + t) + k_{ot}q_t^o + k_{oe}q_e^o](p_o - c_t q_t^{o2} - c_e q_e^{o2}) - F$$

s.t. $q_t^o + rq_e^o = 1$.

The manufacturer's profit decreases with tax.

3.2. One product-green product

In this scenario, manufacturer only produces green product, then demand function of green product with government subsidy is

$$D_g = a_g - b_g(p_g - s) + k_{gt}q_t^g + k_{ge}q_e^g ,$$

manufacturer's profit function is as follows

$$\pi_1^g(q_e^g, p_g) = [a_g - b_g(p_g - s) + k_{gt}q_t^g + k_{ge}q_e^g](p_g - c_t q_t^{g2} - c_e q_e^{g2}) - F$$

s.t. $q_t^g + rq_e^g = 1$.

Proposition 1. If $k_{gt}r - k_{ge} - 2rb_g c_t > 0$ and

$$2c_e k_{gt} - a_g(c_e + c_t r^2) + b_g c_t c_e - rc_t k_{ge} + (k_{ge} - k_{gt}r)^2 / 2b_g - 3c_e k_{ge} / r ,$$
$$+3b_g c_e{}^2 / r^2 - b_g c_t r^2 s - b_g c_e s < 0$$

then manufacturer's profit function $\pi_1^g(q_e^g, p_g)$ is joint concave with q_e^g, p_g.

Theorem 1. When government chooses to subsidize environmental consumer and tax to traditional consumer, then green product's optimal price is

$$p_g^* = \frac{a_g + b_g s + k_{ge}q_{ge} + k_{gt}q_t^g + b_g(c_t q_t^{g2} + c_e q_e^{g2})}{2b_g}$$

, the optimal environmental quality q_{e1}^{g*} is determined by $d\pi_1^g(q_e^g, p_g^*) \big/ dq_e^g = 0$.

3.3. Two products-ordinary product and green product

In this scenario, manufacturer produces both green product and ordinary product, with government subsidy and tax to consumers, the manufacturer's profit function with two products is given as follow,

$$\begin{aligned}\pi_2(q_e^g, p_g) &= [a_g - b_g(p_g - s) + \theta_g(p_o + t) + k_{gt}q_t^g + k_{ge}q_e^g - l_{gt}q_t^o - l_{ge}q_e^o](p_g - c_t q_t^{g2} - c_e q_e^{g2}) \\ &+ [a_o - b_o(p_o + t) + \theta_o(p_g - s) + k_{ot}q_t^o + k_{oe}q_e^o - l_{ot}q_t^g - l_{oe}q_e^g](p_o - c_t q_t^{o2} - c_e q_e^{o2}) - 2F\end{aligned}$$

s.t. $q_t^g + rq_e^g = 1$.

Proposition 2. If $k_{gt}r - k_{ge} - 2rb_g c_t \succ 0$ and

$$2c_e k_{gt} - a_g(c_e + c_t r^2) - \theta_o c_e{}^2 q_e^{o2} + b_g c_t(c_e - r^2 s) - b_g c_e s - rc_t k_{ge} + c_e l_{ge} q_e^o$$
$$+ c_e l_{gt} q_t^o + (c_e p_o + c_t p_o r^2)(\theta_o - \theta_g) + (k_{ge} - k_{gt} r)^2 / 2b_g - 3c_e k_{ge} / r + 3b_g c_e{}^2 / r^2$$
$$- c_t q_t^{o2}(r^2\theta_o + c_e\theta_o) + c_t r^2(l_{ge} q_e^o + l_{gt} q_t^o) - c_e c_t \theta_o q_e^{o2} r^2 - t\theta_g(c_t r^2 + c_e) < 0$$

, then manufacturer's profit function $\pi_2(q_e^g, p_g)$ is joint concave with q_e^g, p_g.

Theorem 2. When government chooses to subsidize environmental consumer and tax to traditional consumer, then green product's optimal price is

$$p_g^* = \frac{a_g + \theta_g(p_o + t) + b_g s + k_{ge}q_{ge} + k_{gt}q_t^g - l_{ge}q_e^o - l_{gt}q_t^o + \theta_o(p_o - c_t q_t^{o2} - c_e q_e^{o2}) + b_g(c_t q_t^{g2} + c_e q_e^{g2})}{2b_g}$$

the optimal environmental quality q_{e2}^{g*} is determined by $\dfrac{d\pi_2(q_e^g, p_g^*)}{dq_e^g} = 0$.

Remark 1. The price difference between no government policy and with subsidy and tax is

$$\Delta p = \frac{s}{2} + \frac{t\theta_g}{2b_g},$$

if q_e^{g*} keeps a constant.

Both subsidizing to environmental consumer and taxing to traditional consumer increase price of green product, and the demand of green product increases ($\Delta D_g = \frac{sb_g}{2} + \frac{t\theta_g}{2}$), the demand of ordinary product decreases ($\Delta D_o = -b_o t + \frac{\theta_g \theta_o t}{2b_g} - \frac{s\theta_o}{2}$).

The manufacturer will choose the optimal product strategy by comparing profits of above three scenarios. Substituting firm's product strategy including product variety, product quality and price, then the social welfare is as follows:

$$\begin{aligned}W(s,t) &= \alpha_1\pi + \alpha_2[(p_o^{\max} - p_o)D_o / 2 + (p_g^{\max} - p_g^*)D_g / 2] \quad , \\ &+ \alpha_3\sigma(D_g q_e^g + D_o q_e^t) + \alpha_4(tD_o - sD_g)\end{aligned}$$

government as the Stackelberg leader will determine the optimal subsidy and tax to maximize social welfare. We give the solution algorithm to seek the optimal subsidy and tax because of the complexity of analytic solutions.

Algorithm 1.
Step 1:

For s=0:0.2:smax
for t=0:0.2:tmax
solve

$\frac{d\pi_1(q_e^g, p_g^*)}{dq_e^g}=0, \frac{d\pi_2(q_e^g, p_g^*)}{dq_e^g}=0,$ obtain

q_{e1}^{g*}, p_{g1} and q_{e2}^{g*}, p_{g2};

compute $\pi_1^o, \pi_1^g(q_{e1}^{g*}, p_{g1}^*)$, $\pi_2(q_{e2}^{g*}, p_{g2}^*)$, and social welfare W_1^o, W_1^g, W_2;

end
end

Step 2:

Return the maximum of W_1^o, W_1^g, W_2, corresponding $(s_1^o, t_1^o), (q_{e1}^{g*}, p_{g1}, s_1^g, t_1^g), (q_{e2}^{g*}, p_{g2}, s_2, t_2)$; and manufacturer's profit $\pi_1^o(s_1^o, t_1^o)$, $\pi_1^g(q_{e1}^{g*}, p_{g1}, s_1^g, t_1^g)$, $\pi_2(q_{e2}^{g*}, p_{g2}, s_2, t_2)$;

Step 3:

Compare and get the maximum profit $\pi(q_e^{g*}, p_g^*, s^*, t^*)$=max{ $\pi_1^o(s_1^o, t_1^o)$, $\pi_1^g(q_{e1}^{g*}, p_{g1}, s_1^g, t_1^g)$, $\pi_2(q_{e2}^{g*}, p_{g2}, s_2, t_2)$ }, then the optimal environmental quality, price, subsidy and tax is q_e^{g*}, p_g, s^*, t^*, and the welfare is $W(s^*, t^*, \pi(q_e^{g*}, p_g^*, s^*, t^*))$.

4. Subsidy and tax to manufacturer

In this section, government subsidize to manufacturer who sells one unit environmental product and tax to manufacturer who sells one unit traditional product. Similar to Section 3, manufacturer could choose to produce one product-environmental product or traditional product, two products-environmental product and traditional product.

The demand function will not alter directly because the government tax and subsidize directly to manufacturer, however, manufacturer will change products' price with government policy, hence, government policy changes demand function indirectly. Considering manufacturer's three choices, we will discuss each scenario in following subsections.

4.1. One product—ordinary product

In this subsection, manufacturer only produces ordinary product, the marginal profit of one unit ordinary product with government tax is,

$$p_o - c_t q_t^{o2} - c_e q_e^{o2} - t,$$

hence manufacturer's profit is as follows,

$$\pi_1^{'o} = (a_o - b_o p_o + k_{ot} q_t^o + k_{oe} q_e^o)(p_o - c_t q_t^{o2} - c_e q_e^{o2} - t) - F$$

s.t. $q_t^o + r q_e^o = 1$.

Because of the full competition, we assume that price and quality of ordinary product are given, then manufacturer's profit decreases with tax.

4.2. One product—green product

In this scenario, manufacturer only produces green product, then the profit of one unit green product with government subsidy is,

$$p_g - c_t q_t^{g2} - c_e q_e^{g2} + s,$$

The manufacturer's profit function is as follows,

$$\pi_1^{'g}(q_e^g, q_t^g, p_g) = (a_g - b_g p_g + k_{gt} q_t^g + k_{ge} q_e^g)(p_g - c_t q_t^{g2} - c_e q_e^{g2} + s) - F$$

s.t. $q_t^o + r q_e^o = 1$.

Proposition 3. If $k_{gt} r - k_{ge} - 2 r b_g c_t > 0$ and $2c_e k_{gt} - a_g(c_e + c_t r^2) + b_g c_t c_e - r c_t k_{ge} + (k_{ge} - k_{gt} r)^2 / 2b_g - 3c_e k_{ge} / r + 3b_g c_e^2 / r^2 - b_g c_t r^2 s - b_g c_e s < 0$, then manufacturer's profit function $\pi_1^{'g}(q_e^g, p_g)$ is joint concave with q_e^g, p_g.

Theorem 3. When government chooses to subsidize environmental consumer and tax to traditional consumer, then green product's optimal price is

$$p_{g1}^{'*} = \frac{a_g + k_{ge} q_e^g + k_{gt} q_t^g + b_g(c_t q_t^{g2} + c_e q_e^{g2} - s)}{2b_g},$$

the optimal environmental quality q_{e1}^{g*} is determined by $\frac{d\pi_1^{'g}(q_e^g, p_g^*)}{dq_e^g} = 0$.

4.3. Two products-ordinary product and green product

In this scenario, manufacturer produces both green product and ordinary product, with government subsidy to green product and tax to ordinary product, we can present manufacturer's profit function with two products is given as follow,

$$\pi_2^{'}(q_e^g, q_t^g, p_e) = [a_g - b_g p_g + \theta_g p_o + k_{gt} q_t^g + k_{ge} q_e^g - l_{gt} q_t^o - l_{ge} q_e^o](p_g - c_t q_t^{g2} - c_e q_e^{g2} + s)$$
$$+ [a_o - b_o p_o + \theta_o p_g + k_{ot} q_t^g + k_{oe} q_e^g - l_{ot} q_t^o - l_{oe} q_e^o](p_o - c_t q_t^{o2} - c_e q_e^{o2} - t) - 2F$$

s.t. $q_t + r q_e = 1$.

Proposition 4. If $k_{gt} r - k_{ge} - 2 r b_g c_t > 0$ and

$$2c_e k_{gt} - a_g(c_e + c_t r^2) - \theta_o c_e^{\,2} q_e^{o2} + b_g c_t c_e - r c_t k_{ge} + c_e l_{ge} q_e^o$$
$$+ c_e l_{gt} q_t^o + (c_e p_o + c_t p_o r^2)(\theta_o - \theta_g) + (k_{ge} - k_{gt} r)^2 / 2b_g - 3c_e k_{ge} / r + 3b_g c_e^{\,2} / r^2$$
$$- c_t q_t^{o2}(r^2 \theta_o + c_e \theta_o) + c_t r^2 (l_{ge} q_e^o + l_{gt} q_t^o) - c_e c_t \theta_o q_e^{o2} r^2 - b_g c_t r^2 s - b_g c_e s - t c_e \theta_o - c_t r^2 \theta_o t < 0$$

, then manufacturer's profit function $\pi_2^{'}(q_e^g, p_g)$ is joint concave with q_e^g, p_g.

Theorem 4. When government chooses to subsidize environmental consumer and tax to traditional consumer, then green product's optimal price is

$$p_{g2}^{'*} = \frac{a_g + \theta_g p_o + k_{ge} q_{ge} + k_{gt} q_t^g - l_{ge} q_e^o - l_{gt} q_t^o + \theta_o (p_o - c_t q_t^{o2} - c_e q_e^{o2} - \mathrm{t}) + b_g (c_t q_t^{g2} + c_e q_e^{g2} - s)}{2b_g}$$

, the environmental quality $q_{e2}^{'g*}$ is determined by

$$\frac{d\pi_2^{'}(q_e^g, p_g^*)}{dq_e^g} = 0 .$$

Remark 2. The price difference between no government policy and with subsidy and tax is

$$\Delta p = -\frac{s}{2} - \frac{\theta_o t}{2b_g},$$

if $q_{e2}^{'g*}$ keeps constant.

Subsidizing to manufacturer who produces green product reduces price of green product, and taxing to manufacturer who produces ordinary product also enforces manufacturer decreases price of green product. Therefore, both subsidy and tax have positive effect on increasing sales of green product.

Similar to Section 3, the manufacturer will choose the optimal product strategy by comparing profits of above three scenarios. Then the government gives the optimal subsidy and tax according to the welfare function. We omit the solution algorithm to seek the optimal subsidy and tax similar to Algorithm 1.

Because the complexity of the analytical solutions, we will give some numerical examples to illustrate the results obtained in Section 3 and 4.

5. Numerical Examples

In this section, we will verify the results obtained in Section 3 and 4, compare the two policies more intuitive.

5.1. Optimal government policy

In this subsection, we will present the optimal subsidy and tax policies, product quality and price of green product (if manufacturer determines to produce green product), and present the change of the optimal solutions with a_g.

The parameters are set as follows: $a_o = 60, b_g = b_o = 2, r = 2, p_o = 20, c_e = 20, c_t = 5, F = 50,$ $q_e^o = 0, q_t^o = 1, \theta_g = \theta_o = 0.2, k_{ge} = 1, k_{gt} = 1, k_{ot} = 2, k_{oe} = 0, l_{gt} = l_{ot} = 0.2,$ $l_{ge} = l_{oe} = 0.1, s_{\max} = 10, t_{\max} = 10,\ \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \frac{1}{4},\ \sigma = 100$.

From Table 1, we can see that when the number of the potential green consumer is much smaller, subsidizing and taxing to consumer is the optimal government policy; as the number of the potential green consumer increases, government should change from subsidizing to consumer to subsidize and tax to manufacturer.

In both scenarios, the price, firm's profit and social welfare increases with a_g, however, the environmental quality keeps a constant with a_g.

When the government determines to subsidize green consumers, the optimal subsidy should decreases with a_g, and there should no tax to ordinary consumer when the number of green consumer excesses a threshold point.

When the government implements policies to manufacturer, the optimal subsidy and tax achieve its upper limits with a_g. When a_g is much smaller, the manufacturer will only produce ordinary product. The firm begins to produce when a_g is large enough, and the optimal policies is to subsidy and tax to manufacturer.

Therefore, when the number of the green consumer is small, it is much better to subsidizing and tax to consumer; when the number of the green consumer is very large, subsidy and tax to manufacturer is the best choice.

Table 1. Optimal policies with a_g

	I Subsidize and tax to consumer					Optimal policy
a_g	q_e^g	p	Profit/ product variety*	(s,t)	welfare	
10	0.24	9.1	135	(8.4,5.6)	172	I
20	0.24	12.1	397	(8,0)	148	I
30	0.24	14	485	(7,0)	190	II
40	0.24	16	590	(6,0)	240	II
50	0.24	18	709	(5,0)	299	II
60	0.24	20	845	(4,0)	365	II

	II Subsidize and tax to manufacturer					Optimal policy
a_g	q_e^g	p	Profit/ product variety	(s,t)	welfare	
10	-	-	280/o	0	100	I
20	-	-	280/o	0	100	I
30	0.24	5.24	367	(10,10)	298	II
40	0.24	7.74	371	(10,10)	507	II
50	0.24	10.14	624	(10,10)	456	II
60	0.24	12.64	812	(10,10)	548	II

Note*: 'o' represents manufacturer only produce ordinary, 'g' represents green product, if there is no 'o' and 'g', it represents manufacturers produces two products.

5.2. Social welfare change with subsidy and tax

In this subsection, we present the change of social welfare with subsidy and tax to consumer. When the social planner applies these policies to manufacturer, the changes of welfare are similar to above results, so we omit them. The parameters are set as follows:

$$a_o = 30, a_g = 20, b_g = b_o = 1, r = 2, p_o = 15, c_e = 20,$$

$$c_t = 10, F = 20, q_e^o = 0, q_t^o = 1, \theta_g = \theta_o = 0.2,$$

$$k_{ge} = k_{oe} = 1, k_{gt} = k_{ot} = 2, l_{gt} = l_{ot} = 0.2,$$

$$l_{ge} = l_{oe} = 0.1, \quad \alpha_1 = \alpha_2 = \alpha_3 = \frac{1}{5}, \quad \alpha_4 = \frac{2}{5}, \quad \sigma = 100.$$

Figure1 shows that the social welfare is joint concave with s and t. It compares the social welfare change with different three policies: a). with subsidy and tax; b). with only subsidy; c). with only tax. It shows that the social welfare will not obtain maximum when social planner only uses subsidy, similarly, the social welfare will not obtain maximum when social planner only employs tax.

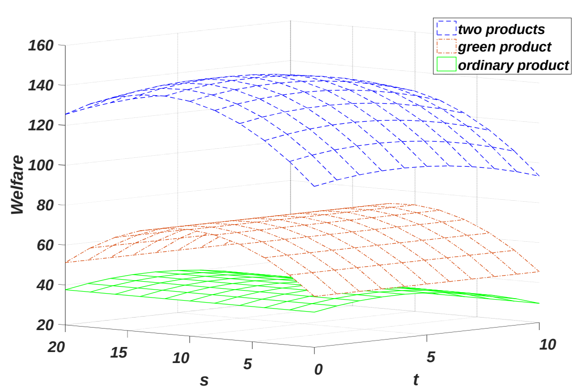

Figure 1. Welfare as a function of *t* and s

5.3. Comparison between policy to consumers and manufacturer

In this subsection, we compare the price, profit, social welfare and environment quality between subsidy/tax to consumer and manufacturer. Let

$$a_o = 30, a_g = 20, b_g = b_o = 1, r = 2, p_o = 15, c_e = 20, c_t = 10, F = 20,$$

$$q_e^o = 0, q_t^o = 1, \theta_g = \theta_o = 0.2, k_{ge} = k_{oe} = 1, k_{gt} = k_{ot} = 2, l_{gt} = l_{ot} = 0.2,$$

$$l_{ge} = l_{oe} = 0.1, \alpha_1 = \alpha_2 = \alpha_3 = \frac{1}{5}, \alpha_4 = \frac{2}{5}, \sigma = 100.$$

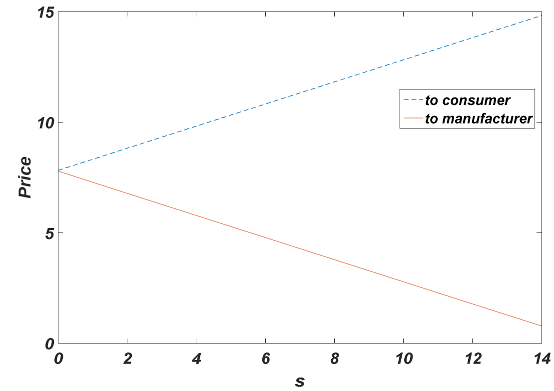

Figure 2. Price as a function of *s*

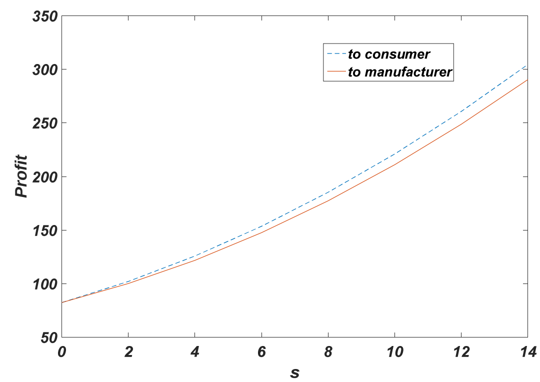

Figure 3. Profit as a function of *s*

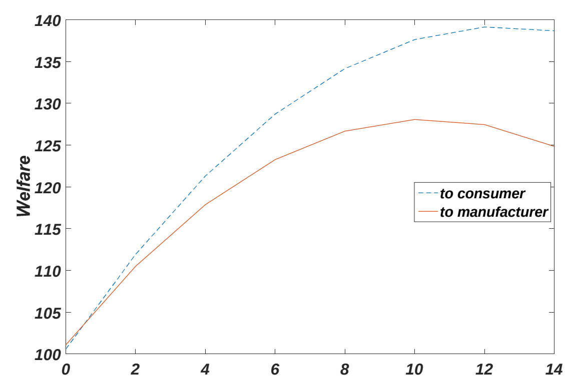

Figure 4. Welfare as a function of *s*

Let t = 0, Figures 2-4 compare the price of green product, profit, and social welfare between government subsidy to consumer and subsidy to manufacturer when manufacturer provides two products. We can see that the profit and welfare are bigger when government subsidizes to consumer.

Let s = 0, Figures 5-7 show the changes of price of green product, profit, welfare and environmental quality with t when manufacturer provides two products, each figure gives two policy: tax to consumer and tax to manufacturer. We can see that taxing to traditional consumer has no effect on price of green product, however, taxing to manufacturer decreases green product's price. Taxing policy decreases manufacturer's profit and increases social welfare. Therefore, when the government intends to implement tax to improve environment quality and social welfare, taxing to manufacturer may be more beneficial.

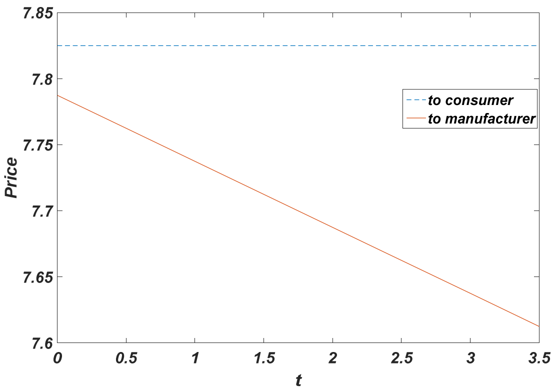

Figure 5. Price as a function of *t*

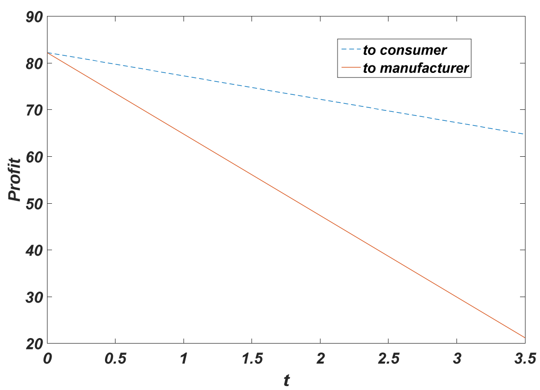

Figure 6. Profit as a function of *t*

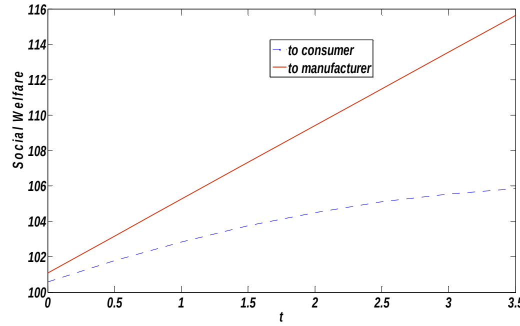

Figure 7. Welfare as a function of *t*

5.4. Optimal policy with division zone

In this subsection, we show how the optimal policy changes with the parameters. First, we apply numerical to the analytical results derived in Section 4, and then present the optimal policy with potential demand of green product and ordinary product, and then we explore the effect of *CEA* and consumer awareness on traditional quality on government policy. The parameters are set as follows:

$b_g = b_o = 2, r = 2, p_o = 20, c_e = 20, c_t = 5, F = 50, q_e^o = 0, q_t^o = 1,$

$\theta_g = \theta_o = 0.2, k_{ge} = 1, k_{oe} = 0, k_{gt} = 1, k_{ot} = 2, l_{gt} = l_{ot} = 0.2,$

$l_{ge} = l_{oe} = 0.1, \alpha_1 = \frac{2}{5}, \alpha_2 = \alpha_3 = \alpha_4 = \frac{1}{5}, \sigma = 100.$

When the number of the potential number of green consumer and ordinary consumer is small, subsidy but no tax is the best choice; when the number of potential green consumer and ordinary consumer excess some threshold points ($a_g^*, a_g^{'*}, a_o^*, a_o^{'*}$) and $a_g^* > a_o^*, a_g^{'*} > a_o^{'*}$, the optimal policies changes. There is an obvious difference between two figures, that is, when the number of the potential green consumer is very large, there still exists subsidy when the government determines to implement policy to manufacturer, while there is no subsidy.

Assume that the manufacturer produces two products with the considerable marginal profit, and this scenario is the most common for the vehicle manufacturers. In this example, we discuss the optimal government policy with CEA k_{ge} and the consumers' emphasis on traditional quality k_{gt} of green consumer. Parameters are set as follows:

$a_g = 20, a_o = 60, q_e^g = 0.3, b_g = b_o = 1, r = 2, p_o = 15, c_e = 20,$

$c_t = 10, F = 50, q_e^o = 0, q_t^o = 1, \theta_g = \theta_o = 0.2, k_{ot} = 2, k_{oe} = 1,$

$l_{gt} = l_{ot} = 0.2, l_{ge} = l_{oe} = 0.1, \alpha_1 = \frac{2}{5}, \alpha_2 = \alpha_3 = \alpha_4 = \frac{1}{5}, \sigma = 100.$

Let $k_{ge}, k_{gt} \in [0,5]$, we can give the optimal zone division according to k_{ge} and k_{gt} .

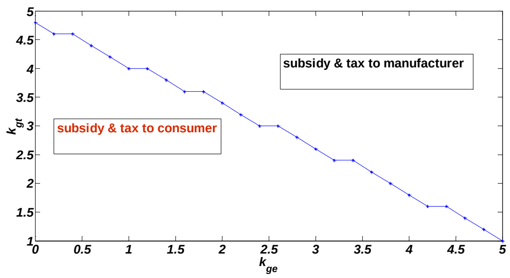

Figure 8. Optimal policies with k_{ge} and k_{gt}

6. Conclusion

In this paper, we present two optimal government policies with different environmental quality and *CEA*, and compare the subsidy and tax policies to consumer and manufacturer, then give the optimal choice for government. There are main four meaningful management insights: firstly, subsidizing and taxing to consumer is more beneficial when the number of potential green consumers is small and environmental technology is high. As the number of the potential green consumer increases, government should change from subsidizing to consumer to subsidize and tax to manufacturer; secondly, whenever government implements policy to consumer or manufacturer, the social welfare is concave with government subsidy and tax, firm's profit decreases with tax and increases with subsidy; thirdly, subsidizing to consumer, the social welfare and firm's profit increases much larger compared with subsidy to manufacturer; however, the tax has almost opposite results with subsidy, taxing to manufacturer may obtain higher social welfare than taxing to consumer; fourthly, subsidy and tax to manufacturer may be more beneficial when either CEA or consumer awareness on traditional quality is very high.

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