

How Does Low-Carbon Subsidy for Consumer Affect Social Welfare

Cheng Wang*

Business School, Hubei University, Wuhan 430000, China

*Corresponding author: Cheng Wang, 2314759513@qq.com

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Abstract: With consideration of consumer environmental awareness (CEA) and upstream competition, this paper discusses the joint pricing strategy of enterprises based on low-carbon subsidy and the impact of low-carbon subsidy on social welfare. Results indicate that the market demand for ordinary products is always lower than that for low-carbon products under low-carbon subsidy policy; thus policy-planners can use low-carbon subsidy to expand the market share of low-carbon products, and effectively improve the market competitiveness of low-carbon products. Low-carbon subsidy policy is beneficial to improving social welfare, especially when the competition between manufacturers is less intensive or consumers are more environmentally aware, in which case a suitable low-carbon subsidy policy can significantly improve social welfare.

Keywords: Low-carbon subsidy; Upstream competition; Consumer environmental awareness; Social welfare

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1. Introduction

In recent years, greenhouse gas emissions based on carbon dioxide have been regarded as the driving factor of global warming, which has attracted worldwide attention. Many countries have issued a series of strategic measures for the promotion of a low-carbon economy, including the implementation of various regulations on carbon emissions. Among the various regulations, low-carbon subsidy is an important policy tool used by governments to curb carbon emissions and stimulate the promotion of products with environmental benefits. Some countries have also introduced low-carbon subsidies to stimulate the production and consumption of low-carbon products. For example, a United States government bill in 2009 proposed that consumers who buy electric cars can enjoy preferential tax policies ^[1]. Moreover, in 2012 and 2013, the U.S. government provided nearly 10% federal tax relief for home appliances including biofuel furnace and water heaters. In 2012, the State Council of China announced that it would provide a total of 26.5 billion RMB for a one-year subsidy for energy-saving household appliances. In addition, to better distinguish between energy-saving and environmentally friendly products and

ordinary products, the carbon Reduction Label Scheme, launched by the Carbon Trust in the UK in 2006, has been a pioneer in creating certification for low-carbon products, with dozens of carbon footprints calculated on a pilot basis. Moreover, the China Development and Reform Commission has also clarified the low-carbon product certification system through the issuance of the Interim Measures for the Administration of Low-Carbon Product Certification, and provided a reference range for low-carbon product subsidies. On June 27, 2014, representatives from companies such as Feng Aluminum Group and Zhonglian Group took the lead in obtaining China's first batch of low-carbon product certifications.

When companies face carbon policies such as carbon taxes and low-carbon subsidies, they are trying to change their operating strategies, including adjusting pricing and production decisions, and setting emission reduction targets. For instance, Dell set a target of 40% reduction in emissions by 2015, based on the level of carbon emissions in 2007^[2]. Wal-Mart was trying to achieving the goal of reducing carbon emissions by 20 million tons by 2015^[3].

Considering that government's low-carbon subsidy policy will have a significant influence on firms' optimal operational decisions, the question of how to formulate an appropriate low-carbon subsidy rate from the perspective of policy planners is particularly important. At present, a few scholars have explored the formulation of the optimal low-carbon subsidy rate from an empirical perspective^[4-7]. However, the existing studies on the optimal low-carbon subsidy based on theory and model are relatively few^[8-10]. Park *et al.* discussed the design of optimal low-carbon subsidy for retailers in 2015. Zhou and Huang explored the optimal subsidy mechanism based on two environmental goals under the budget constraints of minimum total energy consumption and minimum average energy consumption in 2016. These few theoretical documents related to the formulation of low-carbon subsidy are the significant basis of this study. However, the research in this paper differs from existing literature in the research background. Most of the existing literature on formulation of optimal carbon policy was carried out in a bilateral monopolistic supply chain or a last-mile supply chain, whereas the background of this paper is a two-level supply chain composed of two competing manufacturers and a common retailer. This can further enrich the existing research in theory.

Thus, in this paper, with consideration of CEA and product competition, the supply chain system consisting of duopoly manufacturers, one retailer, and government was taken as the research object, and the joint pricing strategy under low-carbon subsidies was discussed. Moreover, the design of government's optimal low-carbon subsidy policy based on the goals of maximizing social welfare is presented.

2. The model under government's subsidy for low-carbon product consumers

To encourage the production and demand of low-carbon and energy-saving products, policy-makers in many countries have successively proposed subsidy policies for low-carbon manufacturers or low-carbon consumers^[10]. Considering that high prices of low-carbon products directly hinder their promotion, low-carbon subsidies proposed by policy makers in many countries are more directly targeted at low-carbon consumers rather than producers. For example, since 2007, Canada has provided the consumers who purchase a new energy vehicle with a subsidy of 1,000–2,000 Canadian dollars^[10]. In 2009, the United States proposed the American Recovery and Reinvestment Act (ARRA), which provides a tax relief program for consumers that purchase electric cars. The bill states that consumers that buy electric cars can get a one-time bonus of up to 7,500 USD^[11]. In May 2012, the Chinese government proposed a subsidy policy for consumers buying energy-efficient home appliances. The subsidy policy stipulates that the government will give a subsidy of 70-260 RMB to consumers who purchase drum washing machines that consume

less than 0.23 kWh of electricity^[10]. Thus, the low-carbon subsidy policy considered in this paper is assumed to be levied on low-carbon consumers instead of low-carbon producers.

Based on the above description, when the government implements low-carbon subsidy policy for low-carbon products (product 2) consumers, the actual price paid by consumers when purchasing low-carbon products (product 2) is $(p_2^s - s(e_1 - e_2))$. Then, the demand functions for ordinary products (product 1) and low-carbon products (product 2) can be expressed as:

$$q_1^s = a - p_1^s + \eta[p_2^s - s(e_1 - e_2)] - \beta(e_1 - \eta e_2) \quad (1)$$

$$q_2^s = a - [p_2^s - s(e_1 - e_2)] + \eta p_1^s - \beta(e_2 - \eta e_1) \quad (2)$$

Under low-carbon subsidy, the profit function of manufacturer i ($i = 1, 2$) $\pi_{m_i}^s$ is $\pi_{m_i}^s = (w_i^s - c)q_i^s$, the retailer's profit function π_r^s is $\pi_r^s = \sum_{i=1}^2 (p_i^s - w_i^s)q_i^s$, and the profit of the supply chain system is $\pi_{sc}^s = \pi_r^s + \sum_{i=1}^2 \pi_{m_i}^s$.

Besides, the carbon emissions E_1^s and E_2^s of manufacturer 1 (ordinary manufacturer) and manufacturer 2 (low-carbon manufacturer) can be expressed as $E_1^s = e_1 q_1^s$ and $E_2^s = e_2 q_2^s$ respectively; the total carbon emissions of supply chain system is $E_t^s = e_1 q_1^s + e_2 q_2^s$.

The social welfare function under low carbon subsidy policy is

$$SW^s = \Pi^s + U^s + G^s - V^s \quad (3)$$

The first term can be expressed as $\Pi^s = \pi_{sc}^s$. The second item is $U^s = \int_0^{q_1^s} [a - q + \eta(p_2^s - s(e_1 - e_2)) - \beta(e_1 - \eta e_2) - p_1^s] dq + \int_0^{q_2^s} [a - (q - s(e_1 - e_2)) + \eta p_1^s - \beta(e_2 - \eta e_1) - p_2^s] dq$. The third item can be expressed as the government's subsidy expenditure on low carbon products consumers, ie $G^s = -s(e_1 - e_2)q_2^s$. The fourth term is $V^s = \sigma(E_1^s + E_2^s)$.

Therefore, the social welfare function under low-carbon subsidy policy can be reduced to

$$SW^s = \pi_{sc}^s - s(e_1 - e_2)q_2^s - \sigma(E_1^s + E_2^s) + \sum_{i=1}^2 \int_0^{q_i^s} [a - q + \eta p_{3-i}^s - \beta(e_i - \eta e_{3-i}) - p_i^s] dq + \alpha(E_1^s + E_2^s) - \sigma(E_1^s + E_2^s) \quad (4)$$

3. Equilibrium strategy under low-carbon subsidy policy

The solution is obtained by using the reverse induction method. This section focuses on the joint pricing and production strategies of the two competing manufacturers and the monopoly retailer under a given low-carbon subsidy. Besides, we will further explore the optimal low-carbon subsidy with the aim of maximizing social welfare in the case of competitive manufacturers.

3.1. Firms' optimal strategies under low-carbon subsidy

In this subsection, Theorem 1 first describes the firms' optimal strategies under a given low-carbon subsidy policy.

3.1.1. Theorem 1

When the given low-carbon subsidy rate (S) satisfies $s \leq \hat{s}$ in the case of competitive manufacturers, where $\hat{s} = \frac{(2+\eta)[a+(\eta-1)c]+\beta[(\eta^2-2)e_1+\eta e_2]}{\eta(e_1-e_2)}$, the optimal decisions of enterprises are as follows:

$$w_1^S = \frac{(a+c)(2+\eta)+\beta A_1-\eta s(e_1-e_2)}{(2+\eta)(2-\eta)}, w_2^S = \frac{(a+c)(2+\eta)+\beta A_2+(2-\eta^2)s(e_1-e_2)}{(2+\eta)(2-\eta)}$$

$$p_1^S = \frac{(3-2\eta)a+(1-\eta)c}{2(1-\eta)(2-\eta)} + \frac{\beta N_1-\eta s(e_1-e_2)}{2(2+\eta)(2-\eta)}, p_2^S = \frac{(3-2\eta)a+(1-\eta)c}{2(1-\eta)(2-\eta)} + \frac{\beta N_2-(2\eta^2-6)s(e_1-e_2)}{2(2+\eta)(2-\eta)}$$

$$q_1^S = \frac{(2+\eta)[a+(\eta-1)c]+\beta A_1-\eta s(e_1-e_2)}{2(4-\eta^2)}, q_2^S = \frac{(2+\eta)[a+(\eta-1)c]+\beta A_2+(2-\eta^2)s(e_1-e_2)}{2(4-\eta^2)}$$

In Theorem 1, the condition $s \leq \hat{s}$ guarantees that there is at least one manufacturer in the market in equilibrium under low-carbon subsidies. Let Δw_i^S , Δp_i^S , and Δq_i^S ($i = 1, 2$) be the difference in wholesale price, retail price, and demand for product i ($i = 1, 2$) in the case with low-carbon subsidy policy and the scenario without carbon policy respectively. From the equilibrium results in Theorem 1, Lemma 1 can be obtained.

3.1.2. Lemma 1

$$\Delta w_1^S < 0, \Delta w_2^S > 0; (2) \Delta p_1^S < 0, \Delta p_2^S > 0; (3) \Delta q_1^S < 0, \Delta q_2^S > 0.$$

Lemma 1 shows that the wholesale and retail prices of ordinary products are lower than the wholesale and retail prices under anarchic carbon policy when policy planners implement the subsidy policy to the consumers of low-carbon products. In contrast, the wholesale and retail prices of low-carbon products in the scenario with low-carbon subsidy policy are higher than those of low-carbon products in the absence of a carbon policy. The low-carbon subsidy for low-carbon consumers is beneficial for the improvement of the price of low-carbon products.

Importantly, the demand for low-carbon products under low-carbon subsidy is larger than that in the absence of a carbon policy, whereas the market demand of ordinary products is lower than that in the absence of a carbon policy. This shows that compared with the scenario without carbon policy, low-carbon subsidy policy has a positive impact on increasing the market demand for low-carbon products.

3.2. The optimal low-carbon subsidy maximizing social welfare

Under low-carbon subsidy policy, the social welfare can be expressed as follows:

$$SW^S = \{p_1^S - c + q_1^S - \sigma e_1\}q_1^S + \{p_2^S - c + q_2^S - \sigma e_2\}q_2^S - q_1^{S^2}/2 - q_2^{S^2}/2 - s(e_1 - e_2)q_2^S \quad (5)$$

Further, when policy planners want to maximize social welfare through low-carbon subsidies, the policy planners' optimization problem can be expressed as

$$\max_s \left\{ (p_1^S - c + q_1^S - \sigma e_1)q_1^S + (p_2^S - c + q_2^S - \sigma e_2)q_2^S - \frac{q_1^{S^2}}{2} - \frac{q_2^{S^2}}{2} - s(e_1 - e_2)q_2^S \right\} s. t. s \leq \frac{(2+\eta)[a+(\eta-1)c]+\beta[(\eta^2-2)e_1+\eta e_2]}{\eta(e_1-e_2)} \quad (6)$$

Wherein, the restriction condition guarantees that there is at least one manufacturer in the market under low-carbon subsidy; otherwise, it will be beyond the scope of this paper. To solve the above optimization problem, we can obtain the following Theorem 2.

3.2.1. Theorem 2

In the supply chain where manufacturers compete, there is an optimal low-carbon subsidy rate maximizing social welfare and the optimal subsidy rate is

$$S_{max}^* = \frac{3(2+\eta)^2(1-\eta)[a+(\eta-1)c]+3\beta[(2-\eta^2)A_2-\eta A_1]+2\sigma(4-\eta^2)A_2}{(1-\eta^2)(\eta^2+4)(e_1-e_2)} \quad (7)$$

The conclusion in Theorem 1 is visually reflected through **Figure 1**, which shows the variation trend of S_{max}^* as a function of β and η with the following example ($a = 450, c = 15, e_1 = 95, e_2 = 20, \delta = 3$). **Figure 1** shows that when β is small, the optimal subsidy rate that maximizes social welfare shows a significant increase trend with the increase of η .

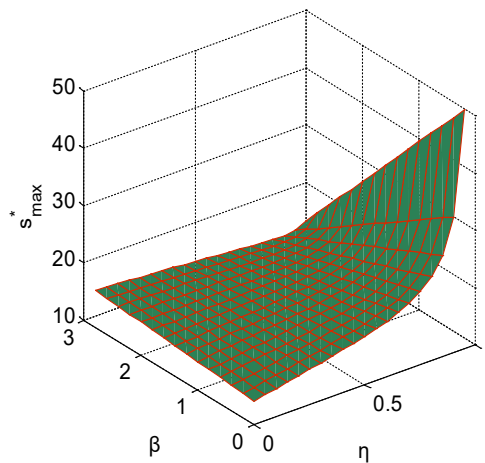


Figure 1. Impact of β and η on S_{max}^* .

This shows that when the CEA is weak (β is small), an increase in the subsidy rate for low-carbon consumers will help improve social welfare as the competition intensity among manufacturers (η) increases. This is likely to be because when β is small, increasing the subsidy rate for low-carbon consumers will give consumers and enterprises the incentive to purchase, produce or sell low-carbon products under the fierce competition, which will effectively expand the demand and production of low-carbon products in the competitive environment. When β is small, the positive impact of the increase in low-carbon subsidies on the social welfare related to low-carbon products is always greater than its negative impact on the social welfare related to ordinary products. As a result, the increase in the subsidy rate will increase the total social welfare. Thus, when β is relatively small, the optimal subsidy rate that maximizes social welfare increases substantially with the increase of η .

4. Conclusion

In this paper, with consideration of CEA and product competition, the supply chain system consisting of duopoly manufacturers, one retailer, and the government was taken as the research object, and the joint pricing strategy under low-carbon subsidies was discussed. After that, the design of the government's optimal low-carbon subsidy policy based on the goal of maximizing social welfare was presented. The results showed that the wholesale and retail prices of low-carbon products in the scenario with low-carbon subsidy policy are higher than those of low-carbon products in the absence of a carbon policy. Although low-carbon subsidies differ in the price for

common products and low-carbon products, low-carbon subsidies is always conducive to improving the market competitiveness of low-carbon products and expanding the market share of low-carbon products. The optimal carbon tax rate based on social welfare maximization is jointly influenced by CEA and upstream competition. When upstream competition is low, the optimal carbon tax rate increases with the rise in CEA; when upstream competition is high, the optimal carbon tax rate decreases with the rise in CEA. Under upstream competition, the low-carbon subsidy policy is more effective than carbon tax in improving social welfare. In particular, when the upstream competition is high or consumers are more environmentally conscious, optimal low-carbon subsidy policy can significantly improve social welfare.

Disclosure statement

The author declares no conflict of interest.

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