RAIRO-Oper. Res. 56 (2022) 3293–3309
https://doi.org/10.1051/ro/2022148

RAIRO Operations Research
www.rairo-ro.org

GREENING LEVEL AND PRICING DECISIONS OF THE GREEN PRODUCT SUPPLY CHAIN IN THE PRESENCE OF CONSUMERS' ANTICIPATED REGRET

Lili liu[1,*] and Yizhong Li[2]

Abstract. When a firm introduces a new improved eco-friendly product into the market of the congeneric non-green product with the same baseline attribute, consumers are uncertain about the true valuation of this green product. Thus, when choosing between the green product and non-green product, consumers will anticipate the potential regret in the future and try to minimize it, and their purchasing decisions will be affected. This paper investigates the impact of consumers' anticipated regret on the manufacturer's and retailer's optimal pricing and greening level decisions of these two kinds of products. By a game theoretic model in which the manufacturer is the leader, we derive the optimal wholesale price, greening level and retail price. Our analysis shows that the manufacturer and retailer can benefit or loss from consumers' two types of anticipated regret in equilibrium. Furthermore, the green product' optimal wholesale price and retail price, and greening level all decrease with green product-purchase regret but increase with non-green product-purchase regret in equilibrium. Interestingly, we also find that the non-green product's optimal wholesale price and retail price are not affected by the consumers' anticipated regret and the green product. This study provides retailers and manufacturers with new marketing management insights from the perspective of consumers' anticipated regret behavior, and outlines the guidelines for them on invoking or mitigating consumers' regret to increase profit or demand at the right time.

Mathematics Subject Classification. 90B50, 90B70.

Received December 30, 2021. Accepted August 23, 2022.

1. Introduction

With the promulgation and implementation of series of green legislation as well as the increasing environmental concern of consumers, lots of manufacturers are aware the importance of the sustainable development and environmental management and have launched green operations to gain a competitive advantage in the market [22]. The development, production and marketing of green products are important parts of sustainable development [18]. When a firm introduces a new green product, competitions between green and non-green

Keywords. Anticipated regret, green products, greening level, pricing.

[1] College of Economics and Management, Zhengzhou University of Light Industry, Zhengzhou, P.R. China.
[2] College of Mechanical and Electrical Engineering, Zhengzhou University of Light Industry, Zhengzhou, P.R. China.
*Corresponding author: lililiu4117@163.com

© The authors. Published by EDP Sciences, ROADEF, SMAI 2022

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (https://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

products are unavoidable. Consumers can know the green attribute through the product introductions, but they are still uncertain about its true valuation [5]. Besides, The extant literature on psychology has provided a lot of evidence that uncertain preferences lead consumers have wrong valuations for the new product [12]. Therefore, consumers' environmental awareness also leads consumers to underestimate or overestimate the true valuation of the green product, eventually affects the price they're willing to pay [17]. More specifically, the higher a consumer environmental awareness is, the more he is willing to pay [8]. Since the new green product and the incumbent non-green product are substitute and the green product has price premium in the market, consumers' uncertain valuations of the new green product probably result in consumers experiencing post-purchase regret when they find that the forgone alternative would have been more preferable [21]. Such as, when a consumer chosen a new energy vehicle instead of a common petrol vehicle and then found some issues, *e.g.*, a limited driving range or fewer recharging points, he would regret having wasted money to buy this new energy vehicle with higher price. By contrast, if a consumer purchased a non-green product, and then found out that the green product was much better than he had expected before, he would regret too. When consumers experience post-purchase regret in their past green products consumption, they gradually anticipate the potential regret in the future and try to minimize it, eventually, their purchasing decisions will be affected [11,30]. So, when the manufacturer and retailer make decisions on price and the greening level of the green product, and the price of the non-green product, they need to consider the impact of consumers anticipated regret.

Given the significant effect of anticipated regret, understanding how consumers assess and make purchase decision between these competing products has been one of the significant factors for manufacturers and retailers in increasing the demand and realizing the potential value of green products [14] Therefore, this paper investigates the pricing and production problems in a green product supply chain with two competing products, when consumers have anticipated regret occurs. In this paper, the following questions are expected to be responded: (1) whether and how does anticipated regret affect consumers' purchase decision? (2) How does consumers' anticipated regret affect the greening level of the green product and the wholesale and retail prices of these two competing products? (3) How does consumers' anticipated regret influence the retail's and manufacturer' profits?

To address these research questions, we construct a game theoretic model under two scenarios to explore the impact of consumers' anticipated regret. In the model, there are two types of products, the non-green product and the green product which are substitute and complementary in function. Since consumers have different environmentally friendly propensity and different levels of knowledge with the green product, consumers' valuations are uncertain. And, they may experience two types of potential regret in the future: the regret from purchasing the green product (green product-purchase regret) and the regret from purchasing the non-green product (non-green product-purchase regret). The interactions between the manufacturer and retailer are modeled as a Stackelberg game where the manufacturer acts as the leader and the retailer acts as the follower. The manufacturer determines the greening level of the green product and wholesale prices of the two types of products, and the retailer decides the retail prices of them. We investigate the pricing and greening level strategies for members in the green product supply chain under two scenarios. The first scenario is called the normative benchmark model, in which consumers do not anticipate the potential regret, and the second one consists of the consumers' potential anticipated regret. We also analyze the impact of regret aversion on the optimal decisions and profits.

Compared with the present research, the main contribution of our paper in three ways. First, the green product and non-green product with the same functionality co-exist in the market, and the competition between them are unavoidable. Therefore, it is necessary to consider a supply chain consists of two competing products. Second, as mentioned before, anticipated regret has significant effect on consumers purchasing decisions, although lots of researches have been done on green supply chain, but none of them has taken consumers anticipated regret into account. This paper considers two types of anticipated regret, green product-purchase regret and non-green product-purchase regret, and compares two scenarios with and without anticipated regret to investigate the impact of the anticipated regret on the manufacturer's and the retailer's optimal decisions about both pricing and greening level and their profits.

This research offers some new insights on relevant research on the green product supply chain and anticipated regret. First, we find that the manufacturer and retailer can benefit or loss from consumers' two types of anticipated regret in equilibrium: comparing with the case in which consumers do not have any anticipated regret, when consumers' aversion to green product-purchase regret aversion is stronger (weaker), they will loss profit (benefit) from anticipated regret. Second, as the aversion to green product-purchase regret increases (or as the aversion to non-green product-purchase regret decreases), the optimal greening level and the manufacturer's and retailer's optimal profits decrease. And when consumers do not have green product-purchase regret and the non-green product-purchase regret aversion is large enough, the manufacturer's and retailer's optimal profits will reach the maximum. Third, the optimal wholesale and retail prices of the non-green product are not affected by the green product and consumers' anticipated regret in equilibrium.

This paper is organized as follows. In Section 2, we briefly review the related literature. In Section 3, we introduce our basic assumptions and notations and present a model without consumers' anticipated regret as a natural normative benchmark, then investigate the optimal pricing and greening level decisions in this case. After that, we construct the model with consumers' anticipated regret and explore its effect on the manufacturer's and retailer's optimal decisions. In Section 4, we present a numerical example to illustrate some insights. Finally, we summarize our insights in Section 5.

2. Literature review

For the substantial development, production and development cost of the green product, manufacturers need trade off the greening level and the investment [18]. Besides, consumers are also concerned about both the price and greenness when they choose from the green product and the non-green product with the same functionality. Therefore, the optimal decisions about both greening level and price of the two products are important issues for manufacturers and retailers. This work lies at the confluence of the green product supply chain literature and anticipated regret literature, which have received substantial interest recently. Therefore, we review the literature on the green product supply chain and anticipated regret.

2.1. The green product supply chain

Some research on the green product supply chain chiefly focuses on the supply chain with the green product only. As the substantial development cost and the uncertain demand of the green product, Li *et al.* [13] concentrated on the risk-averse of the manufacturer and retailer respectively and discussed the optimal decisions and profits in a green supply chain, finding that the product greenness and leader's profit are always higher in the manufacturer-led green product development model. Rahmani and Yavari [22] studied pricing and greening level decisions in a two-stage dual-channel supply chain comprising a manufacturer and a retailer under centralized and decentralized structures when the market demand of the green product was disrupted by unexpected events. Zhu and Wu [32] modeled a green product supply chain composed of two asymmetric retailers and a manufacturer and analyzed the impact of the retailers' strategic decisions on the introduction of a newer green product. Ma *et al.* [16] considered a two-stage supply chain with two competitive manufacturers and explored the optimal green manufacturing level, wholesale prices, retail prices and the profits of supply chain members under different models. Consumers' environmental awareness are always considered in analyses of pricing and production strategies. Considering consumers' environmental awareness levels, Shoaeinaeini *et al.* [24] conducted a mixed-integer non-linear programming model and explored a return rate for each customer zone and the optimal acquisition price in the green closed-loop supply chain. Owing the price difference between the green product and the common non-green product, Hong *et al.* [9] explored the impact of the consumers' reference behaviors on the green-product design and pricing decision by a Stackelberg model. Considering two different pricing strategies, Chen *et al.* [7] focused on reverse logistics of a green supply chain with environmentally-conscious customers and fond that it had an impact on the willingness to transfer the used product and the quantity recycled. Sarkar *et al.* [23] considered the environmental risks and constructed three models for two different

types of innovations, finding that the highly green innovative products performed better than the less innovative products. As a new product, consumers are uncertain about its true valuation. Xu and Duan [27] indicated that the block-chain technology can solve this issue, and retailers and consumers could benefit from it. With the entry of the green product, the competition with the non-green product may have impacts on the supply chain partners' performance. Jamali and Rasti-Barzoki [10] also indicated the competition between green and non-green products was essential and investigated the optimal price of two substitute products and the degree of greenness of the green product under two dual-channel supply chains. Similarly, Zhang *et al.* [31] expanded green chain with green and non-green products, they investigated the equilibrium results for two production modes in cooperative and non-cooperative game respectively and indicated that the production cost had an important impact on the choice of production modes.

Among the above literature, Jamali and Rasti-Barzoki [10] and Zhang *et al.* [31] are similar to this study, both of which consider the competition between the green and non-green product. Different from them, this paper considers consumers' anticipated regret. The reason is that green products are more expensive than the non-green product in general [5], and consumers' environmentally friendly propensity is uncertain, which are easy to lead consumers to regret over their purchase choices (non-green products or green products). Thus, it is necessary to incorporate anticipated regret into the green product supply chain management, and investigate its effect on the supply chain members' optimal decisions about both pricing and production.

2.2. Anticipated regret

Loomes and Sugden [15] incorporated the psychology concept–anticipated regret–into the expected utility theory to explain some choice anomalies under uncertainty, which cannot be explained by standard expected-utility theory. When consumers experienced regret they will try to minimize their disutility from post-purchase regret [6]. A vast body of research has indicated that anticipated regret can significantly influence individual's decisions in different fields, such as, work-family conflict [1], entrepreneurial intention [2], auctions [4], consumption action [26], impulse buying behavior [29]. Specifically, a group of researchers have investigated the effect of anticipated regret on consumers' and firms' decisions in different fields [3]. Focusing on the price markdowns in various industries, Özer and Zhang [20] constructed a consumer model and showed that anticipated regret and misconception of product availability affected consumers' purchase decisions and the optimal strategies of seller. Nasiry and Popescu [19] defined two types of anticipated regret-action regret and inaction regret, and indicated that they had significant effect on the consumers' advance purchase decisions and firm profits and policies, thus firms should respond to consumer regrets to maximize the profit in advance selling context. Yang *et al.* [28] explored how anticipated regret affects re-manufacturing strategies for an original equipment manufacturer, finding that anticipated regret did not always hurt his profit. When a firm introduced a new product, Jiang *et al.* [11] indicated that the consumers' anticipated regret had both positive and negative, non-monotonic effect on firms' profits and the level of innovation. Most of these research, except Jiang *et al.* [11], focuses on the anticipated regret stemming from the uncertain valuation for a particular product or service at different periods. This paper considers two substitute products, the non-green product and the green product, which have the same functionality and the only difference is that the green product has a green attribute.

Table 1 summarizes the related recent research on the green product supply chain and the anticipated regret. Focusing on the green product market where consumers' anticipated regret is prevalent, our paper contributes to the recent literature in three ways. First, compared to the deterministic estimation model usually used in supply chain, we construct a novel valuation model for these two substitute products that considers consumers' anticipated regret. This can portray consumers' purchasing decisions exactly. Second, this paper further explores the impact of anticipated regret on retailer's and manufacturer's optimal decisions about both pricing and greening level. Third, our study facilitates retailers and manufacturers in the green products supply chain with new marketing management insights from the perspective of consumers' regret behavior, and outlines the guidelines for retailers and manufacturers on invoking or mitigating consumers' regret to increase profitability or demand of green products at the right time.

TABLE 1. Selected recent studies on the green product supply chain and anticipated regret.

Research perspective	Task	Considering the Substitute Products
Risk-averse [13]	Investigating the optimal greenness decision and profits	No
Demand disruptions [22]	Investigating the optimal pricing and greening level decisions	No
The retailers' strategic decisions [32]	Investigating the introduction of a newer green product	No
Consumers' environmental awareness [24]	Investigating the return rate for each customer zone and the optimal acquisition price	No
Consumers' environmental awareness [7]	Investigating the willingness to transfer the used product and the quantity recycled	No
Consumers' reference behaviors [9]	Investigating the green-product design and pricing decision	Yes
Hybrid production [31]	Investigating the optimal pricing and coordination strategy	Yes
Competition between green and non-green products [10]	Investigating the optimal price of two substitute products and the degree of greenness	Yes
Anticipated regret [20]	Investigating the impact on consumers' purchase decisions and the optimal strategies of seller	No
Anticipated regret [28]	Investigating the re-manufacturing strategies for an original equipment manufacturer	No
Anticipated regret [11]	Investigating the firms' optimal profits and the level of innovation	Yes

3. THE MODEL

Consider a supply chain with one manufacturer and one retailer. The manufacturer offers non-green products (denoted by C) and green products (denoted by G) and delivers them to the retailer, and then the retailer sells them to the demand market. A consumer buys at most one product from the retailer. The retailer is risk-neutral and maximizes its profit by deciding the retail prices of two types of products. The manufacturer needs to determine the greening level of the green product and the wholesale prices of two types of products, and he is risk-neutral too.

The non-green product has a basic attribute, denoted by a_1. Without loss of generality, the quality for the non-green product is normalized to 1, and the marginal cost of production is normalized to 0. The green product has, in addition to the same baseline attribute a_1 as the non-green product, an environmentally friendly attribute, denoted by a_2. The green product has a greening level of $q(0 < q < 1)$ for attribute. This greening level q represents the level of environmental protection. The research and development and other relevant expenditures of the green product is $\frac{1}{2}tq^2$, t is the fixed cost coefficient, according to the green product design literature [18]. This convex cost function captures the increasing difficulty of developing and improving the green product's eco-friendly level. After successful development, the marginal cost of green products may be higher or lower than that of non-green products. Therefore, it is also normalized to 0 in this paper to reduce the mathematical complexity. w_C and w_G are the wholesale prices of the non-green product and green product, and $w_G > w_C$. Accordingly, the price of the green product paid by consumer p_G is bigger than that of the non-green product p_C, *i.e.*, $p_G > p_C$.

There is a unit mass of consumers in the market, each of whom buys at most one product. v is a consumer's willingness to pay for quality of the basic attribute a_1. Therefore, a consumer's expected valuation for the non-green product is v, and the distribution of it is distributed uniformly over $[0, 1]$. Consumers are different in environmentally friendly propensity, and their preference for green attribute can be either high or low. θ

is consumer's willingness to pay for quality of the green attribute a_2, and θ is distributed uniformly. Each consumer purchases at most one of the two substitute products, and they want to maximize his utility. Before purchase, as consumers may have different levels of knowledge with the green attribute and environmentally friendly propensity, consumers are uncertain about their actual valuations of the green attribute. For simplicity, we assume that the prior probability that consumers will have a high valuation for greening level is $\frac{1}{2}$, and $\theta = v$ after purchasing and experiencing the product. By contrast, the prior probability that consumers will have a low valuation is $\frac{1}{2}$ too, and now $\theta = 0$. Therefore, a consumer's expected valuation for a green product is $v + \frac{1}{2}vq$.

In the equilibrium model, it is crucial to consider players' decisions and interdependence relations. Since the research and development of the green product needs high-technology and massive investment, manufacturer being the leader is a common scenario, in this paper, we model the interactions among the market participants with the following 2-stage game where the manufacturer acts as the leader and the retailer acts as the follower. At stage 1, the manufacturer decides the greening level q and the wholesale prices of the common and green products (*i.e.*, w_C and w_G). And then, at stage 2, the retailer sets the retail prices of the two substitute products (*i.e.*, p_C and p_G). Lastly, consumers make purchase decisions according to their valuations.

3.1. Benchmark case: no anticipated regret

3.1.1. The model under no anticipated regret

In this section, we present a model as a benchmark in which consumers have no anticipated regret. The ex-ante expected utilities from purchasing a non-green product C and a green product G are as follows:

$$u_C = v - p_C \tag{3.1}$$

$$u_G = v + \frac{1}{2}vq - p_G. \tag{3.2}$$

Let v^* denote the willingness to pay of a consumer who is indifferent between buying a green product and a non-green product, *i.e.*, $u_C = u_G$, and we obtain $v^* = \frac{2(p_G - p_C)}{q}$. When a consumer's valuation of a product is smaller than v^*, he will buy a non-green product; a consumer with $v > v^*$ will choose a green product. Thus, the demands for the non-green product D_C and the green product D_G are:

$$D_C = \int\limits_{u_C>0, u_C>u_G, 1>v>0} 1 \, \mathrm{d}v = \frac{2(p_G - p_C)}{q} - p_C \tag{3.3}$$

$$D_G = \int\limits_{u_G>0, u_G>u_C, 1>v>0} 1 \, \mathrm{d}v = 1 - \frac{2(p_G - p_C)}{q}. \tag{3.4}$$

Hence, the manufacturer's and the retailer's profits are:

$$\Pi_m = w_G \cdot D_G + w_C \cdot D_C - \frac{1}{2}tq^2 \tag{3.5}$$

$$\Pi_r = (p_G - w_G) \cdot D_G + (p_C - w_C) \cdot D_C. \tag{3.6}$$

3.1.2. the equilibrium under no anticipated regret

We solve for the equilibrium to have the optimal strategies for the retailer and the manufacturer using backward induction. Specifically, first, we find the retailer's optimal retail prices at stage 2. Next, we derive the manufacturer's optimal wholesale prices and greening level at stage 1, which fully characterizes the equilibrium.

(1) Stage 2

At this stage, the retailer needs to figure out the following problem:

$$\max \Pi_{r-s2} = (p_G - w_G) \cdot D_G + (p_C - w_C) \cdot D_C$$
$$\text{s.t.} \quad \begin{cases} p_G > p_C > 0 \\ p_G > w_G > 0 \\ p_C > w_C > 0, \\ w_G > w_C > 0, \\ 1 > q > 0, \\ t > 0. \end{cases}$$

Lemma 3.1. *Under no anticipated regret, when the wholesale prices of these two substitute products and greening level have been set by manufacturer at stage 1. (a) the retailer's profit function Π_{r-s2} is a strictly jointly concave function with retail prices of the green product p_G and the non-green product p_C. (b) the retailer's optimal prices of non-green product p^*_{C-s2} and green product p^*_{G-s2} at stage 2 are:*

$$p^*_{C-s2} = \frac{1 + w_C}{2} \tag{3.7}$$
$$p^*_{G-s2} = \frac{1}{4}(q + 2 + 2 \cdot w_G). \tag{3.8}$$

Proof. Given the greening level of the green product and the wholesale prices of these two substitute products, combining equations (3.3) and (3.4) to the retailer's profit, we can obtain that $\frac{\partial^2 \Pi_r}{\partial p_G^2} < 0$, $\frac{\partial^2 \Pi_r}{\partial p_C^2} < 0$ and $\frac{\partial^2 \Pi_r}{\partial p_G^2} \cdot \frac{\partial^2 \Pi_r}{\partial p_C^2} - \left(\frac{\partial^2 \Pi_r}{\partial p_G \partial p_C}\right)^2 > 0$. Thus, the Hesse matrix is a negative definite matrix, that is, Π_r is strictly jointly concave in p_G and p_C. And then, let the first derivative of the retailer's profit with respect to p_G and p_C be zero, and we can obtain p^*_{G-s2} and p^*_{C-s2} by solving these equations. □

Combining equations (3.7) and (3.8) to (3.3) and (3.4) gives the demand for these two substitute products: $D_C = \frac{2w_G - 2w_C - qw_C}{2q}$, $D_G = \frac{q - 2(w_G - w_C)}{2q}$. It is not difficult to find that if the manufacturer improves the greening level of green products, the demand for the green product increases, but the demand for the non-green product decreases; however, when the greening level is smaller than twice the wholesale price difference between these two types of products, the demand for green product is 0. When the wholesale price of green product increases, the demand for it decreases, but the demand for the non-green product increases.

Corollary 3.2. *Under no anticipated regret, at stage 2, when $q < 2(w_G - w_C)$, retailer's profit Π^*_{r-s2} decreases with the greening level q but increases with the wholesale price of the green product w_G; when $q > 2(w_G - w_C)$, the retailer's profit Π^*_{r-s2} increases with the greening level q but decreases with the wholesale price of the green product w_G.*

Proof. Form equations (3.6)–(3.8), we have

$$\Pi^*_{r-s2} = \frac{q^2 + q \cdot (2w_C - 4w_G + 2) + 4 \cdot (w_G - w_C)^2}{8q}.$$

Then, $\frac{\partial^2 \Pi^*_{r-s2}}{\partial q^2} = \frac{(w_G - w_C)^2}{q^3}$, $\frac{\partial^2 \Pi^*_{r-s2}}{\partial q \partial w_G} = -\frac{w_G - w_C}{q^2}$, $\frac{\partial^2 \Pi^*_{r-s2}}{\partial w_G^2} = \frac{1}{q}$. After simple calculation, we obtain that its Hesse matrix is a positive semi-definiteness matrix. Hence, Π^*_{r-s2} is a convex function in q and w_G.

$\frac{\partial \Pi^*_{r-s2}}{\partial q} = \frac{q - 2(w_G - w_C)(q + 2(w_G - w_C))}{8q^2}$, when $q > 2(w_G - w_C)$, $\frac{\partial \Pi^*_{r-s2}}{\partial q}$ is positive, and when $q < 2(w_G - w_C)$, $\frac{\partial \Pi^*_{r-s2}}{\partial q}$ is smaller than 0. In the same way, we obtain that when $q > 2(w_G - w_C)$, $\frac{\partial \Pi^*_{r-s2}}{\partial w_G} < 0$; and when $q < 2(w_G - w_C)$, $\frac{\partial \Pi^*_{r-s2}}{\partial w_G} > 0$. □

From Corollary 3.2, we know that the retailer's profit is affected not only by the greening level but also by the wholesale price difference between these two substitute products. The intuition is as follows. When the greening level is higher than twice the wholesale price difference between these two substitute products (*i.e.*, $q > 2(w_G - w_C)$), the unit profit of green products is bigger than non-green products. Therefore, when the greening level increases, the demand for the green product D_G increases, and eventually the retailer's profit increases. By contrast, when the greening level of the green product is lower than $2(w_G - w_C)$, the demand for the green product D_G is 0. Therefore, as the greening level increases, the demand for the non-green product D_C decreases, naturally, the retailer's profit decreases. Similarly, when $q > 2(w_G - w_C)$, the unit profit of the green product is bigger, however, when wholesale price of it increases the demand for green product D_G decreases, eventually the retailer's optimal profit decrease. When $q < 2(w_G - w_C)$, the demand for green product D_G is 0, consumers prefer non-green product to green product. When the wholesale price of the green product increases the demand for non-green product D_C increases, and the unit profit of the non-green product is bigger now, thus the retailer's optimal profit will increase.

(2) Stage 1

Having the optimal retail prices of these two substitute products at stage 2, we now consider manufacturer's optimal strategies at stage 1. Specifically, following Lemma 1, the profit of the manufacturer is

$$\Pi_m = \frac{w_G}{2} - \frac{w_G^2}{q} + \frac{2w_G w_C}{q} - \frac{w_C^2}{q} - \frac{w_C^2}{2} - \frac{1}{2}tq^2. \tag{3.9}$$

Equation (3.9) shows that if the wholesale prices of these two types of products are given, the impact of greening level on the manufacturer's profit is non-monotonic and there is a maximum point $\left(\frac{\partial^2 \Pi_m}{\partial q^2} < 0\right)$. As greening level increases, the manufacturer's profit first increases and then decreases, and when $q = \frac{(w_G - w_C)^{\frac{2}{3}}}{t^{\frac{1}{3}}}$ it reaches the maximum.

Lemma 3.3. *Under no anticipated regret, manufacturer's profit function Π_m is a strictly jointly concave function with greening level q and wholesale prices of green product w_G and non-green products w_C.*

Proof. From equation (3.9), we can obtain $\frac{\partial^2 \Pi_m}{\partial q^2} = -\frac{2w_G^2 + 4w_G w_C - 2w_C^2}{q^3} - t$, $\frac{\partial^2 \Pi_m}{\partial w_G^2} = -\frac{2}{q}$, $\frac{\partial^2 \Pi_m}{\partial w_C^2} = -\frac{2}{q} - 1$, they are negative. And from $\frac{\partial^2 \Pi_m}{\partial w_G \partial w_C} = \frac{2}{q}$, $\frac{\partial^2 \Pi_m}{\partial w_G \partial q} = \frac{2(w_G - w_C)}{q^2}$, and $\frac{\partial^2 \Pi_m}{\partial w_C \partial q} = -\frac{2(w_G - w_C)}{q^2}$, we obtain that its Hesse matrix is a symmetric negative definite matrix by calculation, thus Π_m is a strictly jointly concave function with q, w_G, and w_C. □

Thus, the objective function Π_m has an optimal solution.

Proposition 3.4. *Under no anticipated regret, the equilibrium greening level q^*, wholesale prices of the non-green product w_C^* and the green product w_G^*, and retail prices of the non-green product p_C^* and the green product p_G^* are as follows.*

$$q^* = \frac{1}{16t},\ w_C^* = \frac{1}{2},\ w_G^* = \frac{1}{2} + \frac{1}{64t},\ p_C^* = \frac{3}{4},\ p_G^* = \frac{3}{4} + \frac{3}{128t}.$$

Proof. Let the first derivative of manufacturer's profit with respect to q, w_G, and w_C be zero,

$$\frac{\partial \Pi_m}{\partial w_G} = \frac{1}{2} - \frac{2w_G}{q} + \frac{2w_C}{q} = 0 \tag{3.10}$$

$$\frac{\partial \Pi_m}{\partial w_C} = \frac{2w_G}{q} - \frac{2w_C}{q} - w_C = 0 \tag{3.11}$$

$$\frac{\partial \Pi_m}{\partial q} = \frac{w_G^2}{q^2} - \frac{2w_G w_C}{q^2} + \frac{w_C^2}{q^2} - tq = 0. \tag{3.12}$$

From equations (3.10) and (3.11), the equilibrium wholesale price of the non-green product is $w_C^* = \frac{1}{2}$. Then we obtain $w_G^* = \frac{1}{2} + \frac{1}{64t}$, therefore, in equilibrium the optimal greening level q^* is $\frac{1}{16t}$. And then we can get the optimal retail prices of the two types of products: $p_C^* = \frac{3}{4}$, $p_G^* = \frac{3}{4} + \frac{3}{128t}$. □

According to Proposition 3.4, under no anticipated regret, the green product doesn't affect the non-green product's equilibrium wholesale and retail prices that are constant. In equilibrium, the optimal profits of the retailer and manufacturer are $\Pi_r^* = \frac{1}{16} + \frac{1}{512t}$ and $\Pi_m^* = \frac{1}{8} + \frac{1}{512t}$. It is obvious that the manufacturer's profit is $\frac{1}{16}$ higher than that of retailer in equilibrium.

3.2. Analysis with anticipate regret

3.2.1. The model under anticipated regret

In this section, we consider the optimal strategies for retailer and manufacturer when consumers have anticipated potential purchase regret. At the time of purchase, a consumer is uncertain about the true value he will derive from the green product. He can know the actual value either through direct usage experience or word-of-mouth from other consumers who bought it. When he finds out that the utility of the product he purchased is lower than that of the forgone alternative, he will regret. The regret is classified into two different types in this paper. The first type of regret arises from purchasing a non-green product, *i.e.*, a consumer purchased a non-green product and ended up with the awareness that the true value of the green product is much more than he had expected, and he would have been better off if he had purchased the green product. By contrast, the second type of regret occurs from purchasing a green product, *i.e.*, a consumer bought a green product and found out that its green attribute is not as much as he had expected, he would have gained a higher utility if he had chosen the non-green product. We refer to the former type of regret as "non-green product-purchase regret" and the latter type as "green product-purchase regret". The regret consumers experience in the past consumption leads them to anticipate the potential regret when making a purchase decision in the future. Let parameter r_C $(0 \le r_C \le 1)$ measure consumers' aversion to non-green product-purchase regret, and r_G $(0 \le r_G \le 1)$measure the consumers' aversion to green product-purchase regret. To facilitate expression and analysis, we define the regret function $\rho = \frac{1+r_G}{1+r_C}$, which is an indicator of consumers' relative propensity of regret. Obviously, $\frac{1}{2} \le \rho \le 2$ and it increases with r_G but decreases with r_C. When $\rho > 1$ (*i.e.*, $r_G > r_C$), consumers are more sensitive to the regret from buying a green product than a non-green product; when $\rho < 1$ (*i.e.*, $r_G < r_C$), this case corresponds to the situation in which a consumer's aversion to green product-purchase regret is lower than his non-green product-purchase regret; when $\rho = 1$, it represents $r_G = r_C$.

When a consumer finds that the forgone alternative would have given him a higher utility than his actual choice, he will experience some regret. As mentioned before, we assume that the prior probability that a consumer will have a higher (or a lower) valuation for the green product is 1/2 after purchasing, therefore, the probability of a consumer experiencing regret also is 1/2. Based on the model of Niladri *et al.* [25], we introduce a linear regret term to express the consumer's disutility of potential outcomes brought by anticipated regret. Thus, consumer's expected utility from purchasing a non-green product C or a green product G are equal to

$$u_C = v - p_C - \frac{1}{2} r_C (vq - p_G + p_C) \tag{3.13}$$

$$u_G = v + \frac{1}{2} vq - p_G - \frac{1}{2} r_G (p_G - p_C). \tag{3.14}$$

Then the willingness to pay of a consumer who is indifferent between buying a green product and a non-green product v^* equals $\frac{p_G - p_C}{q} \cdot (\rho + 1)$. As in the benchmark case, when a consumer's valuation of the product is smaller than v^* (*i.e.*, $v < v^*$), he will choose a non-green product, otherwise, he will buy a green product. Thus, when consumers have anticipated regret, the demands for the non-green product D_C and the green product D_G are:

$$D_C = \int\limits_{u_C > 0, u_C > u_G, 1 > v > 0} 1 dv = \frac{(\rho + 1)(p_G - p_C)}{q} - p_C \tag{3.15}$$

$$D_G = \int_{u_G>0, u_G>u_C, 1>v>0} 1dv = 1 - \frac{(\rho+1)(p_G - p_C)}{q}. \tag{3.16}$$

Given p_G, p_C and q, as the consumer's green product-purchase regret increases or non-green product-purchase regret decreases (*i.e.*, ρ increases), the willingness to pay of a consumer who is indifferent between buying the green product and the non-green product v^* increases, eventually demand for green products decreases but demand for non-green products increases.

Hence, when consumers have anticipated regret, the profits of the manufacturer and the retailer are:

$$\Pi_m = w_G \cdot D_G + w_C \cdot D_C - \frac{1}{2}tq^2 \tag{3.17}$$

$$\Pi_r = (p_G - w_G) \cdot D_G + (p_C - w_C) \cdot D_C. \tag{3.18}$$

3.2.2. The equilibrium under anticipated regret

Now, we will analyze the optimal strategies for the retailer and manufacturer in the context where consumers have anticipated regret.

(1) Stage 2

Lemma 3.5. *When consumers have anticipated regret, and the wholesale prices of these two substitute products and greening level have been set by manufacturer at stage 1. (a) the retailer's profit function Π_r is a strictly jointly concave function with retail prices of the green product and the non-green product at stage 2. (b) the retailer's optimal prices of the non-green product p^*_{C-s2} and green product p^*_{G-s2} at stage 2 are:*

$$p^*_{C-s2} = \frac{1 + w_C}{2} \tag{3.19}$$

$$p^*_{G-s2} = \frac{q + (\rho+1) + (\rho+1) \cdot w_G}{2(\rho+1)}. \tag{3.20}$$

Proof. From equation (3.18), We obtain the second derivative of p_G and p_C are $\frac{\partial^2 \Pi_r}{\partial p_G^2} = -\frac{2(\rho+1)}{q} < 0$, $\frac{\partial^2 \Pi_r}{\partial p_C^2} = \frac{2(\rho+1)}{q} - 2 < 0$ and $\frac{\partial^2 \Pi_r}{\partial p_G \partial p_C} = \frac{2(\rho+1)}{q}$. Thus, $\frac{\partial^2 \Pi_r}{\partial p_G^2} \cdot \frac{\partial^2 \Pi_r}{\partial p_C^2} - \left(\frac{\partial^2 \Pi_r}{\partial p_G \partial p_C}\right)^2 = \frac{4(\rho+1)}{q} > 0$. Therefore, Π_r is a strictly jointly concave function with p_G and p_C.

As in the benchmark case, when consumers have anticipated regret, the objective function Π_r is also a jointly concave function with p_G and p_C, and continuously differentiable, thus there is an optimal prices p_G and p_C. Let the first derivative of the retailer's profit with respect to p_G and p_C be zero, and then, we can obtain p^*_{G-s2} and p^*_{C-s2} by solving these equations. □

At stage 2, consumers' anticipated regret and the green product have no impact on the optimal retail price of the non-green product. By contrast, when consumers' aversion to green product-purchase regret increases r_G (*i.e.*, ρ increases), consumers' expected utility from the green product decrease. Thus, retailer should lower its price to convince the customer to buy.

Corollary 3.6. *When consumers have anticipated regret, and the wholesale prices of these two substitute products and greening level have been set by the manufacturer at stage 1, the retailer's optimal profit Π^*_{r-s2} showed an inverted U-shaped relationship with ρ, and when $\rho = 1$, the retailer's optimal profit reaches its maximum at stage 2.*

Proof. Form equations (3.18)–(3.20), we have

$$\Pi^*_{r-s2} = \frac{\left(q(w_C^2 - 1)^2 + 2(w_G - w_C)^2\right)(\rho+1)^2 + 2(\rho+1)q^2 - 2q^2}{4(\rho+1)^2 q}.$$

And then, $\frac{\partial^2 \Pi^*_{r-s2}}{\partial \rho^2} \leq 0$, so Π^*_{r-s2} is a concave function with ρ. Since $\frac{\partial^2 \Pi^*_{r-s2}}{\partial \rho^2} = \frac{-q}{2^4}$ is less than 0 at critical point $\rho = 1$, Π^*_{r-s2} has a maximum at this critical point. □

Corollary 3.6 states that, given q, w_G, and w_C, the impact of anticipated regret on the retailer's profit is non-monotonic. When $\rho < 1$ (*i.e.*, $r_G < r_C$), that is, consumers are more sensitive to non-green product-purchase regret, the retailer's profit increases with ρ. And the retailer's optimal profit at stage 2 will reach the maximum when $\rho = 1$ (*i.e.*, $r_G = r_C$). This is intuitive, because an increase in aversion to non-green product-purchase regret or green product-purchase regret will both lead to a higher disutility, and eventually influence the demand.

(2) Stage 1

Having the optimal retail prices of these two substitute products, we can now deduce the manufacturer's optimal strategies. Combining equations (3.19), (3.20) into (3.17), the profit of manufacturer is

$$\Pi_m = \frac{w_G}{2} - \frac{(\rho+1)w_G^2}{2q} + \frac{(\rho+1)w_G w_C}{q} - \frac{(\rho+1)w_C^2}{2q} - \frac{w_C^2}{2} - \frac{1}{2}tq^2. \tag{3.21}$$

Lemma 3.7. *When consumers have anticipated regret, the manufacturer's profit function Π_m is a strictly jointly concave function with greening level q and wholesale prices of these substitute products, w_G, and w_C.*

Proof. From equation (3.21), we obtain $\frac{\partial^2 \Pi_m}{\partial w_G^2} = -\frac{\rho+1}{q}$, $\frac{\partial^2 \Pi_m}{\partial w_C^2} = -\frac{\rho+1}{q} - 1$, $\frac{\partial^2 \Pi_m}{\partial w_G \partial w_C} = \frac{\rho+1}{q}$, $\frac{\partial^2 \Pi_m}{\partial q^2} = \frac{-(\rho+1)w_G^2 + (\rho+1)2w_G w_C - (\rho+1)w_C^2}{q^3} - t$, $\frac{\partial^2 \Pi_m}{\partial w_G \partial q} = \frac{(\rho+1)(w_G - w_C)}{q^2}$, $\frac{\partial^2 \Pi_m}{\partial w_C \partial q} = -\frac{(\rho+1)(w_G - w_C)}{q^2}$.

Therefore, its Hesse matrix is a symmetric negative definite matrix, therefore Π_m is a strictly jointly concave function with q, w_G, and w_C. □

Proposition 3.8. *When consumers have anticipated regret, in equilibrium, the optimal greening level q^*, wholesale prices and retail prices of the substitute products, w_C^*, w_G^*, p_C^* and p_G^* are as follows:*

$$q^* = \frac{1}{8t(\rho+1)},\ w_G^* = \frac{1}{2} + \frac{1}{16t(\rho+1)^2},\ w_C^* = \frac{1}{2},\ \ p_C^* = \frac{3}{4},\ p_G^* = \frac{3}{4} + \frac{3}{32t(\rho+1)^2}.$$

Proof. Let the first derivative of manufacturer's profit with respect to q, w_G, and w_C be zero,

$$\frac{\partial \Pi_m}{\partial w_G} = \frac{1}{2} - \frac{(\rho+1)w_G}{q} + \frac{(\rho+1)w_C}{q} = 0 \tag{3.22}$$

$$\frac{\partial \Pi_m}{\partial w_C} = \frac{(\rho+1)w_G}{q} - \frac{(\rho+1)w_C}{q} - w_C = 0 \tag{3.23}$$

$$\frac{\partial \Pi_m}{\partial q} = \frac{(\rho+1)w_G^2}{2q^2} - \frac{(\rho+1)w_G w_C}{q^2} + \frac{(\rho+1)w_C^2}{2q^2} - tq = 0. \tag{3.24}$$

From (3.22) and (3.23), we obtain $w_C^* = \frac{1}{2}$, $w_G^* = \frac{1}{2} + \frac{1}{16t(\rho+1)^2}$ ($\frac{1}{2}$ discarded), and $q^* = \frac{1}{8t(\rho+1)}$. And then we can now reformulate the optimal retail prices of the two types of products: $p_C^* = \frac{3}{4}$, $p_G^* = \frac{3}{4} + \frac{3}{32t(\rho+1)^2}$. □

Proposition 3.8 gives the optimal pricing and production strategies for the retailer and the manufacturer under anticipated regret. When consumers have anticipated regret, in equilibrium, the equilibrium wholesale price and retail price of the non-green product are constant, $\frac{1}{2}$ and $\frac{3}{4}$, which are not affected by the green product and consumers' anticipated regret. For the green product, its optimal wholesale price is $\frac{1}{2} + \frac{(1+r_C)^2}{16t(2+r_C+r_G)^2}$, and retail price is $\frac{3}{4} + \frac{3(1+r_C)^2}{32t(2+r_C+r_G)^2}$. The optimal profits of the retailer and manufacturer are $\Pi_r^* = \frac{1}{16} + \frac{1}{128t(\rho+1)^2}$ and $\Pi_m^* = \frac{1}{8} + \frac{1}{128t(\rho+1)^2}$. The manufacturer's profit is $\frac{1}{16}$ higher that of retailer, and cannot be effect by consumers' anticipated regret and the greening level, which is similar to the conclusion in the benchmark model.

Next, we will characterize the way consumers' anticipated regret affects the retailer's and manufacturer's equilibrium profits elaborately.

Corollary 3.9. *In equilibrium, the optimal wholesale and retail price, and the greening level of the green product increase with non-green product-purchase regret but decrease with green product-purchase regret, i.e.,* $\frac{\partial w_G^*}{\partial r_C} > 0$, $\frac{\partial w_G^*}{\partial r_G} < 0$, $\frac{\partial p_G^*}{\partial r_C} > 0$, $\frac{\partial p_G^*}{\partial r_G} < 0$, $\frac{\partial q^*}{\partial r_C} > 0$, $\frac{\partial q^*}{\partial r_G} < 0$.

It shows that when consumers' aversion to green product-purchase regret (common-purchase regret) decreases (increases), the greening level increases. The intuition is as follows. When consumers' aversion to green product-purchase regret increases, their disutility from the green product increase. Thus, the manufacturer should reduce the greening level to mitigate the negative impact of green product-purchase regret.

Corollary 3.10. *In equilibrium, when* $1 < \rho \leq 2$, *i.e.,* $r_C < r_G$, *the retailer's and manufacturer's optimal profits under anticipated regret are smaller than those in the case without anticipated regret; when* $\rho = 1$, *i.e.,* $r_C = r_G$, *their optimal profits are the same as those in the case without anticipated regret; when* $\frac{1}{2} < \rho < 1$, *i.e.,* $r_C > r_G$, *their optimal profits under anticipated regret is higher than those in the case without anticipated regret; when* $\rho = \frac{1}{2}$, *i.e.,* $r_C = 1$ *and* $r_G = 0$ *their optimal profits reach the maximum.*

Corollary 3.10 shows the retailer and manufacturer can benefit or loss profit from consumers' two types of anticipated regret in equilibrium. Comparing with the case without consumers' anticipated regret, when consumers' aversion to green product-purchase regret is higher than that of non-green product-purchase regret, their optimal profits are smaller. That is, anticipated regret hurts their profits. When consumers have the same propensities for green product-purchase regret and non-green product-purchase regret, the retailer and manufacturer have the same optimal profits as in the case without anticipated regret. When consumers' aversion to green product-purchase regret is lower than non-green product-purchase, the retailer and manufacturer can benefit from consumers' anticipated regret. And if consumers' non-green product-purchase regret reaches the maximum, and green product-purchase regret reaches the minimum (that is, consumers will not regret purchasing green product but certainly regret purchasing non-green product), their optimal profits reach the maximum. In this situation, the profit from the green product is more than offset the profit loss from the non-green product. Therefore, the retailer and manufacturer can adopt different approaches to evoke consumers' non-green product-purchase regret and alleviate their green product-purchase regret to increase their profits.

Corollary 3.11. *When consumers have anticipated regret, in equilibrium, the retailer's and manufacturer's optimal profits increase with non-green product-purchase regret but decrease with green product-purchase regret.*

Proof. From $\rho = \frac{1+r_G}{1+r_C}$, the retailer's and manufacturer's optimal profits are

$$\Pi_r^* = \frac{1}{16} + \frac{(1+r_C)^2}{128t(2+r_C+r_G)^2} \quad \text{and} \quad \Pi_m^* = \frac{1}{8} + \frac{(1+r_C)^2}{128t(2+r_C+r_G)^2}.$$

Since $\frac{\partial \Pi_m^*}{\partial r_C} = \frac{\partial \Pi_r^*}{\partial r_C} > 0$ and $\frac{\partial \Pi_m^*}{\partial r_G} = \frac{\partial \Pi_r^*}{\partial r_G} < 0$, their optimal profits increase with the non-green product-purchase regret but decrease with green product-purchase regret in equilibrium. □

4. Numerical study

In this section, we conduct a numerical study to assess the robustness of the results derived before by Maple16. Satisfied the constrain in the model, we set the parameter for the coefficient of fixed cost function of green product t to be 6. Considering that the non-green product's production technique is mature and the cost is constant in the long run, we set the wholesale price of it to be $\frac{1}{2}$ in all the numerical experiments.

(1) Case 1 without consumers' anticipated regret.

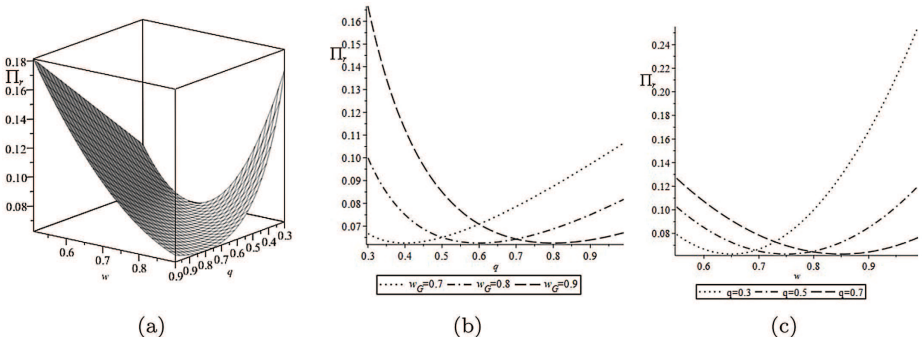

FIGURE 1. The effect of greening level and wholesale price of green product on the retailer's optimal profit.

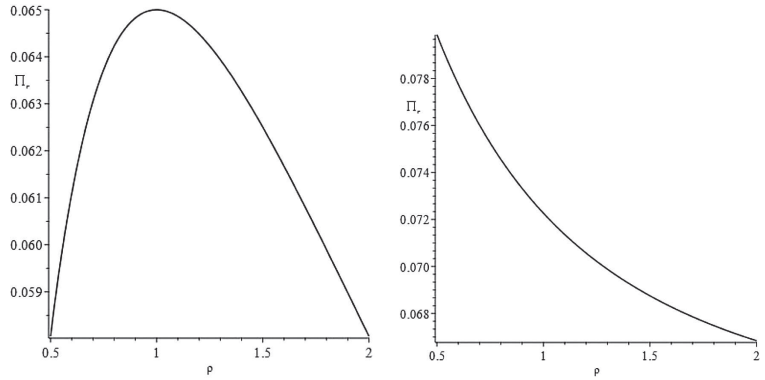

FIGURE 2. The effect of consumers' anticipated regret on the retailer's optimal profit.

Figure 1 plots the impact of greening level and wholesale price of the green product on the retailer's optimal profit when consumers don't have anticipated regret. Figure 1a provides a representative illustration of Corollary 3.2 and shows that the retailer's optimal profit is a convex function with the greening level q and wholesale price w_G. Figure 1b shows that given wholesale price of the green product, the retailer's optimal profit has a U-shaped relationship with greening level. For example, if $w_G = 0.7$, when $q < 0.4$ (*i.e.*, $q < 2w_G - 1$) the retailer's optimal profit decrease with greening level; it reaches its minimum when $q = 0.4$ (*i.e.*, $q = 2w_G - 1$); and when $q > 0.4$ (*i.e.*, $q > 2w_G - 1$), an increase in greening level will increase retailer's optimal profit. Similarly, given greening level, the retailer's optimal profit has a U-shaped relationship with the wholesale price of the green product (see Fig. 1c for the case $q = 0.3, 0.5, 0.7$ respectively). The results in the second and third graphs are consistent with Corollary 3.2.

(2) Case 2 with consumers' anticipated regret.

Figure 2 plots the impact of consumers' anticipated regret on the retailer's optimal profit.

Figure 2a shows that given the greening level and wholesale price of the green product ($w_G = 0.7$, $q = 0.5$), the retailer's optimal profit shows an inverted U-shaped relationship with ρ, and when $\rho = 1$, it reaches maximum. Thus, in practice, when the greening level and wholesale price of the green product have been determined by manufacturer, the retailer should focus on the difference between the two types of consumers' anticipated regret and adopt different approaches to decrease this difference.

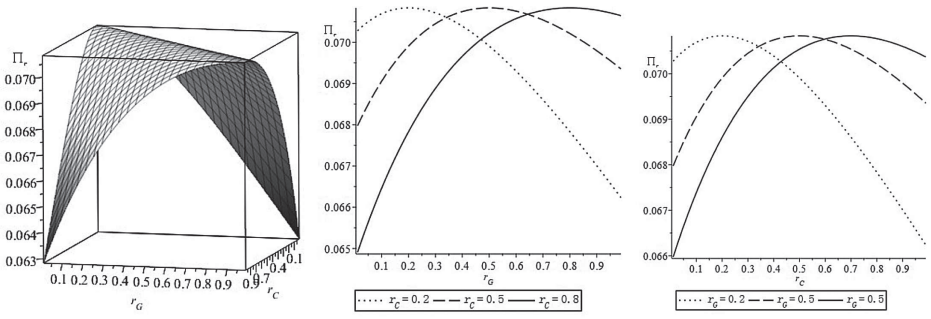

FIGURE 3. The effect of anticipated regret on the retailer's optimal profit when the greening level and wholesale price are given.

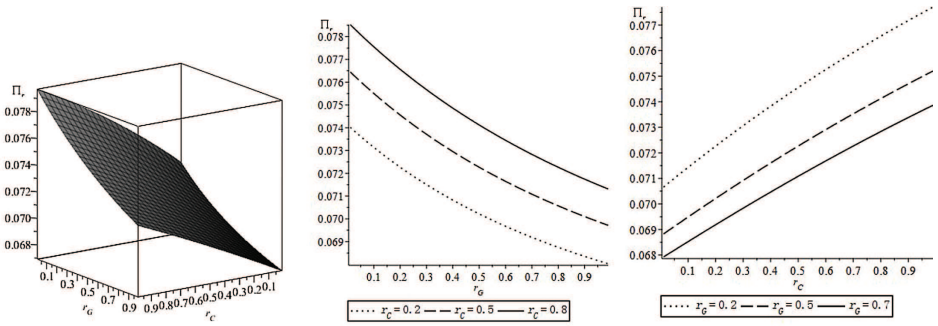

FIGURE 4. The effect of anticipated regret on the retailer's optimal profit in equilibrium.

Since the manufacture's profit is $\frac{1}{16}$ higher that of retailer in equilibrium, Figure 2b only illustrates the impact of ρ on retailer's optimal profit. Comparing with Figure 2a, Figure 2b shows that the retailer's profit decreases with ρ in equilibrium.

Figure 3 elaborates how consumers' green product-purchase regret and non-green product-purchase regret affect retailer's optimal profit when the greening level and wholesale price of the green product have been determined by manufacturer ($w_G = 0.7$, $q = 0.5$). As illustrated in Figure 3a, when the difference between product-purchase regret and non-green product-purchase regret is high, no matter which one is bigger, the retailer's profit is lower, which is consistent with Corollary 3.6. Furthermore, Figures 3b and 3c indicate that if consumers' green (common) product-purchase regret is a constant, retailer's optimal profit shows an inverted U-shaped relationship with non-green (green) product-purchase regret, and reaches the maximum at the point $r_C = r_G$.

In equilibrium, since the manufacturer's optimal profit is bigger than that of the retailer $\frac{1}{16}$, they have the same relationship with green product-purchase regret and non-green product-purchase regret. Thus, we will only elaborate how consumers' anticipated regret affects retailer's optimal profit too. Comparing to the case where the greening level and wholesale price of the green product have been determined by manufacturer as illustrated in Figure 3, Figure 4 shows that two types of regret have different effect on retailer's optimal profit in equilibrium. Figures 4a–4c indicate that retailer's optimal profit increases with non-green product-purchase regret but decreases with green product-purchase regret. The intuition is that the unit profit of the green

product is $\frac{1}{4} + \frac{1}{32t(\frac{1+r_G}{1+r_C}+1)^2}$, and it is bigger than that of the non-green product $\frac{1}{4}$ in equilibrium. So, when green product-purchase regret r_G decreases or non-green product-purchase regret r_C increases, the demand for green products increases, and eventually the profit increases.

5. Conclusion

A large number of environmental conscious consumers presents opportunities for the popularization of green products. While lots literature has been addressing issues within this broad subject, few studies have explored consumers' anticipated regret in the green product market. As there are always substitute non-green products for green products in the market and post purchase regret is ubiquity, this paper shed light on how consumers' anticipated regret affects manufacturer's and retailer's optimal strategies by a game theoretic model. In the model, the manufacturer sets the greening level and the wholesale prices of the two substitute products, the retailer sets their retail prices, and then customers with anticipated regret decide which kind of product to buy. And there are two types of regret: green product-purchase regret and non-green product-purchase regret. Our analysis shows that consumers' anticipated regret has important implications on the manufacturer's and retailer's optimal pricing and production decisions.

First, the greening level increases with non-green product-purchase regret but decreases with green product-purchase regret in equilibrium. That is, the lower green product-purchase regret and the higher non-green product-purchase regret can foster the greening level of green product. Our analysis shows that, in equilibrium, when consumers' green product-purchase regret increases, consumers' disutility from green products increase, the manufacturer should reduce the greening level to help him mitigate the negative impact of green product-purchaser regret. By contrast, when consumers have low green product-purchase regret and high non-green product-purchase regret, the firm can improve the greening level to better extract the surplus from consumers who prefer green products.

Second, consumers' two types of regret have different effects on the optimal prices of the non-green product and green product in equilibrium. For non-green product, its equilibrium wholesale price and retail price are constant, which are not affect by green product and consumers' anticipated regret. For green product, its equilibrium wholesale and retail prices increase with non-green product-purchase regret but decrease with green product-purchase regret.

Third, comparing with the case without consumers' anticipated regret, we find that retailer and manufacturer can benefit or loss from consumers' anticipated regret in equilibrium. When green product-purchase regret is higher than non-green product-purchase regret, their optimal profits are smaller than the case without regret. That is, they lose profit from consumers' anticipated regret; when green product-purchase regret is lower than non-green product-purchase regret, retailer and manufacturer benefit from consumers' anticipated regret. Furthermore, in equilibrium, the green product-purchase regret can lower their optimal profits while the non-green product-purchase regret can benefit them. And interestingly, the manufacturer's profit is higher than retailer's in equilibrium in both cases with or without consumers' anticipated regret.

Finally, our results offer a theoretical basis for manufacturer's and retailer's pricing and production strategies and the regret management practices. Consumers' anticipated regret can play a very important role in improvement and market expansion of the green product. The manufacturer and retailer should create crafted and targeted advertising messages to introduce the green attribute to evoke consumers' non-green product-purchase regret and alleviate their green product-purchase regret to stimulate consumers' green consumption. On the other hand, they should increase consumers' environmental awareness to increase the valuation of the green product.

In this paper, we construct a game theoretic model to investigate the impact of consumers' anticipated regret on a manufacturer's and retailer's greening level and pricing decisions. In particular, we assumed that consumers' valuations for green products are deterministic. While it is reasonable in the short run, consumers can learn more about the greening level and their valuations will change over time in practice. Therefore, future research can explicitly model dynamic interactions between the consumers and manufacturer and retailer over

multiple periods in a dynamic setting where consumers' learning can influence their valuations, and will acquire a different insight about anticipated regret. Besides, block-chain has potential to significantly transform the information asymmetry between consumers and manufacturer to eliminate the consumers' uncertain valuations. Thus, the other one direction for further research is to add block chain to the green product supply chain and investigate the effect of its presence.

Acknowledgements. This work was supported by Science and Technology Department of Henan Province 202400410201.

References

[1] J, Bagger, J. Reb and A. Li, Anticipated regret in time-based work-family conflict. *J. Manager. Psychol.* **29** (2014) 304–320.
[2] R. Bouderbala, The direct role of anticipated regret in the formation of student's entrepreneurial intention. *J. Enterp. Culture* **27** (2019) 385–417.
[3] R. Caldentey, Y. Liu and I. Lobel, Intertemporal pricing under minimax regret. *Oper. Res.* **65** (2017) 104–129.
[4] A. Chaturvedi, E. Katok and D.R. Beil, Split-award auctions: insights from theory and experiments. *Manage. Sci.* **65** (2019) 71–89.
[5] Y.-S. Chen, C.-H. Chang and Y.-H. Lin, Green transformational leadership and green performance: the mediation effects of green mindfulness and green self-efficacy. *Sustainability (2071-1050)* **6** (2014) 6604–6621.
[6] J. Chen, L. Teng, S. Liu and H. Zhu, Anticipating regret and consumers' preferences for counterfeit luxury products. *J. Bus. Res.* **68** (2015) 507–515.
[7] D. Chen, J. Ignatius, D. Sun, S. Zhan, C. Zhou, M. Marra and M. Demirbag, Reverse logistics pricing strategy for a green supply chain: a view of customers' environmental awareness. *Int. J. Prod. Econ.* **217** (2019) 197–210.
[8] B. Cheng, Y. Wang, X. Shi and M. Zhou, Fashion retail competition on product greenness with overconfidence. *RAIRO: Oper. Res.* **56** (2022) 101–114.
[9] Z. Hong, H. Wang and Y. Gong, Green product design considering functional-product reference. *Int. J. Prod. Econ.* **210** (2019) 155–168.
[10] M.-B. Jamali and M. Rasti-Barzoki, A game theoretic approach for green and non-green product pricing in chain-to-chain competitive sustainable and regular dual-channel supply chains. *J. Cleaner Prod.* **170** (2018) 1029–1043.
[11] B. Jiang, C. Narasimhan and Ö. Turut, Anticipated regret and product innovation. *Manage. Sci.* **63** (2017) 4308–4323.
[12] Y. Kim and R. Krishnan, On product-level uncertainty and online purchase behavior: an empirical analysis. *Manage. Sci.* **61** (2015) 2449–2467.
[13] B. Li, H. Wang and W. Zheng, Who will take on green product development in supply chains? Manufacturer or retailer. *J. Cleaner Prod.* **314** (2021) 128000.
[14] G. Li, L. Yang, B. Zhang, X. Li and F. Chen, How do environmental values impact green product purchase intention? The moderating role of green trust. *Environ. Sci. Pollut. Res.* **28** (2021) 46020–46034.
[15] G. Loomes and R. Sugden, Regret theory: an alternative theory of rational choice under uncertainty. *Econ. J.* **92** (1982) 805–824.
[16] P. Ma, C. Zhang, X. Hong and H. Xu, Pricing decisions for substitutable products with green manufacturing in a competitive supply chain. *J. Cleaner Prod.* **183** (2018) 618–640.
[17] R. Mungkung, K. Sorakon, S. Sitthikitpanya and S.H. Gheewala, Analysis of green product procurement and ecolabels towards sustainable consumption and production in thailand. *Sustainable Prod. Consumption* **28** (2021) 11–20.
[18] K. Murali, M.K. Lim and N.C. Petruzzi, The effects of ecolabels and environmental regulation on green product development. *Manuf. Serv. Oper. Manage.* **21** (2019) 519–535.
[19] J. Nasiry and I. Popescu, Advance selling when consumers regret. *Manage. Sci.* **58** (2012) 1160–1177.
[20] Ö. Özer and Y. Zheng, Markdown or everyday low price? The role of behavioral motives. *Manage. Sci.* **62** (2016) 326–346.
[21] A. Panno, M. Lauriola and A. Pierro, Regulatory mode and risk-taking: the mediating role of anticipated regret. *PLoS One* **10** (2015) 1291–1293.
[22] K. Rahmani and M. Yavari, Pricing policies for a dual-channel green supply chain under demand disruptions. *Comput. Ind. Eng.* **127** (2019) 493–510.
[23] B. Sarkar, M. Ullah and M. Sarkar, Environmental and economic sustainability through innovative green products by remanufacturing. *J. Cleaner Prod.* **332** (2022) 129813.
[24] M. Shoaeinaeini, K. Govindan and D. Rahmani, Pricing policy in green supply chain design: the impact of consumer environmental awareness and green subsidies. *Operational Research* **22** (2022) 3989–4028.
[25] N. Syam, P. Krishnamurthy and J.D. Hess, That's what I thought I wanted? Miswanting and regret for a standard good in a mass-customized world. *Marketing Sci.* **27** (2008) 323–540.
[26] A. Trivella, S. Nadarajah, S.-E. Fleten, D. Mazieres and D. Pisinger, Managing shutdown decisions in merchant commodity and energy production: a social commerce perspective. *Manuf. Serv. Oper. Manage.* **23** (2021) 311–330.
[27] J. Xu and Y. Duan, Pricing and greenness investment for green products with government subsidies: When to apply blockchain technology? *Electron. Commerce Res. App.* **51** (2022) 101108.

[28] F. Yang, M. Wang and S. Ang, Optimal remanufacturing decisions in supply chains considering consumers' anticipated regret and power structures. *Transp. Res. Part E: Logistics Transp. Rev.* **148** (2021) 102267.
[29] C.Y. Yin and H.Y. Yu, The impact of anticipated regret on consumer impulse buying behavior. *Manage. Rev.* **21** (2009) 71–79.
[30] M. Zeelenberg, Anticipated regret, expected feedback and behavioral decision making. *J. Behav. Decis. Making* **12** (1999) 106–161.
[31] C.T. Zhang, H.X. Wang and M.-L. Ren, Research on pricing and coordination strategy of green supply chain under hybrid production mode. *Comput. Ind. Eng.* **72** (2014) 24–31.
[32] X. Zhu and G. Wu, Green product diffusion: the impacts of asymmetric retailers' strategic product decisions. *RAIRO: Oper. Res.* **55** (2021) 1459–1486.

Subscribe to Open (S2O)
A fair and sustainable open access model

This journal is currently published in open access under a Subscribe-to-Open model (S2O). S2O is a transformative model that aims to move subscription journals to open access. Open access is the free, immediate, online availability of research articles combined with the rights to use these articles fully in the digital environment. We are thankful to our subscribers and sponsors for making it possible to publish this journal in open access, free of charge for authors.

Please help to maintain this journal in open access!

Check that your library subscribes to the journal, or make a personal donation to the S2O programme, by contacting subscribers@edpsciences.org

More information, including a list of sponsors and a financial transparency report, available at: https://www.edpsciences.org/en/maths-s2o-programme