The impact of peer-induced fairness concerns on competitive manufacturers' optimal decisions under C&T regulation

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Abstract. As major economies around the world have proposed their carbon neutrality targets in recent years, governments and companies have gradually increased their focus on decarbonization. Cap-and-trade (C&T) regulation is widely regarded as an effective mechanism for reducing carbon emissions. This paper considers a supply chain consisting of two competitive manufacturers and one fairness-neutral retailer, where one manufacturer is fairness-neutral and has invested in Carbon Emission Reduction (CER) technology, the other manufacturer is concerned with peer-induced fairness, and then explores the pricing and carbon emission reduction decisions of a two-tier supply chain under C&T regulation. Two models are constructed under different fairness attitudes, and the equilibrium results are derived to analyze the joint role of peer-induced fairness concerns and the policy. Results indicate that the manufacturer's peer-induced fairness concerns increase her profit and those of the retailer, reduce the optimal emission reduction and profit of her rival, and also increase the total carbon emissions of the supply chain, which is detrimental to the environment. In addition, the carbon emission reduction level can be affected by the cost coefficient of CER and carbon quotas.

Keywords: Cap-and-trade regulation; Carbon emission reduction; Peer-induced fairness concerns; Competitive manufacturers

1 Introduction

In recent years, there has been a growing global attention on low-carbon development. To achieve carbon neutrality by 2050, many countries have adopted carbon emission policies. C&T regulation is currently the main tool to combat climate change and reduce greenhouse gas emissions.

In response to carbon emissions policies, more and more manufacturers are investing in CER technology, which has a positive impact on their competitiveness and attracts more consumers to their products. Manufacturers investing in CER technology can enhance their competitiveness and sustainability in new industries and markets. Besides,

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as the international community's focus on CER raises public awareness of environmental protection, consumers' willingness to purchase green products will gradually increase, which will also push manufacturers to take advantage of environmental protection and promote low-carbon products, thus increasing their market competitiveness.

However, some manufacturers find the cost of investing in CER technology unaffordable and therefore do not actively pursue carbon emission reduction, resulting in poor environmental performance and loss of competitiveness for their products. This gives a greater advantage to other companies that take action and improve the environmental performance of their products. There is a fairness issue between competitive manufacturers, which is known as peer-induced fairness. Fairness concerns play an important role in the face of unfair treatment by competitors[1].

In this paper, we consider a supply chain consisting of two competitive manufacturers and a common retailer, where one manufacturer has invested in CER technology to make its products competitive, and thus it holds a higher market share and generates more revenue, which leads to peer-induced fairness concerns for the other manufacturer who has not made carbon emission reduction. The aim of this paper is to analyze the joint role of peer-induced fairness concerns and C&T on pricing and emission reduction, thus providing some managerial insights for enterprises and policymakers.

2 Literature review

This paper reviews the relevant literature from two aspects: (1) competition between manufacturers under C&T regulation, (2) peer-induced fairness concerns.

In respect to competition between manufacturers, several scholars have studied the impact of competitive behavior on social welfare. For example, Liu et al. [2]showed that intense competition for emission reduction under C&T regulation can benefit consumers from lower prices. Other scholars have focused more on the environmental impacts of competitive behavior. For example, Giri et al.[3] studied the environmental impacts of the competitive behavior of two manufacturers producing green products with different environmental friendliness.

As for peer-induced fairness concerns, most studies have focused on analyzing its effects on pricing strategies and profits in supply chains. For example, Du et al. [4]studied the impacts of two forms of peer-induced fairness, namely empathy and gloating, on distribution channel equilibrium prices and channel performance. And Liu et al.[5], Li et al.[6], and Shu et al. [7]incorporate distributional fairness and peer-induced fairness issues into the logistics service supply chain, reverse supply chain, and closed-loop supply chain settings, respectively.

The aforementioned literature on fairness issues focuses on examining its impact on supply chain operations and coordination, but less research has been conducted on this topic in the low-carbon context, and even less on peer-induced fairness issues. To broaden the research in this area, this paper analyzes the combined effects of C&T regulation and member's fairness attitudes on the pricing and emission reduction decisions.

3 Model establishment and assumptions

This paper considers a two-stage supply chain in which the retailer (it) sells two homogenous alternative products made by two competitive manufacturers (denoted as manufacturer 1 and manufacturer 2). Among them, the low-carbon product manufacturer 1 (he) invests in technological innovation to reduce carbon emissions, and the emission reduction per unit of his product is e_c, while the general product manufacturer 2 (she) does not do so. Manufacturer 2 exhibits peer-induced fairness concerns because she is faced with a relatively strong low-carbon product manufacturer 1. The notations of models are shown in Table 1.

Table 1. Notations.

Symbol	Description
α	The base market potential
θ	Intensity of price competition between two substitutable products
d_i	Product i's market demand, $i = 1,2$
e_i	Manufacturer i's initial unit amount of carbon emissions
p_c	Unit carbon trading price
λ_2	Manufacturer 2's degree of fairness concerns
γ	Consumer environmental awareness (CEA)
h	Manufacturer 1's cost coefficient of CER
E_i	Manufacturer i's free carbon quotas, allocated by the government
p_i	Product i's retail price, $i = 1,2$
w_i	Product i's wholesale price, $i = 1,2$
e_c	CER per unit of low-carbon product
$\pi_{m_i}^j$	The profit of the manufacturer i, $i = 1,2$, $j = CN, CF$
π_r^j	The profit of the retailer, $j = CN, CF$
$U_{m_2}^j$	The utility of the manufacturer 2, $j = CF$

3.1 Assumptions

Assumption 1. Product demand is linear with the selling price set by the retailer, the emission abatement level of the manufacturer, and consumer environmental awareness. (Bai et al.[8]; Zhang et al[9]; Liu, Anderson, & Cruz[10])

The two products' demand function is denoted as follows:

$$d_1 = \alpha - p_1 + \theta p_2 + \gamma e_C \tag{1}$$

$$d_2 = \alpha - p_2 + \theta p_1 \tag{2}$$

The coefficient θ and γ are restricted in the interval $(0,1)$ to ensure the retail price of the product itself has a larger effect on the demand than competitive product prices and the emission reduction.

Assumption 2. Low-carbon product manufacturer need to pay the corresponding cost $C(e_c)$ to improve the carbon emission reduction e_c of products through technological innovation and other means[11]. This paper assumes that CER investment is a quadratic function, that is $C(e_c) = he_c{}^2/2$. Here $h\ (h > 0)$ is the carbon emission reduction cost coefficient.

3.2 Benchmark model: Fairness neutral (model CN)

Under C&T regulation, the total carbon quota of the two manufacturers is distributed by the government. Under this premise, manufacturer 1 firstly makes decisions on the CER level and set product 1's wholesale price. Then, manufacturer 2 decides on product 2's wholesale price. Finally, the retailer decides the optimal retail prices.

The manufacturers' profit function can be expressed as follows:

$$\pi_{m_1}^C(w_1, e_C) = w_1 d_1 - (e_1 - e_C - E_1)d_1 p_C - h\, e_C{}^2/2 \tag{3}$$

$$\pi_{m_2}^C(w_2) = w_2 d_2 - (e_2 - E_2)d_2 p_C \tag{4}$$

Here, in order to simplify the model, the production costs of two products are normalized to be zero. In particular, $(e_1 - e_C - E_1)d_1 p_C < 0$ or $(e_2 - E_2)d_2 p_C < 0$ represents the revenue that manufacturers get from selling carbon quota in the carbon market, $(e_1 - e_C - E_1)d_1 p_C > 0$ or $(e_2 - E_2)d_2 p_C > 0$ represents the cost that manufacturers pay for carbon quota in the carbon trading market.

The retailer's profit is:

$$\pi_r^C(p_1, p_2) = (p_1 - w_1)d_1 + (p_2 - w_2)d_2 \tag{5}$$

In the model CN, we first consider the benchmark case in which neither the two competitive manufacturers nor the retailer is concerned with fairness.

We solve this model using backward induction and assume $h > \frac{((\theta^2-2)p_C-2\gamma)^2}{8(2-\theta^2)}$ holds to ensure the optimal decisions exist. The optimal decisions of the manufacturers and the retailer are summarized in column 2 of Table 2**.** Based on these, we derive the effect of C&T regulation on decisions and provide it in Proposition 1.

Table 2. Equilibrium solutions under C&T regulation.

	$j = CN$	$j = CF$
${w_1}^j$	$\frac{A_1 + A_2}{(2\gamma + (2-\theta^2)p_C)^2 - 8h(2-\theta^2)}$	$\frac{4p_C(e_1 - E_1)h\theta^2(1-\lambda_2) - (1+\lambda_2)(B_1 + p_C^2 B_2 - 2p_C B_3)}{(1+\lambda_2)(2\gamma - (\theta^2-2)p_C)^2 + 8h((\theta^2-2) - 2\lambda_2)}$
${w_2}^j$	$\frac{\alpha + p_C(e_2 - E_2) + \theta(A_1 + A_2)}{2((2\gamma + (2-\theta^2)p_C)^2 - 8h(2-\theta^2))}$	$\frac{(1+\lambda_2)B_6 + 2h\theta B_7}{(1+\lambda_2)(2\gamma - (\theta^2-2)p_C)^2 + 8h((\theta^2-2) - 2\lambda_2)}$
${e_C}^j$	$\frac{(2\gamma - (\theta^2-2)p_C)A_4}{8h(2-\theta^2) - (2\gamma + (2-\theta^2)p_C)^2}$	$\frac{((\theta^2-2)p_C - 2\gamma)A_4(1+\lambda_2)}{(1+\lambda_2)(2\gamma - (\theta^2-2)p_C)^2 + 8h((\theta^2-2) - 2\lambda_2)}$
${p_1}^j$	$\frac{(1+\theta)(\alpha + (1-\theta){w_1}^{CN}) + \gamma {e_C}^{CN}}{2(1-\theta^2)}$	$\frac{\alpha(1+\theta) + \gamma {e_C}^{CF} + {w_1}^{CF}(1-\theta^2)}{2(1-\theta^2)}$

${p_2}^j$	$\frac{(1+\theta)(\alpha+(1-\theta){w_2}^{\mathrm{CN}})+\gamma\theta {e_C}^{\mathrm{CN}}}{2(1-\theta^2)}$	$\frac{\alpha(1+\theta)+\gamma\theta {e_C}^{\mathrm{CF}}+{w_2}^{\mathrm{CF}}(1-\theta^2)}{2(1-\theta^2)}$
${d_1}^j$	$\frac{h(-2+\theta^2)A_4}{(2\gamma+(2-\theta^2)p_C)^2-8h(2-\theta^2)}$	$\frac{hA_4(-2+\theta^2-2\lambda_2)}{(1+\lambda_2)(2\gamma-(\theta^2-2)p_C)^2+8h((\theta^2-2)-2\lambda_2)}$
${d_2}^j$	$\frac{\alpha A_5+\theta A_3+p_C(e_2-E_2)A_6}{2((2\gamma+(2-\theta^2)p_C)^2-8h(2-\theta^2))}$	$\frac{(1+\lambda_2)B_{10}+2\alpha B_{11}+2h\theta p_C B_{12}}{2(1+\lambda_2)(2\gamma-(\theta^2-2)p_C)^2+16h((\theta^2-2)-2\lambda_2)}$

Note:

$A_1=2\alpha(2+\theta)(p_C\gamma-2h)+p_C^2\alpha(4+2\theta-2\theta^2-\theta^3)$, $A_2=\theta p_C(e_2-E_2)(2\gamma p_C-(\theta^2-2)p_C^2-4h)+2A_3$

$A_3=p_C(e_1-E_1)\big(2\gamma^2+(\theta^2-2)(2h-\gamma p_C)\big)$, $A_4=\alpha(2+\theta)+(2-\theta^2)p_C(E_1-e_1)+(e_2-E_2)\theta p_C$,

$A_5=2\gamma^2+(4+2\theta-\theta^2)(\gamma p_C-2h)+p_C^2(2+2\theta-\theta^2-\theta^3)$, $A_6=(4-3\theta^2)(2h-\gamma p_C)-(2-3\theta^2+\theta^4)p_C^2-2\gamma^2$,

$B_1=4h\alpha(2+\theta)+\theta(-2+\theta^2)p_C^3(e_2-E_2)$, $B_2=\alpha(-4-2\theta+2\theta^2+\theta^3)+2\gamma(-2+\theta^2)(e_1-E_1)+2\gamma\theta(E_2-e_2)$,

$B_3=\alpha\gamma(2+\theta)+2(\gamma^2-2h)(e_1-E_1)+2h\theta(E_2-e_2)$, $B_4=\alpha(2+2\theta-\theta^2-\theta^3)-\gamma\theta(\theta^2-2)(e_1-E_1)-\gamma(\theta^2-4)(e_2-E_2)$

$B_5=2\alpha(-4h+\gamma^2)+p_C(\alpha\gamma(2(\theta+2)-\theta^2))-2p_C\theta(E_1-e_1)\gamma^2$, $B_6=(2-\theta^2)p_C^3(e_2-E_2)+p_C^2B_4+B_5-2p_C(e_2-E_2)(4h-\gamma^2)$

$B_7=\alpha(\theta-2)+p_C(E_1-e_1)(2-\theta^2+4\lambda_2)+p_C\theta(e_2-E_2)$,

$B_8=\alpha(2+2\theta-\theta^2-\theta^3)-\gamma\theta(\theta^2-2)(e_1-E_1)-\gamma(4-3\theta^2)(e_2-E_2)$

$B_9=\big(2(\gamma^2-4h)(E_2-e_2)\big)-2\gamma^2\theta(E_1-e_1)+\alpha\gamma(4+2\theta-\theta^2)$, $B_{10}=(2-3\theta^2+\theta^4)p_C^3(E_2-e_2)+p_C^2B_8+p_CB_9$

$B_{11}=(\gamma^2-4h)(1+\lambda_2)-h\theta((2-\theta)+2\lambda_2(2+\theta))$, $B_{12}=(E_1-e_1)(2\theta^2\lambda_2+2-\theta^2)+\theta(3+2\lambda_2)(E_2-e_2)$.

Proposition 1. *In CN model, the following properties hold:*

(1) $\frac{\partial {e_C}^{CN}}{\partial E_1}>0$, $\frac{\partial {e_C}^{CN}}{\partial E_2}<0$, $\frac{\partial {e_C}^{CN}}{\partial h}<0$ *and* $\frac{\partial {\pi_{m_1}}^{CN}}{\partial h}<0$;

(2) $\frac{\partial {\pi_{m_1}}^{CN}}{\partial E_1}>0$, $\frac{\partial {\pi_{m_1}}^{CN}}{\partial E_2}<0$, $\frac{\partial {\pi_{m_2}}^{CN}}{\partial E_1}<0$ *and* $\frac{\partial {\pi_{m_2}}^{CN}}{\partial E_2}>0$.

Proposition 1 suggest that manufacturer 1's profit and the optimal emission reduction level increase with the increase of his carbon quotas, while declining with the increase of the cost coefficient of CER and his rival's carbon quotas. Manufacturer 2 will also experience the same situation.

3.3 The model with peer-induced fairness (model CF)

In the model CF, manufacturer 2 is concerned with peer-induced fairness. This means that she seeks to maximize her utility when making decisions, the utility function for manufacturer 2 is as follows:

$$U_{m_2}^{CF}(w_2) = \pi_{m_2}^{C} - \lambda_2(\pi_{m_1}^{C} - \pi_{m_2}^{C}) \tag{6}$$

To assure the optimal solutions exist, we assume $h > \frac{(2\gamma+2p_C-\theta^2 p_C)^2(1+\lambda_2)}{8(2-\theta^2+2\lambda_2)}$ holds, and the optimal solutions under this scenario are shown in column 3 of Table 2. Similarly, we derive the impact of manufacturer 2's fairness concerns on solutions in CF model and provide it in Proposition 2.

Proposition 2. *In CF model, the following properties hold:*

(1) $\frac{\partial {e_C}^{CF}}{\partial \lambda_2} < 0$, $\frac{\partial {\pi_{m_1}}^{CF}}{\partial \lambda_2} < 0$, $\frac{\partial {\pi_{m_2}}^{CF}}{\partial \lambda_2} > 0$, $\frac{\partial {\pi_r}^{CF}}{\partial \lambda_2} > 0$

Proposition 2 reveals that manufacturer 2 and the retailer will experience a rise up in profit when the degree of fairness concerns increases. However, manufacturer 1 will experience a fall in profit, decreasing the available funding for emission reduction.

3.4 Comparative analysis

Then we discuss the impact of manufacturer 2's fairness attitude under C&T regulation by comparing the optimal decisions and profits under the two models and summarize the results in Proposition 3.

Proposition 3.

(1) If $p_C > \frac{2\gamma}{(2-\theta^2)}$ and $h < \frac{1}{4}p_C(2\gamma - (\theta^2 - 2)p_C)$, then ${w_1}^{CN} < {w_1}^{CF}$, otherwise ${w_1}^{CN} \geqslant {w_1}^{CF}$;

(2) If $p_C > \frac{2\gamma}{(2-\theta^2)}$ and $h < \frac{1}{16}(4\gamma^2 + 8\gamma p_C - (\theta^4 - 4)p_C^2)$, then ${w_2}^{CN} < {w_2}^{CF}$, otherwise ${w_2}^{CN} \geqslant {w_2}^{CF}$;

(3) ${e_C}^{CN} \geqslant {e_C}^{CF}$, ${\pi_{m_1}}^{CN} > {\pi_{m_1}}^{CF}$.

According to this proposition, in most circumstances, the emergence of manufacturer 2's peer-induced fairness concerns will not only result in a lower wholesale price for her rival but also for herself. In addition, the presence of λ_2 would lead to a decrease in manufacturer 1's overall profit and discourage his emission reduction.

4 Conclusions

The main conclusion of this paper is that the emergence of peer-induced fairness concerns under C&T regulation leads to a rise up in the profits of manufacturer 2 and the retailer, but a decrease in manufacturer 1's profit, which is why manufacturer 2 strives for fairness. Also, peer-induced fairness concerns discourage manufacturer 1 from investing in emission reduction, making total carbon emissions higher and detrimental to the environment. In addition, carbon emission reduction can be affected by the cost coefficient of CER and carbon quotas. Specifically, manufacturer 1 will decrease emission reduction to pay for the cost of purchasing carbon quotas as the cost coefficient of CER increases. And when manufacturer 1's carbon cap increases, he will increase emission reduction to improve the competitiveness of his product, but if his rival's carbon cap increases, the wholesale prices of the two products will fall and manufacturer 1 will reduce emission reduction to maintain his profit level.

The managerial implications of this paper can be summarized as follows: First, low-carbon manufacturers should adjust their emission reduction investments when noting the existence of peer competitors who are concerned about fairness. Second, for manufacturers that do not reduce emissions, the government should strengthen its regulation. Third, retailers could encourage manufacturers to reduce emissions by sharing the cost of abatement technologies. Finally, when setting the parameters of C&T regulation, it would be advisable for the government to adjust them according to the amount of emission reduction and total emissions of different enterprises.

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