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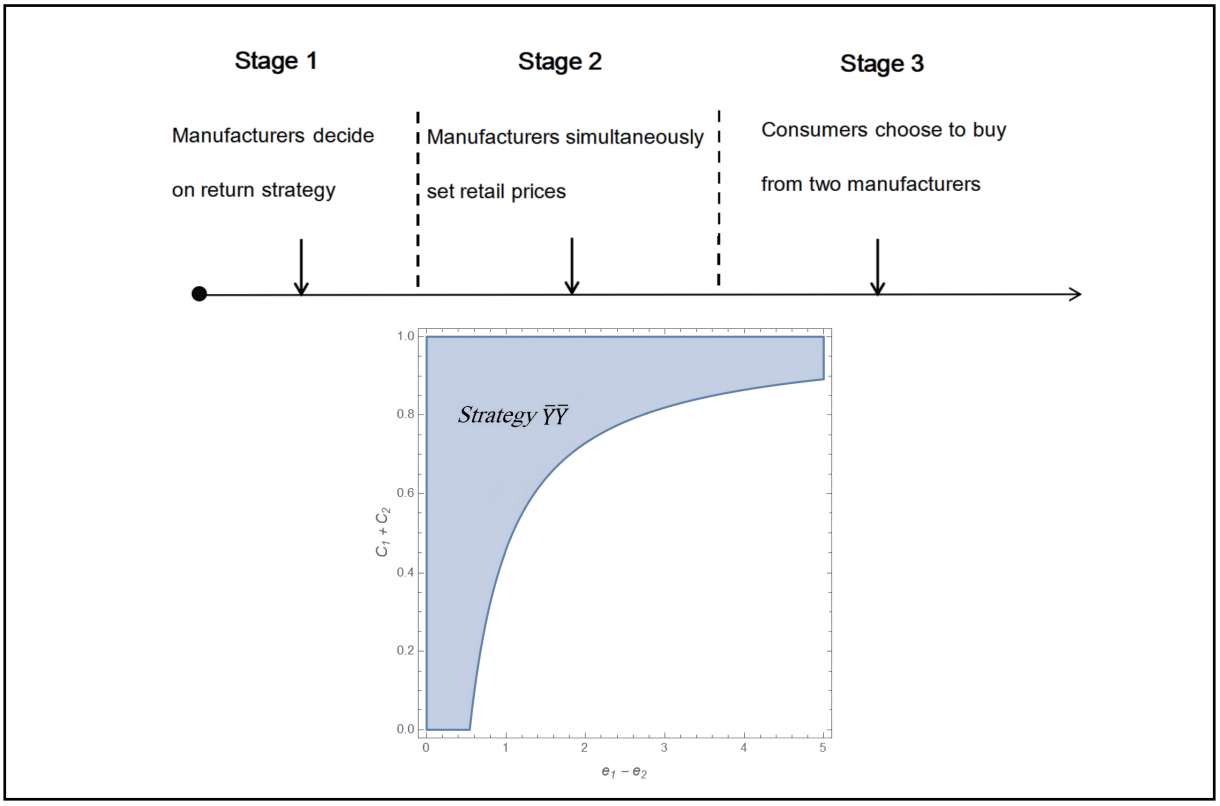
Return strategy for competing manufacturers under cap-and-trade regulation

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Graphical abstract



Model timeline and equilibrium of the manufacturer's return strategy.

Public summary

- This paper investigates the return strategies of two manufacturers with different levels of energy consumption in a competitive scenario under cap-and-trade regulation.
- In the first stage, considering cap-and-trade regulation, both firms make simultaneous return decisions; in the second stage, both firms make simultaneous pricing decisions; and in the third stage, based on the pricing of both firms, the consumer makes a purchase decision.
- When the return cost and the difference in carbon consumption between two manufacturers are low, it is optimal for both manufacturers not to provide return services due to restrictions from cap-and-trade regulation and competitive pressures.

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Abstract: In recent years, the booming development of the e-commerce platform economy has brought new momentum to economic growth. As a crucial commercial tool for businesses operating on online platforms, the return strategy has been widely of concern in industry and academia. On the one hand, return strategies can stimulate consumer demand and increase sales. On the other hand, the production process typically generates significant carbon dioxide emissions. Currently, governments are paying increasing attention to carbon emissions issues, and cap-and-trade regulation is one of the most widely adopted carbon emission policies by governments. This paper utilizes game theory models to investigate the issue of returns for competing enterprises with energy consumption differences under the backdrop of cap-and-trade regulation. The study results indicate the following: First, controlling the cap can effectively control carbon emissions. Second, when the return cost and the difference in carbon consumption between the two manufacturers are low, it is optimal for both parties not to provide return service due to restrictions from cap-and-trade regulation and competitive pressures. Additionally, low-energy-consumption manufacturers have an advantage in competition. Furthermore, this paper explores the changes in parameters such as the profits and production quantities of competing enterprises with variations in the cap. Consequently, it offers favorable suggestions for the government's concerns during the implementation of carbon emission policies and provides practical guidance for manufacturers' return decisions.

Keywords: return strategy; competition; cap-and-trade regulation; game theory; carbon emission; operations management

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1 Introduction

With the continuous maturation of digital technology, the Internet of Things, and other technologies, the platform economy has rapidly emerged as a new engine of global economic growth. The emergence of platforms, such as Taobao.com, JD.com, and Amazon, has changed how people shop, greatly facilitated life convenience, and become deeply integrated into daily life. During the Tmall Double 11 and JD Double 11 events in 2023, for example, the user traffic exceeded 800 million, and the viewership surpassed 380 million, demonstrating the vigorous growth of online retail. According to data released by the National Bureau of Statistics of China, the total retail sales of consumer goods reached 4.71 trillion CNY in 2023, with online retail sales reaching 1.54 trillion CNY, representing a year-on-year increase of 11.0%. Research findings from comScore on the state of digital commerce reveal that online retail sales in the United States reached a record high of 1.3 trillion USD in 2023. Online sales channels offer numerous advantages compared to traditional offline channels. Consumers can purchase goods through platforms anytime or anywhere without being limited by location or time. Platforms offer a diverse range of products, providing consumers with more choices. Additionally, platforms utilize algorithms to provide personalized recommendations to consumers. Moreover, online channels have a competitive advantage in pricing.

Despite the numerous advantages of online sales channels, which are favored by consumers and manufacturers, they also have certain limitations. Customers cannot physically observe the details of products or experience them firsthand during purchases, and the product information presented on online platforms is not always entirely accurate[1], and may even involve false advertising. Additionally, online sales lack the immediacy of face-to-face service, making it difficult for consumers to obtain sufficient product information in a timely manner. As a result, consumers may demand refunds or returns based solely on the information provided on the platform[2]. According to a report jointly released by the National Retail Federation (NRF) and Appriss Retail, the total amount of retail returns in the U.S. was 743 billion USD in 2023, with an online return rate of 17.6%. According to an Optoro survey, 5 billion pounds (2.3 billion kilograms) of returned products in the United States become waste each year.

The return strategy is one of the critical operational strategies in the platform economy. According to a report commissioned by PayPal and released by Happy Returns in August 2023, 81% of American online shoppers consult the return policy when purchasing from a merchant for the first

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time, and 55% of consumers choose to abandon a purchase because the merchant does not offer convenient return options. Flexible return policies can enhance consumer purchasing intentions, thereby increasing demand[3]. Taleizadeh et al.[4] suggested that providing refund guarantees can increase consumer demand when the return rate can be accurately calculated.

Returns are increasingly viewed from an environmental perspective. On the one hand, lenient return policies indeed stimulate higher consumer demand; on the other hand, higher production means higher carbon emissions, which can harm the environment. According to data from the Carbon Monitor Network, global industrial carbon emissions in 2023 were 10.38 Gt CO_2. To achieve green and sustainable economic growth, many governments have implemented various carbon reduction policies. Enterprises, in turn, should take into account the impact of environmental policies on their operational decisions.

Against the backdrop of global carbon emission reduction policies, Taobao launched the "88 Carbon Account" in 2022, covering more than 1 billion consumers and collecting carbon reduction data from consumers on platforms such as Xianyu, Ele.me, Cainiao Logistics, and Tmall; displaying carbon footprints and carbon reduction achievements to consumers; encouraging consumers to purchase low-carbon products, energy-saving appliances, recycled packaging, and idle products; and designing incentive mechanisms such as carbon credits to guide consumers toward low-carbon consumption. Additionally, Taobao introduced the "Energy-saving Treasure" carbon reduction tool for enterprises. Furthermore, to address the cost pressure, carbon emissions, and defective product losses caused by returns, Amazon launched the "Frequently Returned Items" label in 2023, indicating products with high return rates. If a product's return rate ranks in the top 25% of its category, its product detail page will display a "high return rate" label to guide consumers in making more informed purchasing decisions.

Globally, controlling total carbon emissions and establishing trading systems are widely adopted policies. Governments allocate free carbon emission quotas (caps) to manufacturers, and emissions exceeding the cap require the purchase of additional carbon emission quotas in the carbon trading market. If the manufacturer's emissions are lower than the cap allocated by the government, the surplus carbon emission quotas can be sold on the carbon trading market. Environmental policies implemented by the government will inevitably affect enterprise operational decisions. Enterprises or platforms need to consider when to provide return service under cap-and-trade regulation. Existing studies on return policies mainly focus on specific aspects, such as return shipping insurance, return leniency, and channel structure, while there is a lack of research considering the impact of macro-carbon emission policies on enterprises' return decisions. Considering that various competitive factors, such as price competition and substitute competition, exist in the market, we focus on the return strategy of manufacturers under cap-and-trade regulation in competitive scenarios. This paper aims to answer the following questions. First, how should competing companies formulate their return strategies under cap-and-trade regulation? Second, how do cap-and-trade regulations affect company profits in a competitive environment?

To address the above issues, we consider competition between two manufacturers with energy consumption differences under cap-and-trade regulation, assuming that consumers are uniformly distributed according to the ideal product taste and purchases from one of the two competing manufacturers are made to maximize utility. We explore the return strategy choices of two competing manufacturers and analyze the impact of government carbon caps on manufacturer profits. We find that:

First, increasing the cap for low-energy-consumption (LEC) manufacturers will also encourage production by high-energy-consumption (HEC) manufacturers.

Second, based on a comparison of manufacturer profits between not offering return service and offering return service, when the return cost and the carbon consumption difference between two manufacturers are low, due to the constraints of cap-and-trade regulation and competitive pressure from competitors, the advantages of offering return service to stimulate demand are not obvious. In contrast, manufacturers offering return service have a smaller market share than those not offering return service, and the profits are higher when return service are not provided. Ultimately, both parties not offering return service become the optimal equilibrium.

Finally, when neither party offers return service, the profits of HEC manufacturers are affected by the degree of product differentiation and the carbon trading price coefficient when the government adjusts the cap for HEC manufacturers; the profits of LEC manufacturers are affected by their energy consumption difference with competitors and the degree of product differentiation when the government adjusts the cap for LEC manufacturers.

The remainder of this paper is organized as follows: Section 2 reviews and summarizes the relevant literature. Section 3 defines the research questions and constructs the model. Section 4 presents the main results. Section 5 concludes the paper and suggests future research directions.

2 Literature review

This study is related to the management of customer returns. McWilliams[5] examined the impact of offering MBG (money back guarantee) on retailers and concluded that offering MBG impairs the profitability of retailers selling high-quality products while the profitability of retailers selling low-quality products increases. Li et al.[6] considered the dual-channel structure and constructed a model incorporating the direct channel and the indirect channels. It is argued that when the return rate is low, manufacturers should offer full refund return service in both channels, and it is more advantageous for retailers to offer full refund returns only in the indirect channel. Nageswaran et al.[7], on the other hand, took an omnichannel perspective and construct an omnichannel model that allows for cross-channel returns and internalization of customers' purchasing and return decisions, and the study finds that omnichannel firms, as well as retailers with brick-and-mortar customers should offer full refunds. Yang et al.[8] argued that offering a BORS (buy online and return in

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store) policy allows retailers to reduce inventory. Some scholars have also studied return strategies in terms of the leniency of returns. Ma et al.[9] explored the effect of return period length and found that in a heterogeneous model of consumer willingness to pay for product quality, decentralized channels may have longer return periods compared to centralized channels, and the return periods for high-quality products should be shorter than those for low-quality products. Chen et al.[10] constructed a duopoly model to study the return insurance (RI) decisions of online sellers of different qualities (purchasing RI to offer it to consumers or allowing consumers to purchase it), and argued that it is optimal for online sellers to offer RI when the RI premium is low, the probability of product fit is low, and the compensation for return shipping is high. Kalantary et al.[11] considered a partial money-back guarantee, and argued that the value of the partial money-back guarantee has no impact on the profits of the market and retailers. Regarding the handling of returned products, Wan et al.[12] argued that even if a retailer cannot handle customer returns efficiently, it may choose to offer an MBG return policy and resell the returned product as an out-of-box product if the cost of inspecting the returned products is lower.

This study is also related to cap-and-trade regulation. Some scholars have conducted comparative studies between cap-and-trade regulation and other policies. Guo et al.[13] analyzed the impacts of cap-and-trade regulation with different carbon quota allocation modes and the carbon tax policy with different tax rates on the carbon emissions, profits, and bidding prices of electric power enterprises. Yu et al.[14], from the perspective of comparing carbon emission policies, argued that when the environmental damage coefficient is low, the government should implement cap-and-trade regulation, and when the coefficient is high, it should adopt a carbon tax model. A concern in considering firms' operational decisions under the government's cap-and-trade regulation is whether the price of carbon trading is fixed. Several studies assume a fixed carbon trading price. Chang et al.[15] assumed a fixed carbon trading price and, by studying monopoly manufacturers with two-stage production and remanufacturing, argued that in both the independent demand market (ID-market) and the substitutable demand market (SD-market), the carbon price is more effective than the carbon cap in controlling production and emissions. Jauhari et al.[16], under the assumption of a fixed price for carbon trading, found that total profits are greater in a centralized channel structure than in a decentralized channel structure. While He et al.[17], assuming that the carbon emission price is inversely proportional to the cap, explored the optimal production decisions of manufacturers and the optimal cap-setting decisions of regulators under the cap-and-trade regulation, and found that both the optimal total emissions and the optimal cap first decrease and then increase as carbon emission intensity decreases. Another concern is the impact of the cap-and-trade regulation on profits and supply chain coordination. Zhang et al.[18] constructed a model of a multi-project production plan under the cap-and-trade regulation and investigated the impacts of the cap and the carbon price on carbon emissions, the shadow price of common production capacity, and total profit. Du et al.[19] constructed an emission-dependent supply chain model and found that manufacturers' profits decrease as the cap decreases, and that the profits of suppliers increase as the cap decreases. Ji et al.[20] argued that the government's allocation of excessive carbon credits may reduce manufacturers' profits under either wholesale or agency model contracts. Regarding channel coordination, Qian et al.[21] considered channel-optimal coordination strategies in sustainable supply chains consisting of responsible manufacturers and fairness-focused retailers under the cap-and-trade regulation. They concluded that carbon emissions per product are the highest under wholesale contracts. Zhao et al.[22] considered the context of cap-and-trade regulation and argued that carbon emission reductions only benefit the manufacturer when the manufacturer encroaches, while all participants in the supply chain benefit when the manufacturer does not encroach.

This study is also relevant to channel competition. Wei et al.[23] constructed two competing supply chains, where both manufacturers and retailers engage in competition, analyzing the optimal strategies of supply chain members. Geng et al.[24] explored the significance of add-on pricing, suggesting that two competing companies may both adopt add-on pricing pricing and fall into a prisoner's dilemma. Bian et al.[25] found that upstream complicity is more likely to be sustained under Cournot competition than under Bertrand competition, while upstream complicity is least likely to be sustained under mixed Bertrand–Cournot competition. Regarding product returns, Chen et al.[26] studied a supply chain consisting of one manufacturer and two retailers and indicated that when a dominant retailer with MBG is present in the market, newly entering retailers can choose to offer MBG or non-MBG return policies. Jin et al.[27] explored whether a retailer adopts a BORP (buy-online, return-to-physical store) policy from a competitive perspective and found that it is optimal for neither retailer to offer BORP when competition is too intense.

Previous research on return strategies has mainly focused on specific perspectives, such as whether return service are provided in different channel structures, the degree of return leniency, and post-return processing. However, there is a lack of research that considers the impact of macro carbon emission policies. In this paper, we continue to adopt the assumption proposed by He et al.[17] that the cap is inversely proportional to the carbon price. In contrast to prior research, our study provides complementary insights in the following areas. First, we examine return strategies from the perspective of the cap-and-trade regulation. By considering the influence of macro-level carbon emission policies, we expand the research scope of return strategies and provide both practical guidance and theoretical support for enterprises' return decisions. Second, we present a novel perspective derived from the study of the cap-and-trade regulation, incorporating considerations of return management and competitive scenarios. We analyze the fluctuations in manufacturers' parameters within this context, thereby providing beneficial suggestions for the government's implementation of carbon emission policies.

3 Model

This study examines the return strategies of manufacturers in a competitive environment under the cap-and-trade regulation. Assuming the presence of two companies, A and B,

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positioned at the endpoints of the Hotelling line, where company A is located at position 0 and company B at position 1 (i.e., $L_A = 0$, $L_B = 1$), both companies sell similar products. V represents the maximum willingness to pay matched to consumer demand. Company i ($i = A, B$) sells product i at price p_i. Products come in various styles, such as colors and designs. Companies A and B can adopt a strategy of not providing return service ($\overline{Y}$) or a strategy of providing return service (Y), resulting in four potential product return strategies: $\{\overline{Y}\overline{Y}, \overline{Y}Y, Y\overline{Y}, YY\}$.

This paper investigates return strategies within a Hotelling line framework, where consumers are uniformly distributed along the line, with their positions indicating relative ideal preferences for products offered by competing firms. Consumers maximize their utility by selecting between the products of two companies, under the assumption that each consumer purchases at most one product. The overall market size is normalized to 1, and parameter t ($t > 0$) represents the unit cost of deviation between consumers' ideal preferences and the purchased product rather than transportation costs. A smaller t implies lower product differentiation and fiercer market competition. Consumers have a probability α of being dissatisfied with a product, and if they are dissatisfied and the company offers a return service, they will return the product to minimize losses. The utility of a consumer who purchases a product from company i is $V - t|x - L_i| - p_i$ if satisfied, $-t|x - L_i| - p_i$ if dissatisfied and company i does not offer a return service, and $-t|x - L_i|$ if dissatisfied and company i offers a return service.

Assuming that the carbon price is $d = a_0 - b_0(C_1 + C_2)$, a_0 represents the baseline price, b_0 denotes the price sensitivity of the cap, C_1 denotes the carbon emission allocation to manufacturer A by the government, and C_2 represents the carbon emission allocation to manufacturer B. Thus, the cap is inversely proportional to the carbon trading price. Manufacturer A emits e_1 units of carbon emissions per unit of production, while Manufacturer B emits e_2 units ($e_1 > e_2$).

The game unfolds in three stages: In the first stage, both companies simultaneously make decisions regarding return service, choosing from the set $\{\overline{Y}\overline{Y}, \overline{Y}Y, Y\overline{Y}, YY\}$; in the second stage, both companies simultaneously determine their prices; and in the third stage, based on the prices set by the companies, consumers make purchasing decisions. The primary parameters are described in Table 1. And the model timeline is shown in Fig. 1.

Table 1. Parameters and corresponding definitions.

Parameters	
α	Return rate
a_0	Maximum potential carbon price
b_0	Price sensitivity of the cap
C_1	The cap of manufacturer A
C_2	The cap of manufacturer B
e_1	Unit product carbon emission of manufacturer A
e_2	Unit product carbon emission of manufacturer B
V	Consumer's valuation of a product that matches their expectation
t	Unit cost of deviating from a retailer's location
x	Random variable representing preference of consumers
π	Profit of the members
Superscript	
$\overline{Y}, Y$	Not provide return service and provide return service, respectively
*	Denotes an optimal decision
Decision variables	
p_A	Retail price of manufacturer A
p_B	Retail price of manufacturer B

4 Results

4.1 Symmetric strategy analysis of two manufacturers

In this section, we analyze the return policies of two competing manufacturers (i.e., whether to offer return service). First, we derive the equilibrium prices and profits for the subgame $\{\overline{Y}\overline{Y}, \overline{Y}Y, Y\overline{Y}, YY\}$.

4.1.1 No return service provided by both manufacturers

When both manufacturers do not provide return service ($\overline{Y}\overline{Y}$), the utility functions for consumers of each manufacturer are as follows:

$$U_A^{\overline{Y}\overline{Y}} = (1-\alpha)V - tx^{\overline{Y}\overline{Y}} - p_A^{\overline{Y}\overline{Y}},$$
$$U_B^{\overline{Y}\overline{Y}} = (1-\alpha)V - t(1-x^{\overline{Y}\overline{Y}}) - p_B^{\overline{Y}\overline{Y}}. \quad (1)$$

When both manufacturers do not provide return service ($\overline{Y}\overline{Y}$), the profit functions for each manufacturer are as follows:

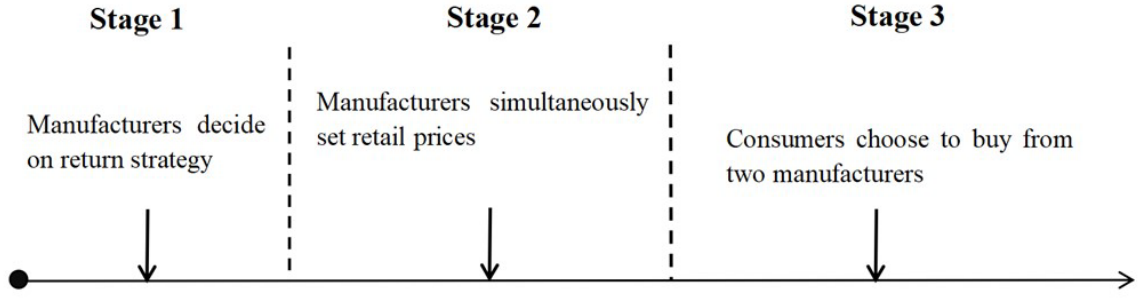


Fig. 1. Model timeline.

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$$\pi_A^{\overline{YY}} = p_A^{\overline{YY}} x^{\overline{YY}} - (a_0 - b_0(C_1 + C_2))(e_1 x^{\overline{YY}} - C_1),$$
$$\pi_B^{\overline{YY}} = p_B^{\overline{YY}}(1 - x^{\overline{YY}}) - (a_0 - b_0(C_1 + C_2))(e_2(1 - x^{\overline{YY}}) - C_2). \quad (2)$$

Lemma 1. The optimal decisions and profits for both manufacturers under the $\overline{YY}$ strategy are shown in Table 2.

From Lemma 1, it can be concluded that when neither manufacturer with energy consumption differences offers return service, both prices are inversely proportional to the total carbon credits allocated by the government to the two firms and directly proportional to the energy consumption of the two firms in the case where both have output. The higher the cap allocated by the government to the two manufacturers, the higher the product prices set by both manufacturers. Moreover, regardless of whether its own energy consumption or that of its competitors is higher, a manufacturer will set a higher price.

When the difference in energy consumption between the two sides is larger, the manufacturer with lower energy consumption will get more demand and gain a larger market share. Therefore, in a competitive environment, if the government implements cap-and-trade regulation, manufacturers can benefit from reducing carbon emissions per unit of product through emission-reduction technologies to gain a larger market share.

Proposition 1. If competing manufacturers with energy consumption differences do not offer return service and both have output:

(a) When the carbon price coefficient b_0 is low and the product differentiation degree t is low, the profits of HEC manufacturers increase as the cap C_1 decreases.

(b) When the carbon price coefficient b_0 is high and the product differentiation degree t is high, the profit of HEC manufacturers decreases as the cap C_1 decreases.

(c) When the carbon price coefficient b_0 is low and the product differentiation degree t is high, the profit of HEC manufacturers initially increases and then decreases as the cap C_1 decreases.

(d) When the carbon price coefficient b_0 is high and the product differentiation degree t is low, the profit of HEC manufacturers initially decreases and then increases as the cap C_1 decreases.

Proposition 1 indicates that the trend of profits for HEC manufacturers with changes in the cap is mainly affected by changes in retail prices, carbon trading prices, and demand. On the one hand, retail prices and carbon trading prices increase as the cap decreases. On the other hand, consumer demand for HEC manufacturers will decrease as the cap decreases. For HEC manufacturers with low carbon price coefficients and low product differentiation do not dominate the competition for market share when the cap decreases, and the lower the degree of differentiation is, the more demand is reduced. At this point, the increase in retail prices and gains in the carbon market dominate, and thus, their profits increase as the cap decreases. For HEC manufacturers with low carbon price coefficients and high product differentiation, when the cap decreases, the high degree of product differentiation makes the reduction in demand smaller. The increase in retail price and gains in the carbon trading market play dominant roles in the beginning. By contrast, the reduction in demand and the cost of purchasing carbon emission rights in the carbon trading market ultimately play dominant roles, and thus, their profits are shown to increase initially and then decrease with the lowering of the cap.

For HEC manufacturers with high carbon price coefficients and a high degree of product differentiation, when the cap decreases, the high carbon price factor reduces their demand even more, at which point the reduction in demand dominates, and thus, their profits decrease with the cap. For HEC manufacturers with high carbon price coefficients and low product differentiation, when the cap decreases, profits are initially reduced by the reduction in demand, and then, retail prices and gains in the carbon market dominate, causing profits to increase as the cap decreases.

Therefore, considering the competitive environment, for the government to restrain the development of HEC enterprises in the same industry and promote the industry's green and low-carbon development, it is necessary to consider the sensitivity of carbon prices in the carbon trading market. If the sensitivity is relatively high, then reducing the carbon emission cap for HEC enterprises would be beneficial. It is important to note that when the degree of product differentiation is relatively low, the government should pay close attention to the threshold at which the profit of HEC enterprises changes direction with the variation of the cap. Further reducing the cap will contradict the objectives when it falls below this threshold.

Proposition 2. If competitive manufacturers with energy consumption differences do not offer return service and both have output:

(a) When the energy consumption difference between two

Table 2. The optimal decisions and profits for manufacturers under the $\overline{YY}$ strategy.

	$t > \frac{1}{3}(e_1 - e_2)(a_0 - (C_1 + C_2)b_0)$	Other conditions
$p_A^{\overline{YY}*}$	$t + \frac{1}{3}(a_0 - (C_1 + C_2)b_0)(2e_1 + e_2)$	$(a_0 - (C_1 + C_2)b_0)e_1$
$p_B^{\overline{YY}*}$	$t + \frac{1}{3}(a_0 - (C_1 + C_2)b_0)(e_1 + 2e_2)$	$-t + (a_0 - (C_1 + C_2)b_0)e_1$
$x^{\overline{YY}*}$	$\frac{1}{2} - \frac{(a_0 - (C_1 + C_2)b_0)(e_1 - e_2)}{6t}$	0
$\pi_A^{\overline{YY}*}$	$\frac{t}{2} + \frac{(a_0 - (C_1 + C_2)b_0)(18C_1 t + (-6t + (a_0 - (C_1 + C_2)b_0)(e_1 - e_2))(e_1 - e_2))}{18t}$	$C_1(a_0 - (C_1 + C_2)b_0$
$\pi_B^{\overline{YY}*}$	$\frac{t}{2} + \frac{(a_0 - (C_1 + C_2)b_0)(18C_2 t + (6t + (a_0 - (C_1 + C_2)b_0)(e_1 - e_2))(e_1 - e_2))}{18t}$	$-t + (a_0 - (C_1 + C_2)b_0)(C_2 + e_1 - e_2)$

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manufacturers is low, the profit of the LEC manufacturer increases as the cap C_2 decreases.

(b) When the energy consumption difference between two manufacturers is high and the degree of product differentiation t is high, the profit of the LEC manufacturer decreases as the cap C_2 decreases.

(c) When the energy consumption difference between two manufacturers is high and the degree of product differentiation t is low, the profit of the LEC manufacturer first decreases and then increases as the cap C_2 decreases.

Proposition 2 illustrates the trend of profit for LEC manufacturers with changes in the cap allocated by the government in a competitive environment. The retail price, demand, and carbon trading price for LEC manufacturers all increase as the cap decreases. When the energy consumption difference between two manufacturers is low, as the cap decreases, the market share of the LEC manufacturer increases, albeit relatively moderately. LEC manufacturers can benefit from growth in demand and an increase in retail price, resulting in an increase in profit as the cap decreases. However, when the energy consumption difference between two manufacturers is high and the degree of product differentiation is significant, demand significantly increases as the cap decreases. Nonetheless, constrained by the cap, the dominant effect comes from the purchase cost of carbon emission allowances in the carbon trading market, leading to a decrease in profit as the cap decreases. Conversely, when the energy consumption difference between two manufacturers is high and the degree of product differentiation is low, as the cap decreases, although initially the increase in demand leads to an increase in the cost of purchasing carbon emission allowances and subsequently a decrease in profit, then the dominant effect shifts to the increase in retail price and demand, resulting in an overall pattern where profit decreases initially and then increases as the cap decreases.

Therefore, considering the competitive environment, if the government aims to encourage the development of LEC manufacturers, it can focus on the enterprises with the lowest energy consumption within the same industry and increase their cap. This strategy can enable them to benefit from market competition. It is important to note that when product differentiation within the same industry is relatively low, the government should pay attention to the threshold at which the profit of LEC enterprises changes direction with the variation of the cap. Increasing the cap will deviate from the objective when it exceeds this threshold.

4.1.2 Return service provided by both manufacturers

When both manufacturers provide return service (YY), the utility functions for consumers of each manufacturer are as follows:

$$\begin{aligned} U_A^{YY} &= (1-\alpha)V - tx^{YY} - (1-\alpha)p_A^{YY}, \\ U_B^{YY} &= (1-\alpha)V - t(1-x^{YY}) - (1-\alpha)p_B^{YY}. \end{aligned} \tag{3}$$

When both manufacturers provide return service (YY), the profit functions for each manufacturer are as follows:

$$\begin{aligned} \pi_A^{YY} =& (1-\alpha)p_A^{YY}x^{YY} - \alpha mx - (a_0 - b_0(C_1+C_2))(e_1x^{YY} - C_1), \\ \pi_B^{YY} =& (1-\alpha)p_B^{YY}(1-x^{YY}) - \alpha m(1-x^{YY}) - \\ & (a_0 - b_0(C_1+C_2))(e_2(1-x^{YY}) - C_2). \end{aligned} \tag{4}$$

Lemma 2. The optimal decisions and profits for both manufacturers under the YY strategy are shown in Table 3.

From Lemma 2, it can be deduced that when two manufacturers with energy consumption differences both offer return service and have output, the relationships between each manufacturer's price with the total government-allocated carbon credits and with their respective level of energy consumption are similar to those in Lemma 1; the relationship between demand and the difference in energy consumption between the two parties is similar to that in Lemma 1. Notably, in this case, the return rate has no effect on market share competition between the two manufacturers.

4.2 Asymmetric strategy analysis of two manufacturers

4.2.1 A does not offer return service, while B does

When manufacturer A does not offer return service and manufacturer B does ($\overline{Y}Y$), the consumer utility functions for each manufacturer are as follows:

$$\begin{aligned} U_A^{\overline{Y}Y} &= (1-\alpha)V - tx^{\overline{Y}Y} - p_A^{\overline{Y}Y}, \\ U_B^{\overline{Y}Y} &= (1-\alpha)V - t(1-x^{\overline{Y}Y}) - (1-\alpha)p_B^{\overline{Y}Y}. \end{aligned} \tag{5}$$

When manufacturer A does not offer return service and manufacturer B does ($\overline{Y}Y$), the profit functions for each manufacturer are as follows:

Table 3. The optimal decisions and profits for manufacturers under the YY strategy.

	$t > \frac{1}{3}(e_1-e_2)(a_0-(C_1+C_2)b_0)$	Other conditions
p_A^{YY*}	$-\frac{3(t+m\alpha)+(a_0-(C_1+C_2)b_0)(2e_1+e_2)}{3(-1+\alpha)}$	$\frac{-m\alpha-a_0e_1+(C_1+C_2)b_0e_1}{-1+\alpha}$
p_B^{YY*}	$-\frac{3(t+m\alpha)+(a_0-(C_1+C_2)b_0)(e_1+2e_2)}{3(-1+\alpha)}$	$\frac{t-m\alpha+(-a_0+(C_1+C_2)b_0)e_1}{-1+\alpha}$
x^{YY*}	$\frac{1}{2}-\frac{(a_0-(C_1+C_2)b_0)(e_1-e_2)}{6t}$	0
π_A^{YY*}	$\frac{t}{2}+\frac{(a_0-(C_1+C_2)b_0)(18C_1t+(-6t+(a_0-(C_1+C_2)b_0)(e_1-e_2))(e_1-e_2))}{18t}$	$C_1(a_0-(C_1+C_2)b_0)$
π_B^{YY*}	$\frac{t}{2}+\frac{(a_0-(C_1+C_2)b_0)(18C_2t+(6t+(a_0-(C_1+C_2)b_0)(e_1-e_2))(e_1-e_2))}{18t}$	$-t+(a_0-(C_1+C_2)b_0)(C_2+e_1-e_2)$

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$$\pi_A^{\overline{Y}Y} = p_A^{\overline{Y}Y} x^{\overline{Y}Y} - (a_0 - b_0(C_1 + C_2))(e_1 x^{\overline{Y}Y} - C_1),$$
$$\pi_B^{\overline{Y}Y} = (1-\alpha) p_B^{\overline{Y}Y} (1 - x^{\overline{Y}Y}) - \alpha m (1 - x^{\overline{Y}Y}) - (a_0 - b_0(C_1 + C_2))(e_2(1 - x^{\overline{Y}Y}) - C_2). \quad (6)$$

Lemma 3. The optimal decisions and profits for both manufacturers under the $\overline{Y}Y$ strategy are shown in Table 4.

From Lemma 3, we can conclude that when the HEC manufacturer does not offer return service while the LEC manufacturer does, the prices of both parties are inversely proportional to the total carbon emission quota allocated by the government and directly proportional to their respective energy consumption in the scenario where both parties have output. The market share of the HEC manufacturer is inversely proportional to the difference in energy consumption between the two manufacturers.

Additionally, the retail prices of both parties are directly proportional to the return rate, meaning that the higher the return rate, the higher the prices of both manufacturers. The demand for the HEC manufacturer is directly proportional to the return rate; hence, the higher the return rate, the higher the production volume of the HEC manufacturer, leading to an increase in carbon emissions.

4.2.2 A offers offer return service while B does not

When manufacturer A offers return service and manufacturer B does not ($Y\overline{Y}$), the consumer utility functions for each manufacturer are as follows:

$$U_A^{Y\overline{Y}} = (1-\alpha)V - t x^{Y\overline{Y}} - (1-\alpha) p_A^{Y\overline{Y}},$$
$$U_B^{Y\overline{Y}} = (1-\alpha)V - t(1 - x^{Y\overline{Y}}) - p_B^{Y\overline{Y}}. \quad (7)$$

When manufacturer A offers return service and manufacturer B does not ($Y\overline{Y}$), the profit functions for each manufacturer are as follows:

$$\pi_A^{Y\overline{Y}} = (1-\alpha) p_A^{Y\overline{Y}} x - \alpha m x^{Y\overline{Y}} - (a_0 - b_0(C_1 + C_2))(e_1 x^{Y\overline{Y}} - C_1),$$
$$\pi_B^{Y\overline{Y}} = p_B^{Y\overline{Y}} (1 - x^{Y\overline{Y}}) - (a_0 - b_0(C_1 + C_2))(e_2(1 - x^{Y\overline{Y}}) - C_2). \quad (8)$$

Lemma 4. The optimal decisions and profits for both manufacturers under the $Y\overline{Y}$ strategy are shown in Table 5.

From Lemma 4, we can conclude that when the HEC manufacturer does not offer return service while the LEC manufacturer does, in the scenario where both parties have output, the relationship between the prices of the two parties with the total carbon credits allocated by the government and the level of energy consumption of the two companies is similar to that in Lemma 1. Similarly, the relationship between demand and the difference in energy consumption between the two parties is also consistent with that in Lemma 1.

Furthermore, the retail prices of both parties are still directly proportional to the return rate; that is, the higher the return rate, the higher the prices of both manufacturers. The demand of HEC manufacturers is inversely proportional to the return rate; as the return rate increases, the market share of HEC manufacturers decreases, and both the production output and carbon emissions of HEC manufacturers decrease accordingly.

Proposition 3. Under competitive circumstances, regardless of whether the two manufacturers with energy consumption differences provide return service, the production output and carbon emissions of the HEC manufacturer increase with total carbon emission quota in the carbon trading market. Furthermore, if the HEC manufacturer has a higher energy consumption, its production output and carbon emissions are more sensitive to changes in the market's total carbon emission rights.

Proposition 3 suggests that in a competitive environment, regardless of whether the government lowers the cap for HEC manufacturers or LEC manufacturers, the production output of HEC manufacturers will decrease. This is primarily because the reduction in total carbon emissions in the entire carbon trading market leads to an increase in the carbon trading price, thereby increasing production costs. The only way for HEC manufacturers to maintain production is to buy carbon credits at a higher carbon price. However, when the marginal cost of producing a unit of product exceeds the marginal revenue, this strategy is not prudent for HEC manufacturers.

Table 4. The optimal decisions and profits for manufacturers under the $\overline{Y}Y$ strategy.

	$(0 < (e_1 - e_2) \le -\frac{m\alpha}{-a_0 + (C_1 + C_2)b_0}$ && $t > \frac{1}{3}(m\alpha - (e_1 - e_2)(a_0 - (C_1 + C_2)b_0))$ || $((e_1 - e_2) > -\frac{m\alpha}{-a_0 + (C_1 + C_2)b_0}$ && $t > \frac{1}{3}(-m\alpha + (e_1 - e_2)(a_0 - (C_1 + C_2)b_0))$	$(e_1 - e_2) > -\frac{m\alpha}{-a_0 + (C_1 + C_2)b_0}$ && $0 < t < \frac{1}{3}(-m\alpha + (e_1 - e_2)(a_0 - (C_1 + C_2)b_0))$	Other conditions
$p_A^{\overline{Y}Y*}$	$\frac{1}{3}(3t + m\alpha + (a_0 - (C_1 + C_2)b_0)(2e_1 + e_2))$	$(a_0 - (C_1 + C_2)b_0)e_1$	$-t + m\alpha + a_0 e_2 - (C_1 + C_2)b_0 e_2$
$p_B^{\overline{Y}Y*}$	$-\frac{3t + 2m\alpha + (a_0 - (C_1 + C_2)b_0)(e_1 + 2e_2)}{3(-1 + \alpha)}$	$\frac{t + (-a_0 + (C_1 + C_2)b_0)e_1}{-1 + \alpha}$	$\frac{-m\alpha - a_0 e_2 + (C_1 + C_2)b_0 e_2}{-1 + \alpha}$
$x^{\overline{Y}Y*}$	$\frac{3t + m\alpha - (a_0 - (C_1 + C_2)b_0)(e_1 - e_2)}{6t}$	0	1
$\pi_A^{\overline{Y}Y*}$	$\frac{1}{18t}((3t + m\alpha)^2 + (a_0 - (C_1 + C_2)b_0)(18C_1 t + (-2(3t + m\alpha) + (a_0 - (C_1 + C_2)b_0)(e_1 - e_2))(e_1 - e_2)))$	$C_1(a_0 - (C_1 + C_2)b_0)$	$-t + m\alpha + (a_0 - (C_1 + C_2)b_0)(C_1 - e_1 + e_2)$
$\pi_B^{\overline{Y}Y*}$	$\frac{1}{18t}((-3t + m\alpha)^2 + (a_0 - (C_1 + C_2)b_0)(18C_2 t + (6t - 2m\alpha + (a_0 - (C_1 + C_2)b_0)(e_1 - e_2))(e_1 - e_2)))$	$-t - m\alpha + (a_0 - (C_1 + C_2)b_0)(C_2 + e_1 - e_2)$	$C_2(a_0 - (C_1 + C_2)b_0$

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Table 5. The optimal decisions and profits for manufacturers under the $Y\overline{Y}$ strategy.

	$t > \frac{1}{3}(m\alpha + (e_1 - e_2)(a_0 - (C_1 + C_2)b_0)$	Other conditions
$p_A^{Y\overline{Y}^*}$	$-\frac{3t + 2m\alpha + (a_0 - (C_1 + C_2)b_0)(2e_1 + e_2)}{3(-1 + \alpha)}$	$\frac{-m\alpha - a_0e_1 + C_1b_0e_1 + C_2b_0e_1}{-1 + \alpha}$
$p_B^{Y\overline{Y}^*}$	$\frac{1}{3}(3t + m\alpha + (a_0 - (C_1 + C_2)b_0)(e_1 + 2e_2))$	$-t + m\alpha + a_0e_1 - (C_1 + C_2)b_0e_1$
$x^{Y\overline{Y}^*}$	$-\frac{-3t + m\alpha + (a_0 - (C_1 + C_2)b_0)(e_1 - e_2)}{6t}$	0
$\pi_A^{Y\overline{Y}^*}$	$\frac{1}{18t}((-3t + m\alpha)^2 + (a_0 - (C_1 + C_2)b_0)\cdot$ $(18C_1t + (-6t + 2m\alpha + (a_0 - (C_1 + C_2)b_0)(e_1 - e_2))(e_1 - e_2)))$	$C_1(a_0 - (C_1 + C_2)b_0)$
$\pi_B^{Y\overline{Y}^*}$	$\frac{1}{18t}((-3t + m\alpha)^2 + (a_0 - (C_1 + C_2)b_0)\cdot$ $(18C_2t + (6t - 2m\alpha + (a_0 - (C_1 + C_2)b_0)(e_1 - e_2))(e_1 - e_2)))$	$-t + m\alpha + (a_0 - (C_1 + C_2)b_0)\cdot$ $(C_2 + e_1 - e_2)$

Previous studies have focused on the effect of government-adjusted caps on manufacturers' output in monopolistic environments. In contrast to prior studies, this research emphasizes the effects of government adjustments to the cap on competing manufacturers. This study argues that while raising the cap on LEC manufacturers to encourage their production, the government should pay attention to its impact on HEC manufacturers within the same industry. When LEC manufacturers release surplus carbon emission rights into the carbon trading market, this may facilitate an increase in production output and carbon emissions for HEC manufacturers. This effect is particularly pronounced when the energy consumption of HEC manufacturers is higher, leading to a heightened sensitivity of their production output to the increase in carbon emission rights allocated to the entire market by the government.

4.3 Optimal return strategies in competitive scenario

Following the equilibrium outcomes derived for each subgame $\{\overline{Y}\overline{Y}, \overline{Y}Y, Y\overline{Y}, YY\}$, the subsequent analysis delves into the equilibrium return strategies of manufacturers under the cap-and-trade regulation. This section first considers scenarios where each subgame has an inner solution to ensure that neither manufacturer monopolizes the entire market under each subgame. Consequently, a lower bound is imposed on the degree of product differentiation (i.e., $t > \underline{t}$). When illustrating the results in Fig. 2, regions that do not satisfy this condition are designated as "corner solutions."

Proposition 4. When $0 < m < \frac{3t}{\alpha}$ and $0 < e_1 - e_2 < \frac{-3t + m\alpha}{-a_0 + (C_1 + C_2)b_0}$:

(a) Manufacturer A's optimal response to Manufacturer B not offering return service is not to offer return service. In this case, $p_A^{\overline{Y}\overline{Y}^*} < p_A^{Y\overline{Y}^*}$, $x^{\overline{Y}\overline{Y}^*} > x^{Y\overline{Y}^*}$.

(b) Manufacturer A's optimal response to Manufacturer B offering return service is not to offer return service. In this case, $p_A^{\overline{Y}Y^*} < p_A^{YY^*}$, $x^{\overline{Y}Y^*} > x^{YY^*}$.

Proposition 4 indicates that when the return cost and the carbon consumption difference between two manufacturers are low, the market is highly competitive, and changes in manufacturer profits are primarily driven by variations in market share. The primary factors influencing market share are the return rate and the energy consumption disparity between the two manufacturers. The mechanisms affecting profit margins become negligible. Although the retail price

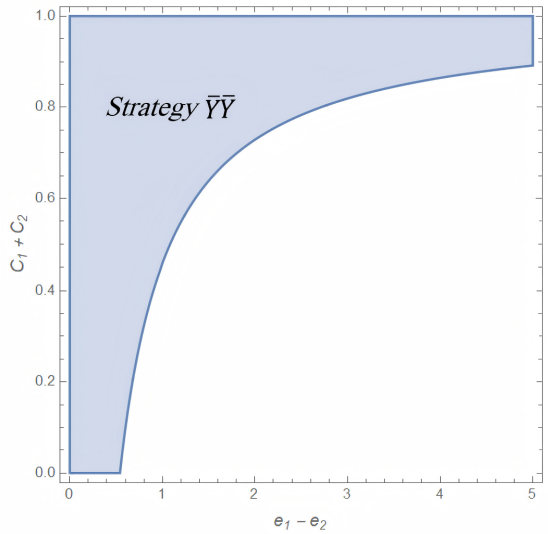


Fig. 2. Equilibrium of the manufacturers' return strategies.

when HEC manufacturers offer return service is higher than when they do not, the demand when HEC manufacturers offer return service is lower than when they do not. Therefore, when the return cost and the carbon consumption difference between two manufacturers are low, it is more advantageous for HEC manufacturers not to offer return service, regardless of whether LEC rivals provide return service.

Proposition 5. When $0 < m < \frac{3t}{\alpha}$ and $0 < e_1 - e_2 < \frac{-3t + m\alpha}{-a_0 + (C_1 + C_2)b_0}$:

(a) Manufacturer B's optimal response to Manufacturer A not offering return service is not to offer return service. In this case, $p_B^{\overline{Y}\overline{Y}^*} < p_B^{\overline{Y}Y^*}$, $1 - x^{\overline{Y}\overline{Y}^*} > 1 - x^{\overline{Y}Y^*}$.

(b) Manufacturer B's optimal response to Manufacturer A offering return service is not to offer return service. In this case, $p_B^{Y\overline{Y}^*} < p_B^{YY^*}$, $1 - x^{Y\overline{Y}^*} > 1 - x^{YY^*}$.

Proposition 5 indicates that when both the return cost and the disparity in carbon emission intensity between two competing manufacturers in the market are low, the LEC manufacturer will not provide return service, regardless of whether the HEC manufacturer does so. Although the price when LEC manufacturers offer return service is higher than when they do not, whether HEC manufacturers provide or do not

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provide return service, demand plays a predominant role. The demand when LEC manufacturers offer return service is lower than when they do not. Therefore, regardless of the return strategy adopted by HEC competitors, LEC manufacturers should refrain from providing return service.

LEC manufacturers enjoy a competitive advantage in a competitive environment due to their higher energy efficiency. When they offer return service, the profits from selling carbon emission rights outweigh those derived from stimulating demand through return service. Consequently, LEC manufacturers proactively raise retail prices to suppress consumer demand. Ultimately, in the equilibrium of market competition with HEC manufacturers, the profits from offering return service are lower than those from not offering return service.

Proposition 6. When $0 < m < \frac{3t}{\alpha}$ and $0 < e_1 - e_2 < \frac{-3t + m\alpha}{-a_0 + (C_1 + C_2)b_0}$, $\overline{YY}$ is the unique optimal equilibrium.

Assuming $m = 2.5$, $\alpha = 0.35$, $t = 0.4$, $a_0 = 0.6$, $b_0 = 0.6$, a numerical analysis is conducted to investigate the equilibrium strategy selection of two manufacturers with energy consumption disparities.

From Proposition 6 and Fig. 2, it is evident that considering the policy effects of the cap-and-trade regulation, in a competitive environment, when the return cost and the carbon consumption difference between two manufacturers are low, the advantage of stimulating demand by offering return service diminishes. At this juncture, not providing return service enables suppliers with energy consumption disparities to maintain their market share and profit margins, thus countering competitive pressures from rivals. Consequently, $\overline{YY}$ emerges as the dominant strategy for both manufacturers. Under the cap-and-trade regulation, regardless of whether manufacturers have high or low energy consumption, raising prices to reduce demand and carbon emissions is more advantageous when they offer return service. This undermine the competitive advantage gained from return service, leading both parties to choose not to provide such service.

Additionally, we also compare scenarios where at least one subgame has a corner solution, as demonstrated in Proposition 7 below.

Proposition 7.

(a) When $0 < m < \frac{3t}{\alpha}$ and $\frac{-3t + m\alpha}{-a_0 + (C_1 + C_2)b_0} < e_1 - e_2 < -\frac{3t}{-a_0 + (C_1 + C_2)b_0}$, or $m \geq \frac{3t}{\alpha}$ and $0 < e_1 - e_2 < -\frac{3t}{-a_0 + (C_1 + C_2)b_0}$, $\overline{YY}$ is the unique optimal equilibrium.

(b) When $e_1 - e_2 > -\frac{3t}{-a_0 + (C_1 + C_2)b_0}$, LEC manufacturers dominate the entire market and do not offer return service.

Proposition 7 suggests that considering corner solutions, manufacturers with energy consumption disparities do not offer return service when the return cost and energy consumption differentials are low. This is primarily due to the dual pressure faced by manufacturers from competitive market and the cap-and-trade regulation. Providing return service stimulates demand, leading to more carbon emissions. Manufacturers, therefore, prefer to reduce demand to attain optimal profits. Consequently, no provision of return service becomes the optimal equilibrium for both parties.

Additionally, Proposition 7 indicates that under the cap-and-trade regulation, manufacturers with lower energy consumption enjoy a competitive advantage in market share competition. This advantage is particularly pronounced when competing against HEC manufacturers with significant energy consumption differentials. Consequently, HEC manufacturers are compelled to exit the market. This underscores how government implementation of the cap-and-trade regulation can restrain the development of HEC manufacturers and steer the entire industry toward green, low-carbon development. To excel in competition within the industry, manufacturers must adopt emission reduction measures to decrease carbon emissions during the production process. Specific measures include utilizing clean energy sources, optimizing facility equipment to reduce energy consumption losses, and refining process designs and workflows.

5 Conclusions

This paper investigates the return strategies of two manufacturers with energy consumption differences under the cap-and-trade regulation by establishing a Hotelling model. This provides a new perspective for analyzing the impact of policies on manufacturer return strategies. Our main research findings are as follows:

First, we argue that in the competition scenario, regardless of whether the two manufacturers offer return service, the output and carbon emissions of the HEC manufacturer decrease with the reduction of carbon credits in the overall carbon market. Furthermore, the higher the energy consumption of HEC manufacturers is, the more sensitive its output and carbon emissions are to the change in carbon credits in the overall carbon trading market. Governments can reduce the carbon emissions of HEC manufacturers by lowering their caps. Considering the competition among manufacturers, when the government raises the cap for LEC manufacturers, it should take care to raise the credits. Because of the existence of the carbon trading market, the government needs to consider its impact on HEC manufacturers.

Second, we analyze the relationship between competing manufacturers' optimal profits and the cap under cap-and-trade regulation when neither manufacturer offers returns. (Ⅰ) For HEC manufacturers, when the carbon emission coefficient is low and the degree of product differentiation is low, their profits increase as the cap decreases; when the carbon price coefficient is large and product differentiation is high, their profits increase as the cap decreases; when the carbon price coefficient is low and the degree of product differentiation is high, their profits increase and then decrease as the cap decreases; when the carbon price coefficient is high and the degree of product differentiation is low, their profits first decrease and then increase as the cap decreases. (Ⅱ) For LEC manufacturers, when the difference in energy consumption between the two manufacturers is low, their profits increase as the cap decreases; when the difference in energy consumption between the two manufacturers is large and product differentiation is high, their profit decreases as the cap is

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lowered; when the difference in energy consumption between the two manufacturers is high and product differentiation is low, their profit first decreases and then increases as the cap decreases. Therefore, when neither of the competing parties provides return service, the government should pay attention to the degree of product differentiation, the stability of the carbon trading price, and the difference in the level of energy consumption when adjusting the cap. Starting from the impact of the government-adjusted cap on the profits of manufacturers competing in the same industry, if both manufacturers are in the optimal equilibrium of not providing return service when the carbon price in the carbon trading market is more sensitive, the government can lower the cap of HEC manufacturers to reduce their profits and inhibit their development in the industry. It is important to note that, when there is low differentiation of the products in the same industry, the government lowers the cap to a threshold value, and the profits of the HEC manufacturers increase with the lowering of the cap, which is contrary to the objective. At the same time, the government raises the cap on LEC manufacturers that have a large difference in energy consumption from their competitors, which can increase their profits and encourage the development of LEC manufacturers. It should be noted that when the degree of differentiation of products in the same industry is small and the government raises the cap to a certain threshold, the profits of HEC manufacturers will decrease with increasing cap, which is contrary to the goal.

Finally, a comparative analysis of each strategy of the manufacturers shows that in a competitive situation, when the return cost and the difference in carbon consumption between two manufacturers are low, it is optimal for both HEC and LEC manufacturers not to offer returns due to the dual pressure from competitors and the cap-and-trade regulation; ultimately, neither of the two sides provides return service as the optimal equilibrium for both sides. Therefore, regardless of competitors' countermeasures, manufacturers should adopt a strategy of not offering return service. Furthermore, LEC manufacturers possess a stronger competitive advantage in the market. To achieve a dominant position in industry competition, manufacturers can adopt strategies including energy conservation, efficiency improvement, and emission reduction. Examples include the use of clean energy, facility and equipment optimization to reduce energy losses, and process design and flow optimization.

This study suggests several avenues for further exploration. First, while this paper focuses on whether decision-makers are willing to provide return service to stimulate demand under the cap-and-trade regulation, it is worth noting that product returns also entail secondary packaging, reverse logistics, and related carbon emission issues. Subsequent research could delve deeper into the carbon footprint associated with product returns. Second, this paper assumes that consumers exhibit no preference regarding products with different energy consumption levels. However, with growing environmental awareness among consumers, future research could consider the environmental consciousness of certain consumer segments. In addition, more complex channel structures are considered in the future, such as exploring the return strategies of decision-making entities under dual-channel or omnichannel structures in the context of carbon emission policies, and considering more specific return strategies, such as whether or not to provide shipping insurance, the return period, and the handling of returned products.

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Conflict of interest

The authors declare that they have no conflict of interest.

Biography

Wei Wang is currently a graduate student at the University of Science and Technology of China. Her research mainly focuses on operations management and marketing science.

References

[1] Dimoka A, Hong Y, Pavlou P A. On product uncertainty in online markets: theory and evidence. *MIS Quarterly*, **2012**, *36* (2): 395–426.

[2] Choi T M, Chow P S, Kwok B, et al. Service quality of online shopping platforms: a case-based empirical and analytical study. *Mathematical Problems in Engineering*, **2013**, *2013*: 128678.

[3] Xu X, Jackson J E. Investigating the influential factors of return channel loyalty in omni-channel retailing. *International Journal of Production Economics*, **2019**, *216*: 118–32.

[4] Taleizadeh A A, Varzi A M, Amjadian A, et al. How cash-back strategy affect sale rate under refund and customers' credit. *Operational Research*, **2023**, *23*: 19.

[5] McWilliams B. Money-back guarantees: helping the low-quality retailer. *Management Science*, **2012**, *58* (8): 1521–1524.

[6] Li G, Li L, Sethi S P, et al. Return strategy and pricing in a dual-channel supply chain. *International Journal of Production Economics*, **2019**, *215*: 153–164.

[7] Nageswaran L, Cho S H, Scheller-Wolf A. Consumer return policies in omnichannel operations. *Management Science*, **2020**, *66* (12): 5558–5575.

[8] Yang L, Li X Y, Xia Y, et al. Returns operations in omnichannel retailing with buy-online-and-return-to-store. *Omega*, **2023**, *119*: 102874.

[9] Ma B Q, Di C C, Hsiao L. Return window decision in a distribution channel. *Production and Operations Management*, **2020**, *29* (9): 2121–2137.

[10] Chen Z W, Fan Z P, Zhu S X. Extracting values from consumer returns: the role of return-freight insurance for competing e-sellers. *European Journal of Operational Research*, **2023**, *306* (1): 141–155.

[11] Kalantary M R, Hejazi S R, Khosroshahi H. Pricing for different return policies in an online marketplace considering appeasement during a post-return out-of-stock. *International Journal of Production Economics*, **2023**, *266*: 109039.

[12] Wan X, Li D, Chen J, et al. Managing customer returns strategy with the option of selling returned products. *International Journal of Production Economics*, **2020**, *230*: 107794.

[13] Guo J R, Xiang Y. Cost-benefit analysis of Gencos market trading with carbon-tax and cap-and-trade policies. *Energy Reports*, **2022**, *8*: 900–907.

[14] Yu Y G, Li X, Xu X P. Reselling or marketplace mode for an online

CSTR: 32290.14.JUSTC-2024-0070
DOI: 10.52396/JUSTC-2024-0070
JUSTC, **2025**, 55(11): 1104

platform: the choice between cap-and-trade and carbon tax regulation. *Annals of Operations Research*, **2022**, *310* (1): 293–329.
[15] Chang X Y, Xia H Y, Zhu H Y, et al. Production decisions in a hybrid manufacturing-remanufacturing system with carbon cap and trade mechanism. *International Journal of Production Economics*, **2015**, *162*: 160–173.
[16] Jauhari W A, Adam N, Rosyidi C N, et al. A closed-loop supply chain model with rework, waste disposal, and carbon emissions. *Operations Research Perspectives*, **2020**, *7*: 100155.
[17] He P, Dou G W, Zhang W. Optimal production planning and cap setting under cap-and-trade regulation. *Journal of the Operational Research Society*, **2017**, *68* (9): 1094–1105.
[18] Zhang B, Xu L. Multi-item production planning with carbon cap and trade mechanism. *International Journal of Production Economics*, **2013**, *144* (1): 118–127.
[19] Du S F, Zhu L L, Liang L, et al. Emission-dependent supply chain and environment-policy-making in the 'cap-and-trade' system. *Energy Policy*, **2013**, *57*: 61–67.
[20] Ji T, Xu X P, Yan X M, et al. The production decisions and cap setting with wholesale price and revenue sharing contracts under cap-and-trade regulation. *International Journal of Production Research*, **2020**, *58* (1): 128–147.
[21] Qian X H, Chan F T S, Zhang J H, et al. Channel coordination of a two-echelon sustainable supply chain with a fair-minded retailer under cap-and-trade regulation. *Journal of Cleaner Production*, **2020**, *244*: 118715.
[22] Zhao Y, Hou R. Manufacturer encroachment with carbon cap-and-trade policy under asymmetric information. *Journal of Cleaner Production*, **2024**, *438*: 104816.
[23] Wei J, Zhao J. Pricing and remanufacturing decisions in two competing supply chains. *International Journal of Production Research*, **2015**, *53* (1): 258–278.
[24] Geng X J, Shulman J D. How costs and heterogeneous consumer price sensitivity interact with add-on pricing. *Production and Operations Management*, **2015**, *24* (12): 1870–1882.
[25] Bian J S, Lai K K, Hua Z S, et al. Bertrand vs. Cournot competition in distribution channels with upstream collusion. *International Journal of Production Economics*, **2018**, *204*: 278–289.
[26] Chen J, Grewal R. Competing in a supply chain via full-refund and no-refund customer returns policies. *International Journal of Production Economics*, **2013**, *146* (1): 246–258.
[27] Jin D, Caliskan-Demirag O, Chen F, et al. Omnichannel retailers' return policy strategies in the presence of competition. *International Journal of Production Economics*, **2020**, *225*: 107595.

Appendix

A.1 Proof of Lemma 1

Let $U_A^{\overline{YY}} = U_B^{\overline{YY}}$, we obtain the indifference point $x^{\overline{YY}} = \frac{t - p_A + p_B}{2t}$, substituting into the profit functions of manufacturer A and manufacturer B. The second-order conditions for profit maximization of the manufacturers are: $\frac{\partial^2 \pi_A^{\overline{YY}}}{\partial^2 p_A^{\overline{YY}}} = -\frac{1}{t} < 0$, $\frac{\partial^2 \pi_B^{\overline{YY}}}{\partial^2 p_B^{\overline{YY}}} = -\frac{1}{t} < 0$. Consider two cases: $t > \frac{1}{3}((e_1 - e_2)a_0 - (C_1 + C_2)(e_1 - e_2)b_0)$ and $0 < t < \frac{1}{3}((e_1 - e_2)a_0 - (C_1 + C_2)(e_1 - e_2)b_0)$.

Case 1 (the inner case): $t > \frac{1}{3}((e_1 - e_2)a_0 - (C_1 + C_2)(e_1 - e_2)b_0)$.

The first-order derivative of $\pi_A^{\overline{YY}}$ with respect to $p_A^{\overline{YY}}$ yields:

$$\frac{\partial \pi_A^{\overline{YY}}}{\partial p_A^{\overline{YY}}} = \frac{t + (a_0 - (C_1 + C_2)b_0)e_1 - 2p_A + p_B}{2t}.$$

Setting $\frac{\partial \pi_A^{\overline{YY}}}{\partial p_A^{\overline{YY}}} = 0$, we obtain

$$p_A^{\overline{YY}} = \frac{1}{2}(t + a_0 e_1 - C_1 b_0 e_1 - C_2 b_0 e_1 + p_B^{\overline{YY}}).$$

Similarly, we can derive: $p_B^{\overline{YY}} = \frac{1}{2}(t + a_0 e_2 - C_1 b_0 e_2 - C_2 b_0 e_2 + p_A^{\overline{YY}})$.

By simultaneously solving the aforementioned two price equations, we obtain $p_A^{\overline{YY}^*} = t + \frac{1}{3}(a_0 - (C_1 + C_2)b_0)(2e_1 + e_2)$ and $p_B^{\overline{YY}^*} = t + \frac{1}{3}(a_0 - (C_1 + C_2)b_0)(e_1 + 2e_2)$.

By substituting the above $p_A^{\overline{YY}^*}$ and $p_B^{\overline{YY}^*}$ into Eq. (2) and $x^{\overline{YY}}$, we can obtain the optimal production decisions and profits within the internal solution of Lemma 1.

At this point, when $0 < x^{\overline{YY}^*} < 1$, $t > \frac{1}{3}((e_1 - e_2)a_0 - (C_1 + C_2)(e_1 - e_2)b_0)$.

Case 2 (the corner case): $0 < t < \frac{1}{3}((e_1 - e_2)a_0 - (C_1 + C_2)(e_1 - e_2)b_0)$, it holds that $x^{\overline{YY}} > 1$ or $x^{\overline{YY}} < 1$.

In this scenario, all consumers purchase from manufacturer B, which represents a corner solution, manufacturer B aims to set the largest $p_B^{\overline{YY}}$.The optimal price for manufacturer B satisfies $p_B^{\overline{YY}} = -t + p_A^{\overline{YY}}$, while the optimal price for manufacturer A satisfies $\frac{\partial \pi_A^{\overline{YY}}}{\partial p_A^{\overline{YY}}} = 0$. Solving these equations simultaneously yields $p_A^{\overline{YY}} = (a_0 - (C_1 + C_2)b_0)e_1$, $p_B^{\overline{YY}} = -t + (a_0 - (C_1 + C_2)b_0)e_1$. Substituting these values into Eq. (1) and $x^{\overline{YY}}$ yields the optimal production decision and profit for the corner solution as depicted in Lemma 1.

The proof methods for Lemmas 2, 3, and 4 are similar to that for Lemma 1. By utilizing the proof method of Lemma 1, Lemmas 2, 3, and 4 can be derived and their detailed proofs are therefore omitted here.

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A.2 Proof of Proposition 1

When both manufacturers do not offer return service, the optimal profit for the HEC manufacturer is given by:

$$\pi_A^{\overline{YY}^*} = \frac{t}{2} + \frac{(a_0-(C_1+C_2)b_0)(18C_1t+(-6t+(a_0-(C_1+C_2)b_0)(e_1-e_2))(e_1-e_2))}{18t}.$$

Here, we discuss the variation in the manufacturer's profit with respect to the cap:

$$\frac{\partial \pi_A^{\overline{YY}^*}}{\partial C_1} = \frac{b_0(-9(2C_1+C_2)t+(3t+(C_1+C_2)b_0(e_1-e_2))(e_1-e_2))+a_0(9t-b_0(e_1-e_2)^2)}{9t}.$$

Setting $\frac{\partial \pi_A^{\overline{YY}^*}}{\partial C_1} = 0$, we obtain

$$C_0 = \frac{-b_0(-9C_2t+(3t+C_2b_0(e_1-e_2))(e_1-e_2))+a_0(-9t+b_0(e_1-e_2)^2)}{b_0(-18t+b_0(e_1-e_2)^2)}.$$

Let $\frac{\partial \pi_A^{\overline{YY}^*}}{\partial C_1} = \frac{C_1A_1+B_1}{9t}$, then

$$A_1 = (-18tb_0+b_0^2(e_1-e_2)^2), \quad B_1 = b_0(-9C_2t+(3t+C_2b_0(e_1-e_2))(e_1-e_2))+a_0(9t-b_0(e_1-e_2)^2).$$

Set:

$$y = e_1-e_2, \quad t_1 = \frac{-y^2a_0b_0+C_2y^2b_0^2}{-9a_0+9C_2b_0-3yb_0}.$$

When $\frac{3a_0}{3C_2+y} < b_0 < \frac{a_0}{C_2}$ and $t > t_1$, then $A_1 > 0$ and $B_1 > 0$, $\frac{\partial \pi_A^{\overline{YY}^*}}{\partial C_1}$ forms a positively sloped line with a positive intercept; or $A_1 < 0$ and $B_1 > 0$ and $C_1 > \frac{a_0-C_2b_0}{b_0}$; thus, $\frac{\partial \pi_A^{\overline{YY}^*}}{\partial C_1} > 0$.

When $0 < b_0 < \frac{3a_0}{3C_2+y}$ and $0 < t < t_1$, then $A_1 < 0$ and $B_1 < 0$, $\frac{\partial \pi_A^{\overline{YY}^*}}{\partial C_1}$ forms a negatively sloped line with a negative intercept, or $A_1 > 0$ and $B_1 < 0$ and $C_1 > \frac{a_0-C_2b_0}{b_0}$; thus, $\frac{\partial \pi_A^{\overline{YY}^*}}{\partial C_1} < 0$.

When $\frac{3a_0}{3C_2+y} < b_0 < \frac{a_0}{C_2}$ and $0 < t < t_1$, then $A_1 > 0$ and $B_1 < 0$, $\frac{\partial \pi_A^{\overline{YY}^*}}{\partial C_1}$ forms a positively sloped line with a negative intercept. Thus, if $C_0 < C_1 < \frac{a_0-C_2b_0}{b_0}$, $\frac{\partial \pi_A^{\overline{YY}^*}}{\partial C_1} > 0$; if $0 < C_1 < C_0$, $\frac{\partial \pi_A^{\overline{YY}^*}}{\partial C_1} < 0$.

When $0 < b_0 < \frac{3a_0}{3C_2+y}$ and $t > t_1$, then $A_1 < 0$ and $B_1 > 0$, $\frac{\partial \pi_A^{\overline{YY}^*}}{\partial C_1}$ forms a negatively sloped line with a positive intercept. Thus, if $C_0 < C_1 < \frac{a_0-C_2b_0}{b_0}$, $\frac{\partial \pi_A^{\overline{YY}^*}}{\partial C_1} < 0$, if $0 < C_1 < C_0$, $\frac{\partial \pi_A^{\overline{YY}^*}}{\partial C_1} > 0$.

A.3 Proof of Proposition 2

The proof of the variation in the profits of LEC manufacturers with changes in the cap follows a similar pattern. Therefore, a detailed explanation is omitted here.

A.4 Proof of Proposition 3

Under the $\overline{YY}$ strategy:

$$\frac{\partial x^{\overline{YY}^*}}{\partial(C_1+C_2)} = \frac{b_0(e_1-e_2)}{6t} > 0; \quad \frac{\partial\left(e_1x^{\overline{YY}^*}\right)}{\partial(C_1+C_2)} = \frac{b_0e_1(e_1-e_2)}{6t}.$$

Continuing, taking the first-order derivative of $\frac{\partial x^{\overline{YY}^*}}{\partial(C_1+C_2)}$ with respect to e_1 and the first-order derivative of $\frac{\partial\left(e_1x^{\overline{YY}^*}\right)}{\partial(C_1+C_2)}$ with respect to e_1:

$$\frac{\partial x^{\overline{YY}^*}}{\partial(C_1+C_2)\partial(e_1)} = \frac{b_0}{4} > 0; \quad \frac{\partial\left(e_1x^{\overline{YY}^*}\right)}{\partial(C_1+C_2)\partial e_1} = \frac{b_0(2e_1-e_2)}{6t} > 0.$$

The proofs for the variations in the demand and carbon emissions of HEC manufacturers with changes in the total market's carbon quota under the $\overline{Y}Y$, $Y\overline{Y}$, and YY strategies follow a similar pattern and are therefore omitted here.

A.5 Proof of Proposition 4

We first consider a lower bound $t > \underline{t}$, ensuring that all subgames have inner solutions, i.e., the demand and profits of both manu-

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facturers are greater than zero, to ensure that neither of the manufacturers monopolizes the entire market in each subgame. Here, the value of $\underline{t}$ is $\frac{1}{3}(m\alpha+(e_1-e_2)(a_0-(C_1+C_2)b_0)$. In this scenario, $0<m<\frac{3t}{\alpha}$ and $0<e_1-e_2<\frac{-3t+m\alpha}{-a_0+(C_1+C_2)b_0}$. At this point, $\pi_A^{\overline{YY}^*}>\pi_A^{Y\overline{Y}^*}$, $\pi_A^{\overline{Y}Y^*}>\pi_A^{YY^*}$.

A.6 Proof of Proposition 5

Similar to Proposition 4, when $0<m<\frac{3t}{\alpha}$ and $0<e_1-e_2<\frac{-3t+m\alpha}{-a_0+(C_1+C_2)b_0}$, it follows that $\pi_B^{\overline{YY}^*}>\pi_B^{\overline{Y}Y^*}$, $\pi_B^{Y\overline{Y}^*}>\pi_B^{YY^*}$.

A.7 Proof of Proposition 6

From Propositions 4 and 5, when $0<m<\frac{3t}{\alpha}$ and $0<e_1-e_2<\frac{-3t+m\alpha}{-a_0+(C_1+C_2)b_0}$, it follows that $\pi_A^{\overline{YY}^*}>\pi_A^{Y\overline{Y}^*}$, $\pi_B^{\overline{YY}^*}>\pi_B^{\overline{Y}Y^*}$.

A.8 Proof of Proposition 7

Similar to Propositions 4, 5, and 6, corner solutions are discussed in different intervals, which therefore are omitted here.

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