RAIRO-Oper. Res. 58 (2024) 4341–4371
https://doi.org/10.1051/ro/2024171

**RAIRO Operations Research**
www.rairo-ro.org

# RETAILER ANTICIPATED REGRET UNDER CARBON TAX POLICY

Xueqing Zhang

**Abstract.** Environmental policies such as carbon tax implementation significantly impact the technology choice and cost structure of the upstream manufacturer, affecting the downstream retailer's the procurement decision and risk management in a sustainable supply chain. This study constructs a single-manufacturer-single-retailer supply chain model constrained by carbon tax policies to analyze the influence of retailer's anticipated regret on the supply chain operation and environmental performance. Utilizing game theory, the research finds that the retailer's anticipated regret behavior suppresses manufacturer's willingness to invest in the green initiative, resulting in a non-monotonic effect on profits. When the retailer's regret level is low and her demand for eco-friendly products is also low, the manufacturer tends to reduce the green investment and increase the wholesale price to maximize the marginal return. Although such the anticipated regret behavior by the retailer may stimulate the manufacturer's profit growth, it reduces retailer's profit. Conversely, as the retailer's regret level increases, the manufacturer increases the green investment and reduces the wholesale price to induce higher procurement by the retailer, leading to a decline in the manufacturer's profit but an upward trend in the retailer's profit. This discovery suggests that the upstream supply chain manager, should closely the monitor retailer's potential anticipated regret and adjust the corresponding strategy accordingly. Furthermore, the study finds that the lower level of retailer's anticipated regret positively impact environmental behavior, offering the policymaker a new perspective on promoting the green supply chain practice.

**Mathematics Subject Classification.** 91-10.

Received December 18, 2023. Accepted August 17, 2024.

## 1. Introduction

The yearly increase in global carbon dioxide emissions has become an undeniable fact. As illustrated in Figure 1, there has been a clear upward trend in carbon emissions since 1940, leading to increasingly severe negative impacts on the environment. Issues such as global warming, frequent extreme weather events, and the disruption of ecosystem balance are closely associated with this trend. Confronted with this pressing challenge, curbing carbon dioxide emissions has become urgent. As Abbasi and Ahmadi Choukolaei [1] noted, with growing awareness of environmental conservation and corporate social responsibility among consumers, carbon reduction has emerged as a crucial objective in the design of sustainable supply chains. To achieve the sustainable development goal, some countries have formulated various environmental standards and carbon tax policies to

*Keywords.* Retailer, anticipated regret, demand uncertainty, Stackelberg game, sustainable supply chain.

School of International Business and Management, Sichuan International Studies University, Chongqing 400031, P.R. China.
*Corresponding author: zxqcqspb@163.com

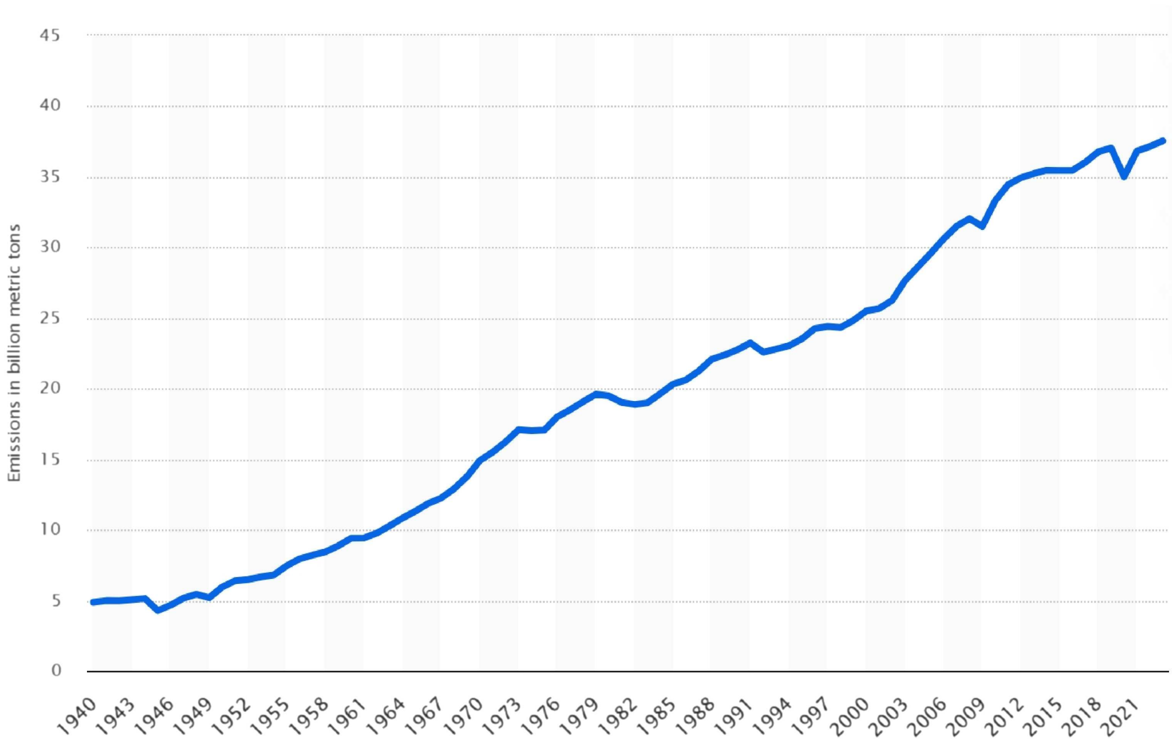


FIGURE 1. Annual carbon dioxide ($CO_2$) emissions worldwide from 1940 to 2023. Source: www.statista.com (Global Carbon Project; Expert(s)).

guide enterprises to reduce carbon dioxide emissions levels. For example, the UK, India, China, Germany and the United States have all proposed the goal of achieving net carbon neutrality by the middle of this century [51]. However, it cannot be denied that despite the numerous benefits of carbon tax policies, they have imposed significant financial pressure on enterprises striving to meet emission reduction targets [2]. Using the EU carbon border tax as an illustration, the enactment of this policy in 2026 is projected to lead to an immediate rise of 15% to 30% in material costs for carbon-intensive producers like China, Russia, and India. This will significantly amplify the financial strain on these upstream manufacturers within the sustainable supply chain [27].

In recent years, the consumer market has been increasingly plagued by various degrees of supply interruptions and periodic fluctuations in demand. These include factors such as the COVID-19 pandemic and regional instability due to wars. Undoubtedly, these factors will further exacerbate the mismatch between product supply and demand. In the face of market demand uncertainty, the enactment of government carbon tax policies is poised to heighten downstream retailers' apprehension about potential regrets, while simultaneously motivating upstream manufacturers to contemplate the adoption of cleaner technologies. For instance, in 2022, Canada implemented a federal carbon tax of $50 per ton. Canadian firms argued that they would not reap any benefits from this policy, as it could lead to a decrease in production volume to evade hefty carbon tax payments, incurring additional costs for investments in cleaner technologies [75]. In such a scenario, the downstream retailer must carefully assess the quantity of the product she procures from upstream sources to prevent incurring substantial losses stemming from supply and demand disparities.

In this paper, we consider a sustainable supply chain driven by the carbon tax policy, where the definition of a sustainable supply chain encompasses efforts to minimize environmental impact and carbon emissions throughout the supply chain while adhering to regulatory requirements and market demands for sustainability.

In this supply chain, an upstream manufacturer prioritizes investing in green technology to minimize carbon emissions and mitigate the financial impact of the carbon tax. Anticipated regret for the downstream retailer in a sustainable supply chain stems from the apprehension and concern they experience regarding the potential negative outcome of their decisions, particularly in the context of uncertain market demand and the implications of carbon tax policies. This concept of anticipated regret refers to the retailer's foresight of regrettable consequences that may result from their action or decision, such as overstocking or understocking inventory levels.

In the context of a sustainable supply chain, the downstream retailer often faces challenges related to balancing their procurement decisions with environmental sustainability goals and financial considerations. It must navigate the complexity of fluctuating consumer demand, driven by factors such as seasonal trends, economic conditions, and unforeseen events like the COVID-19 pandemic. These fluctuations can lead to situations where the retailer must make difficult decisions regarding the quantity of products to procure from the upstream manufacturer.

Furthermore, the implementation of a carbon tax policy by the government introduces an additional layer of complexity for the downstream retailer. The carbon tax increases the cost of production and transportation for manufacturers, which may lead to higher wholesale prices for the retailer. This, in turn, can impact the retailer's profitability and competitiveness in the market. Additionally, the carbon tax policy serves as an incentive for the company to adopt cleaner technology and reduce their carbon emissions. However, the transition to greener practices often requires a significant investment in technology and infrastructure, further complicating procurement decisions for the retailer.

The combination of market demand uncertainty and the financial implication of the carbon tax policy creates a challenging environment for the downstream retailer in a sustainable supply chain. The retailer must carefully evaluate and anticipate the potential regret associated with their procurement decision to minimize financial losses, maintain competitiveness, and align with environmental sustainable objectives. Thus, anticipated regret serves as a crucial factor influencing the decision-making process of the retailer in the context of a sustainable supply chain.

Note that the sustainable supply chain in this paper emphasizes the impact of carbon tax policies on operations, using them as key drivers for sustainability. It focuses on minimizing carbon emissions and optimizing resource use to achieve both economic and environmental benefits. In contrast, the green supply chain primarily aims to reduce environmental impact through technological and managerial approaches, without necessarily prioritizing carbon tax policies as key decision factors. Therefore, the sustainable supply chain constructed in this paper differs significantly from the green supply chain in its core concept and focus.

Hence, within the framework of the carbon tax policy, conducting a thorough examination of the anticipated regret experienced by the downstream retailer in the supply chain and promptly suggesting effective remedies assumes a pivotal role in safeguarding the stability of the supply chain.

It is widely acknowledged that regret plays a pivotal role in human behavior, particularly evident for end-market consumers who frequently grapple with post-purchase remorse. A pertinent example can be drawn from the acquisition of an Apple phone, where consumers may anticipate varying degrees of regret based on the device's memory capacity. In light of this, Jiang and Narasimhan [46], Jin *et al.* [47], and Zou *et al.* [105] introduced two categories of consumer ex-post purchase regret: underpurchase regret and overpurchase regret. Underpurchase regret pertains to the sentiment experienced when a consumer buys a lower-quality product only to later realize that a higher-quality alternative would have offered greater utility. Conversely, overpurchase regret encapsulates the regret felt when a consumer opts for a high-quality product but subsequently discerns that a lower-quality option would have sufficed. While these regret classifications serve to illustrate vertical disparities in consumer product perception, they fundamentally signify an anticipated loss for consumer's post-purchase. In this paper, we refer to these researches by Zhou *et al.* [103], Bell [7], Li and Liu [55] and Li and Li [56], and draw inspiration from these characterizations, applying them to describe the two types of regret-biased behaviors exhibited by the retailer in ex-ant: one when their product acquisitions fall short of meeting market demand (termed underpurchase regret), and the other when their purchases exceed market demand (termed overpurchase regret).

In this article, we establish a sustainable supply chain model consisting of an upstream manufacturer investing in carbon reduction technology and a downstream retailer exhibiting anticipated regret towards order losses that extend the research of Qi *et al.* [75] that they consider a monopolistic enterprise with loss aversion behavior in a centralized supply chain, and investigate the impact of the retailers decisions with an anticipated regret on a sustainable supply chain with environmental carbon taxes under demand uncertainty.

Given the background outlined above, our primary focus centers on the issue of green investment by manufacturers. Consequently, our initial research question to be addressed is:

*How does the manufacturer adjust their investment in green technology and wholesale pricing contracts to address the retailer's decision bias associated with anticipated regret?*

We find that the retailer's anticipated regret significantly influences the determination of the optimal level of environmental sustainability in product design. When the retailer exhibits low regret, the manufacturer perceives less pressure to prioritize environmentally friendly production, opting instead to minimize a green investment and raise the wholesale price to maximize the marginal return. This stems from the expectation that the retailer is less concerned about environmental impact and are unlikely to introduce the greener product. Consequently, when demand for eco-friendly products is low, the manufacturer prioritizes cost savings over sustainability. The retailer's purchasing strategy is influenced by both the underpurchase and overpurchase regret. When the retailer's regret level is high, and the underpurchase regret outweighs that overpurchase regret, the retailer tends to adopt a more proactive purchasing approach. Anticipating this shift, the manufacturer increases the green investment and reduce the wholesale price of the product to incentivize the retailer to increase product procurement. Consequently, the retailer's anticipated regret exerts a non-monotonic influence on both the optimal green level and the optimal wholesale price of the product.

Intuitively, the expected regret of retailers is a decision-making bias that may consistently prove detrimental to the retailer. Hence, our second research question of interest is:

*Does the retailer's anticipated regret behavior always prove detrimental to the supply chain firms?*

Contrary to conventional wisdom, human biases in decision-making may not always have detrimental effects on businesses. Our finding suggests a nuanced relationship between a retailer's anticipated regret and its impact on an upstream manufacturer. When the retailer experiences low regret levels, an increase in the wholesale price benefits the manufacturer, but leads to reduced orders from the retailer. Conversely, a decrease in the wholesale price stimulates retail purchases, positively impacting the manufacturer. Thus, in situations of low regret levels, the manufacturer's positive influence prevails, resulting in augmented expected profit. However, in cases of a high regret level, the manufacturer's profit diminishes due to the dominance of negative impacts.

Optimistic market expectations tend to prompt companies to make positive decisions and investments. In this article, we have also investigated the influence of market expectations. However, whether the research findings align with the aforementioned intuition constitutes our third research question:

*Does optimistic market expectation imply that both manufacturers and retailers always make optimistic decisions?*

Surprisingly, we discover that an increase in market expected demand does not always translate to higher profits for the manufacturer. Particularly in situations where market demand remains modest, the manufacturer may actually experience a decrease in profit despite the uptick in expected demand. This anomaly arises because, despite the manufacturer's implementation of various promotional tactics, retailers with anticipated regret lack a compelling incentive to significantly boost product orders. Essentially, when market expected demand fails to reach a sufficiently high level, retailers tend to adopt a pessimistic outlook. This results in overpurchase regret outweighing underpurchase regret, leading to a continuous decline in product procurement. Consequently, both the manufacturer and the retailer witness a decline in profits despite the marginal increase in market expected demand.

With the tightening of government carbon regulations, our interest extends to the impact of carbon tax policies. Hence, we introduce the concluding research question of this article, that is, *Does an increase in a carbon tax rate always has a negative impact on both a manufacturer and a retailer?*

The carbon tax increases production and transportation costs, raising wholesale prices and complicating the downstream retailer's procurement decisions. This leads to greater anticipated regret as the retailer must carefully balance the risk of financial losses with the need to align with environmental sustainability goals. The tax also pressures retailers to invest in greener technologies, adding further complexity to their decision-making and amplifying the potential for regret in both financial and strategic outcomes. We find that strategically increasing the environmental carbon tax can yield mutual benefits for both the manufacturer and the retailer, depending on the pricing dynamics of the product in the market. Lower-priced products typically stimulate greater demand, benefiting both parties in the supply chain. Therefore, while a slight uptick in the carbon tax rate may initially intensify the dual-margin effect, adversely affecting both the manufacturer and the retailer, judiciously reducing product prices can counterbalance this impact. Consequently, the positive influence of lower-priced products outweighs the negative effects of the increased carbon tax, resulting in enhanced profits for both the manufacturer and the retailer.

The remainder of this article is structured as follows: Section 2 provides a review of relevant literature. Section 3 introduces the model, while Section 4 derives optimal solutions through backward induction. In Section 5, we explore the influence of managerial regret on supply chain decisions, analyzing its impact on expected profits and environmental performance. Finally, Sections 6 and 7 offer key insights and recommendations for future research. Mathematical proofs and related threshold expressions are presented in the Appendices.

## 2. Literature review

Our study focuses on three main bodies of literature: (1) sustainable operations and supply chain management, (2) behavioral operations and supply chain management, and (3) supply chain management with carbon tax policy. We will review these three literature streams. To better delineate the research gap and underscore our contribution, we have categorized previous studies alongside our work in Table 1.

### 2.1. Sustainable operations and supply chain management

This paper investigates the anticipated regret of a retailer in sustainable supply chains; therefore, our paper is first related to sustainable operations and supply chain management.

The sustainable strategy of enterprises is usually driven by two aspects: consumer environmental awareness and government environmental policies. On the one hand, when a manufacturers sustainable strategy is driven by consumer environmental awareness, it incorporates consumer environmental awareness into its strategic decisions when investing in green product development, *e.g.*, Zolfagharinia *et al.* [104], Dye and Hsieh [23], Han *et al.* [36], Dai and Zhang [15], Dong *et al.* [16], Niu *et al.* [70], etc. On the other hand, when the sustainable strategy is driven by government environmental policies, a manufacturer pay more attention to the role of green technology in reducing carbon emissions and adjusting product pricing, *e.g.*, Du *et al.* [20], Bai *et al.* [5], Subramanian *et al.* [82], Wei *et al.* [85], Anand and Giraud-Carrier [4], Dou and Cao [17], and Yu *et al.* [96].

Responsible procurement by supply chain enterprises is an important measure to make the supply chain more sustainable. Guo *et al.* [31], Plambeck and Taylor [74], and Orsdemir *et al.* [72] demonstrate the social and environmental responsibilities of supply chain enterprises by proposing different procurement strategies. The responsible procurement of supply chain enterprises will become more complex when information is asymmetric, and for situations where the enterprise carries private information, Mirzajani *et al.* [64], Ma *et al.* [61], Hong and Guo [39], and Guo *et al.* [32] proposed the optimal procurement contract in sustainable supply chains. In addition, another manifestation of supply chain sustainability is that more and more enterprises are or have already been paying attention to their social responsibilities [59, 65, 71, 90].

This paper explores the impact of a retailer's anticipated regret on a sustainable supply chain amidst uncertain demand, with a focus on government carbon tax policies. It aligns with the broader field of sustainable operations and supply chain management. Enterprise sustainability strategies are typically influenced by consumer environmental awareness and government environmental policies. A manufacturer adjusts its strategy accordingly, either by responding to consumer demands for green products or by adhering to government regulations on carbon emissions and pricing. Responsible procurement practices play a vital role in enhancing supply chain sustainability, with various strategies proposed to address social and environmental responsibilities. An optimal procurement contract is proposed to tackle information asymmetry challenges and ensure sustainability in the supply chain. Our study stands out by specifically examining the impact of a retailer's anticipated regret in a decentralized supply chain environment under government regulations. Unlike previous literature, we focus on the interplay between government policies, retailer, and supply chain sustainability, offering novel insights into sustainable strategy formulation amidst regulatory pressures and market uncertainties.

### 2.2. Behavioral operations and supply chain management

The second literature stream of this article is related to behavioral operations and supply chain management. The literature on behavioral operation management has received widespread attention. On the one hand, many studies have focused on the impact of consumer behavior on business operations, such as regret Zhang *et al.* [100], Guan *et al.* [30], Guo *et al.* [33] and Yang *et al.* [95], unfair aversion [31], strategic waiting [81], and newness concerns [88]. On the other hand, the behavioral factors of managers have been extensively studied, such as fairness concerns [18, 19, 38, 73], risk aversion [11, 29, 43, 92], and social responsibility [12, 26, 84].

Even under simplified operating conditions, such as the famous newsvendor problem, human behavior may still deviate from the best solution [22]. Therefore, research on the behavioral bias of managers is critical to company operations. Recently, there are many literatures on the behavioral bias of managers, such as overconfidence and optimism [49, 62, 86], fairness concerns [44, 91], and managerial commitments [28, 78, 83]. This article focuses on managers' anticipated regret, which is first proposed by Bell [6] which incorporates regret into the utility function. Schweitzer and Cachon [77] argue that newsvendors attempt to minimize regret in their order decisions. Chan *et al.* [10] consider the retailers' regret-averse behavior to explore the effects of the regret-averse behavior on the equilibrium decisions, profits, and utilities of the decision makers. Li and Li [56] examine the impacts of the automation system on order decision in a decentralized supply chain comprising one supplier and one regretful retailer. Qi *et al.* [75] study the retailers risk aversion behavior to profit loss in the centralized supply chain by considering the carbon tax policy. They have proven that risk averse companies, in some cases, have higher optimal profits than risk neutral companies when facing carbon taxes.

Our study contributes to the existing literature on anticipated regret by examining the impact of the retailer anticipated regret on upstream manufacturer's green investments. Firstly, the literature predominantly focuses on the consumer regret behavior, with limited studies addressing the retailer anticipated regret behavior, hence enriching this domain. Secondly, scant attention has been paid to the environmental sustainability implications of the retailer anticipated regret behavior. This paper incorporates the carbon tax policy, exploring the influence on retailer regret behavior and enhancing research on sustainable operations management, which holds significant practical relevance for supply chain enterprises seeking sustainability practices amid uncertain environments.

### 2.3. Supply chain management with carbon tax policy

Our third literature review focuses on government environmental regulations. With the increasing emphasis on carbon reduction in supply chains, there are many other studies on the impact of environmental policies on the supply chain and its enterprises by establishing a game model, *e.g.*, Li *et al.* [57], Zhao *et al.* [101], Hafezalkotob [34], Wu *et al.* [89], Allevi *et al.* [3], Cao *et al.* [9], Halat *et al.* [35], and Liu *et al.* [60].

Environmental intervention plays an important role in the control of environmental pollution [17, 21, 80]. Shi and Xu [79] believe that stricter environmental regulations can restrict the exports of high-polluting enterprises. Faisal *et al.* [24] present a systematic approach to achieve this goal by creating a spatial and temporal decomposed price equilibrium mathematical model for food production and distribution systems and they apply this model specifically to analyze the US apple supply chain. Fan *et al.* [25] studied the effects of total control and trading policies (quantity commitment) and carbon tax policies (price commitment) on enterprise technology investment

TABLE 1. Research gap.

| Research paper | Research topic | Identified gap |
|---|---|---|
| Zolfagharinia *et al.* [104], Dye and Hsieh [23], Han *et al.* [36], Hong and Guo [39], Mirzajani *et al.* [64] and Niu *et al.* [71] | Green product development, Responsible procurement | Neglect of the influence of managerial behavioral factors |
| Zhang *et al.* [100], Guan *et al.* [30], Guo *et al.* [33], Pan *et al.* [73], Xia *et al.* [91], Jia *et al.* [44], Chen [11], Guan *et al.* [29], Xie *et al.* [92], Wu and Chen [86], Mahajan [62], Kirshner and Shao [49], Chan *et al.* [10] Li and Li [56] Zhou *et al.* [103] | Consumer regret, Fairness concerns, Risk aversion, Overconfidence and optimism, Retailer regret | Inadequate exploration of sustainable environmental impacts |
| Shi and Xu [79], Allevi *et al.* [3], Cao *et al.* [9], Li *et al.* [57], Fan *et al.* [25], Qi *et al.* [75] | Government environmental regulations: carbon tax policy | Limited focus on anticipated regret behavior for the retailer in supply chains, and less consideration of the impact of supply chain manager behavior |

and production decisions. Yuan *et al.* [97] study the impact of the retailer's risk aversion on optimal decision-making and channel coordination when consumers' low-carbon preferences exist. Qi *et al.* [75] study the impact of a retailers loss aversion in a centralized supply chain under a carbon tax policy. On the contrary, we expand upon the framework proposed by Qi *et al.* [75] to investigate the influence of retailer loss aversion in a decentralized supply chain operating under demand uncertainty, incorporating the implications of a carbon tax policy.

In comparison to existing literature, this paper demonstrates significant differences and unique contributions. Firstly, this study delves into the impact of downstream retailer anticipated regret in a decentralized supply chain under the backdrop of the carbon tax policy, a research perspective not thoroughly explored in prior literature. Through this investigation, we gain a comprehensive understanding of the influence of carbon tax policies on retailer decision-making behavior in the supply chain, as well as the role of retailer anticipated regret therein. Secondly, this paper innovatively combines decision bias behavior with carbon tax policies, deepening our understanding of decision bias behavior itself and providing valuable insights for the formulation and implementation of the carbon tax policy. By elucidating the inherent connection between decision bias behavior and carbon tax policies, this paper further enriches the research landscape in behavioral operations and supply chain management, offering new perspectives and avenues for related fields. Lastly, despite existing research on carbon tax policies, minimal attention has been paid to retailer regret behavior. This paper fills this research gap by thoroughly analyzing the impact of retailer anticipated regret on supply chain decisions under carbon tax policies, providing new insights and discoveries for related fields. This work not only enriches the interdisciplinary research between carbon tax policies and supply chain management but also offers valuable references and guidance for practical supply chain management and policy-making.

## 2.4. Our contribution

This article presents several key contributions by integrating research on managers' anticipated regret and sustainable supply chain strategies guided by government environmental carbon taxes:

Firstly, against the backdrop of the green transition propelled by government carbon tax policies, this study investigates how a retailer's anticipated regret amid uncertain demand influences the sustainable supply chains. Unlike prior studies, we focus on sustainable strategies driven by governmental environmental policy while accounting for the retailer's anticipated regret regarding order losses in a decentralized supply chain environment. This perspective offers novel insights into enterprises' sustainable strategies amid demand uncertainty.

Furthermore, this research enriches the literature on anticipated regret by examining its impact on the upstream manufacturer's green investment. It offers practical guidance for enterprises to sustainably operate in an uncertain environment, providing managers with a fresh perspective and approach to comprehend and mitigate the adverse effects of anticipated regret behavior in an uncertain context.

Lastly, this article significantly diverges from existing literature. It delves into the ramifications of the carbon tax policy on the retailer's anticipated regret within a decentralized supply chain, enhancing relevant research. Moreover, it amalgamates decision biases with supply chain sustainability, enriching studies in behavioral operations and sustainable supply chain management. It offers a new insight and methodology for implementing the green practice within enterprises.

## 3. Problem definition

In our analysis, we examine a sustainable supply chain configuration comprising a manufacturer (referred to as "he") and a retailer (referred to as "she") operating within the market. The manufacturer, situated upstream, offers a product with a greenness level denoted as $x$ to the downstream retailer at a price denoted as $w$. The retailer is tasked with selecting an order quantity represented by $q$, aiming to vend the item in the market at an exogenous price $p$ [48, 76, 98].

Our paper's model demonstrates significant applicability and importance in real-world engineering environments. Let's take Nike as an example: as a globally renowned manufacturer of sports goods, Nike has successfully reduced carbon emissions through technological research and innovation investments and has set ambitious carbon reduction goals for 2030 [69]. However, market demand uncertainty coupled with carbon taxes exacerbates loss aversion for downstream retailers. For instance, JC Penney, a major department store retailer in the United States and one of Nike's many retail clients, made erroneous procurement decisions in 2018, leading to significant mismatches between acquired goods and consumer demand, resulting in substantial losses. Subsequently, JC Penney adjusted its decisions and adopted a more conservative procurement strategy [53].

Through our model, manufacturers in the supply chain, such as Nike, can better understand the behaviors of downstream retailers, like JC Penney, in the face of market demand uncertainty and plan their production and supply strategies accordingly. Our model provides a framework to help manufacturers predict and adapt to market changes, minimizing risks while maximizing profits. By considering factors such as carbon taxes in supply chain decisions, manufacturers can better address the impacts of environmental policy changes, promoting sustainability.

Implementing our model in practice is not challenging, as it builds upon existing supply chain theories and mathematical models and can be implemented using existing data and technologies. By adopting our model, companies can better manage risks, improve production efficiency, and remain competitive in uncertain market environments. Therefore, our paper's model brings many benefits to companies, including reducing losses, enhancing efficiency, and fostering sustainable development.

Following the literature, *e.g.*, Chen *et al.* [13], Hu *et al.* [40], Liu *et al.* [58], Mu *et al.* [66], Hammami *et al.* [37], we posit that the retailer encounters stochastic demand, which is contingent upon the product price denoted as $p$. This relationship is represented by the following expression:

$$D = A - p + \varepsilon. \tag{1}$$

The market potential, denoted as $A + \varepsilon$, comprises a base demand $A$ acknowledged by both the manufacturer and the retailer, alongside the uncertainty level $\varepsilon$. Following the existing literature on demand uncertainty, such as Mills [63], Nicholas and Maqbool [68], and Huang *et al.* [41], we consider $\varepsilon$ as a random variable uniformly distributed in the interval $[0, 2d]$, where $d > 0$ signifies the demand expectation [41]. It is assumed that the market potential $A$ is substantial enough to ensure positive demand equilibrium for the green product.

This study focuses on industries where sustainable strategies are primarily motivated by environmental regulations rather than consumer environmental awareness. This perspective differs from several studies on sustainable operations, as exemplified by Krass *et al.* [52], Zhou *et al.* [102], and Murali *et al.* [67]. Following the

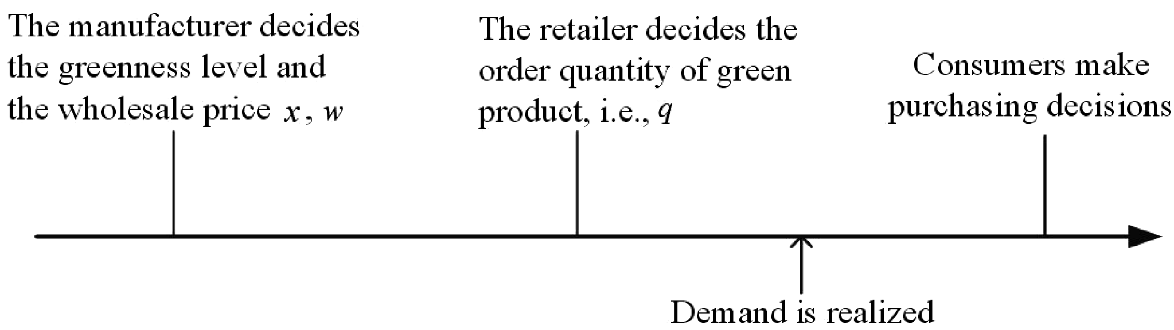


FIGURE 2. Sequence of moves.

literature on the carbon tax policy, *e.g.*, Benjaafar *et al.* [8], Dai and Meng [14], Yang and Chen [94], we assume that the carbon emissions per unit of product produced by a firm are $e$ tons, and there is a linear relationship between environmental carbon tax and carbon emissions generated by production. For each unit of product produced by the manufacturer in the supply chain, the government levies an environmental tax $(1-x)\,te$, which is decreasing in the greenness level of the product. Where $x$ is the greenness level of the product, which captures the different environmental performance, *e.g.*, the life cycle carbon emission, and $t \in (0,1)$ is environmental tax rate. We assume that the manufacturer increases the greenness level $x$ of the product by investing in a green technology to reduce the cost burden of environmental carbon taxes. Aligned with prior research by Yalcin *et al.* [93], Jiang and Yang [45], and Li [54], we adopt the assumption that the manufacturer's cost of developing green products is convex, represented by $kx^2$, where $k$ denotes a cost parameter. This implies that as the green level of the product rises, the manufacturer must exert more effort. To maintain generality, we normalize the unit production cost to 0.

This study adopts a Stackelberg game framework, wherein the upstream manufacturer assumes the role of the leader, and the downstream retailer acts as the follower. The supply chain game unfolds across three stages, as illustrated in Figure 2. Initially, in the first stage, the manufacturer determines the greenness level $x$ of the product and sets the wholesale price $w$ amidst demand uncertainty. Subsequently, in the second stage, the retailer makes decisions regarding the order quantity $q$ under the same demand uncertainty. Finally, in the third stage, consumers make purchases, and the retailer aims to achieve its profit objectives.

Consistent with the literature *e.g.* Wu *et al.* [87], Zhang *et al.* [99], and Huang *et al.* [42], we also assume that both the manufacturer and the retailer are risk-neutral and aim to maximize their own profits. The upstream manufacturer's optimization problem is

$$\max_{x,w>0} \mathrm{E}\Pi_M = (w - t\,(1-x)\,e)\,q - kx^2, \quad \text{s.t.}, U_R \geq 0. \tag{2}$$

The constraint mentioned above, often referred to as the participation constraint, guarantees that the downstream retailer agrees to the contract proposed by the upstream manufacturer. The objective function of the retailer under demand uncertainty is expressed as follows:

$$U_R = \mathrm{E}\left[p \cdot \min\{D, q\} - wq - \delta\,|D-q|\right], \tag{3}$$

where the parameter $\delta > 0$ is the degree to which missing demand induces regret, thus can be interpreted as the retailer's regret level [50, 56]. Note that the parameter $\delta > 0$ represents both the degree of regret when supply exceeds demand and the degree of regret when demand exceeds supply. When $D > q$, the last term in equation (3) becomes $\delta \cdot (D-q)$; otherwise, it will become $\delta \cdot (q-D)$. The former indicates that the retailer experiences negative loss psychology due to a shortage of purchased products; the latter indicates that the retailer experiences negative loss psychology due to an oversupply of purchased products.

Table 2. Symbol definition.

| Variables | Definition |
|---|---|
| Parameters | |
| $A$ | Part of determining market size, *i.e.*, the base demand |
| $\varepsilon$ | The level of uncertainty regarding the market potential, $0 \leq \varepsilon \leq 2d$ |
| $p$ | Retail price of the green product |
| $t$ | Carbon tax rate, $0 < t < 1$ |
| $e$ | The carbon emissions per unit of product |
| $d$ | The expected demand, $d > 0$ |
| $\delta$ | The regret level of the retailer, $\delta > 0$ |
| Decision and auxiliary variables | |
| $x$ | The greenness level of the product |
| $w$ | Wholesale price |
| $q$ | Order quantity |
| $U_R$ | The retailer's Objective function |
| $\mathrm{E}\Pi_M$ | The manufacturer's expected profit |
| $\mathrm{E}\Pi_R$ | The retailer's expected profit |

The carbon tax is represented in the objective function of the upstream manufacturer as a carbon tax rate $t$ (as shown in Eq. (2)). The manufacturer reduces the carbon emission $x \cdot (eq)$ tons by deciding on the green level $x$ of the product, thereby the cost of carbon tax is reduced by $t \cdot (xeq)$. Considering that the carbon tax and green level influence both the cost of the carbon emission and green technology, the combined impact of these factors affects the determination of the wholesale price for the manufacturer's product. On one hand, a high carbon tax and low green level may result in the wholesale price increases, reducing the downstream retailer orders, and exacerbating the risk of order losses caused by supply shortages, thereby leading to the retailer underpurchase regret. On the other hand, implementing a moderate level of green through a low carbon tax may lead to a decrease in wholesale price, encouraging the retailer to increase orders, and increasing the risk of order losses due to oversupply, thereby leading to the retailer overpurchase regret.

For ease of reference, Table 2 provides a summary of the notation used.

## 4. Model formulation

### 4.1. Case without anticipated regret

In this section, we introduce a benchmark scenario where the retailer does not exhibit anticipated regret in response to supply-demand discrepancies. We denote this scenario with the superscript "NR" to signify the absence of regret bias in the retailer's behavior. When the retailer employs a realistic manager, both the manufacturer's and the retailer's optimization problems are

$$\max_{x,w>0} \mathrm{E}\Pi_M = (w - t\,(1-x)\,e)\,q - kx^2. \tag{4}$$

$$\max_{q>0} U_R = \int_0^{p+q-A} \frac{1}{2d}\,(p \cdot D - w \cdot q)\;\mathrm{d}\varepsilon + \int_{p+q-A}^{2d} \frac{1}{2d}\,((p-w)\cdot q)\;\mathrm{d}\varepsilon. \tag{5}$$

According to backward induction, we can obtain the optimal decisions of the manufacturer and the retailer.

**Proposition 1.** *Considering the case without regret, the optimal decisions of the manufacturer and the retailer under uncertain demand is* $x^{N*} = \frac{\left((A+2d)p-p^2-2dte\right)et}{4kp-2de^2t^2}$, $w^{N*} = \frac{p\left(kp(A-p)+\left(\left(e^2t^2+2k\right)p-Ae^2t^2+2ket\right)d-2d^2e^2t^2\right)}{(4kp-2e^2t^2d)d}$, *and* $q^{N*} = \frac{k\left((A+2d)p-2dte-p^2\right)}{2kp-e^2t^2d}$.

From the above proposition, we find that these optimal solutions are related to the market size, expected demand, the tax rate, the price, and so on. Clearly, as the market size increase, the greenness level, the wholesale price, and the order quantity increase.

Based on these optimal decisions, we can obtain the decision makers' expected profits are $\mathrm{E}\Pi_M^{N*} = \frac{k(p(A-p)+2d(p-et))^2}{d(8kp-4dt^2A=1e^2)}$, and $\mathrm{E}\Pi_R^{N*} = \frac{p\left(d\left(et\left(Aet+2k\right)-p\left(e^2t^2+2k\right)\right)-3kp\left(A-p\right)\right)\times\left(kp\left(A-p\right)+d\left(2ket-ae^2t^2+\left(e^2t^2-2k\right)p\right)\right)}{4d(2kp-de^2t^2)}$.

## 4.2. Case with anticipated regret

We now introduce the concept of anticipated regret in the retailer's decision-making process, where the retailer considers ex post inventory regret. This leads to the formulation of the retailer's optimization problem, as depicted in equation (3). To solve this optimization problem, we employ the backward induction method. Initially, we determine the optimal ordering response function of the retailer, considering the green level and wholesale price of the product. Subsequently, we integrate this optimal ordering response function into the manufacturer's objective function. By maximizing the manufacturer's objective function, we can derive the optimal greenness level and wholesale price of the product. Key mathematical proofs and threshold expressions are provided in the Appendices.

When the retailer hires a manager with regretful bias, the manufacturer's and the retailer's objective functions are

$$\max_{x,w>0} \mathrm{E}\Pi_M = (w - t(1-x)e)q - kx^2, \quad \text{s.t.}, U_R \geq 0. \tag{6}$$

$$\begin{aligned}\max_{q>0} U_R &= \mathrm{E}\left[p \cdot \min\{D, q\} - wq - \delta|D-q|\right] \\ &= \int_0^{p+q-A} \frac{1}{2d}\left(p \cdot D - w \cdot q - \delta(q-D)\right) \mathrm{d}\varepsilon \\ &\quad + \int_{p+q-A}^{2d} \frac{1}{2d}\left((p-w)\cdot q - \delta(D-q)\right) \mathrm{d}\varepsilon.\end{aligned} \tag{7}$$

Since the manufacturer assumes the role of the Stackelberg game leader and the retailer acts as the follower, the solution involves employing the backward induction method. Initially, the optimization problem for the retailer can be reformulated for any specified wholesale price $w$ as follows:

$$\max_{q>0} U_R = -\frac{(p+2\delta)q^2}{4d} + \frac{\left(4(A+d)\delta - 4dw + (2A-4\delta+4d)p - 2p^2\right)q}{4d} \tag{8}$$

$$+ \frac{-p^3 + 2(A-\delta)p^2 + \left(4(A+d)\delta - A^2\right)p + \left(-2A^2 - 4Ad - 4d^2\right)\delta}{4d}. \tag{9}$$

The retailer's utility function $U_R$ is evidently concave in terms of $q$. By maximizing the optimization problem (8) pertaining to the retailer, we can derive the optimal order response function of the retailer under demand uncertainty.

**Lemma 1.** *For a given* $w$, *the optimal ordering response function of the retailer under uncertain demand is* $q(w) = \frac{2\delta(A+d-p)+(A+2d)p-p^2-2dw}{p+2\delta}$.

From Lemma 1, we can obtain that for a given wholesale price $w$, the optimal order quantity response function of the retailer decreases with the increase of wholesale prices under uncertain demand. Meanwhile, the size of the optimal ordering response function depends on market expectations $d$, the market size $A$, the price $p$, and the regret level $\delta$. Specifically, as market expectations $d$ and market size $A$ increase, the retailer will increase its procurement volume. But as the regret level of the retailer $\delta$ increases, the change in the optimal order quantity response function depends on the level of wholesale price. If the wholesale price is low, *i.e.*, $w < \frac{p}{2}$, the optimal order quantity response function of the retailer decreases with the increase of regret level. This is because the retailer's anticipated regret makes her more willing to buy less even if the wholesale price is low. If the wholesale price is moderate, that is, $\frac{p}{2} < w \leq p$, as the increase of regret level, the retailer with anticipated regret will always increase her order quantity because they will worry about the negative effects of buying less. If the wholesale price is high, *i.e.*, $w > p$, the retailer will reject the manufacturer's contract because the retailer is not profitable at this time.

Subsequently, by maximizing the manufacturer's objective function (6) for any given greenness level $x$, we can derive the optimal wholesale price response function of the manufacturer under demand uncertainty. It is noteworthy that the constraint $U_R \geq 0$, also recognized as the participation constraint (IR), guarantees the downstream retailer's acceptance of the upstream manufacturer's contract. Regarding $U_R \geq 0$, the manufacturer's objective function can be reformulated as

$$\max_{x,w>0} \mathrm{E}\Pi_M = \frac{1}{p+2\delta}\left(w - t\left(1-x\right)e\right)\left(2\delta\left(A+d-p\right) + \left(A+2d\right)p - p^2 - 2dw\right) - kx^2, \tag{10}$$

$$\text{s.t.,} \quad w \leq \frac{1}{2d}\Big(\left(A+2d-2\delta\right)p + 2\delta\left(A+d\right) - p^2 \tag{11}$$

$$-\sqrt{\left(p+2\delta\right)\left(\left(2p^2+2A^2+4A\left(d-p\right)+4d\left(d-p\right)\right)\delta + p(A-p)^2\right)}\Big). \tag{12}$$

On the basis of Kuhn Tucker conditions for constrained optimization problem, we can obtain the following lemma.

**Lemma 2.** *For any given greenness level $x$, there exists a threshold* $x_0 = \dfrac{2\sqrt{\left(p+2\delta\right)\left(\left(2p^2+2A^2+4A\left(d-p\right)+4d\left(d-p\right)\right)\delta + p(A-p)^2\right)} - \left(p+2\delta\right)A + p^2 + 2\left(\delta+d\right)p + 2d\left(te-\delta\right)}{2dte}$ *such that under the case of the retailer exhibiting regret bias behavior, the manufacturer's optimal wholesale price response function is*

*(i) if* $x < x_0$ then,

$$w\left(x\right) = \frac{2\delta\left(A+d\right) - p^2 + \left(A-2\delta+2d\right)p - \sqrt{\left(p+2\delta\right)\left(\left(2p^2+2A^2+4A\left(d-p\right)+4d\left(d-p\right)\right)\delta + p(A-p)^2\right)}}{2d};$$

*(ii) otherwise,* $w\left(x\right) = \frac{2(p+\delta+(1-x)te)d + (p+2\delta)(A-p)}{4d}$.

For a given greenness level $x$, from Lemma 2, we find that the optimal response function of the manufacturer regarding wholesale prices is related to multiple parameters. When the greenness level is low, *i.e.*, $x < x_0$, the manufacturer will set a constant wholesale price, no matter what level the green level may be below. When the greenness level is high, *i.e.*, $x \geq x_0$, the optimal response function of the manufacturer regarding wholesale prices is inversely related to the greenness level. Furthermore, we observe that a low greenness level results in a higher carbon tax cost for the manufacturer. Consequently, the manufacturer sets the wholesale price at its maximum value. In such cases, while the retailer may agree to the contract, the objective utility is zero. Conversely, a higher greenness level reduces the burden of carbon tax, prompting the manufacturer to establish an appropriate wholesale price that benefits both itself and the downstream retailer by generating positive revenue. Lemma 2 also reveals that the manufacturer's optimal wholesale price response function is influenced by factors such as the retailer's regret level and market size. Notably, when the green level is high, an increase in the retailer's anticipated regret level positively impacts the manufacturer's optimal wholesale price.

Based on Lemmas 1 and 2, we can obtain the manufacture's optimal greenness level, which is presented in the following proposition.

**Proposition 2.** *There exists a threshold $\delta_1$ such that the manufacturer's optimal greenness level under demand uncertainty is*

*(i) if $\delta \le \delta_1$, then* $x^{R*} = \frac{\left(2\delta(A+d)-p^2+(A-2\delta+2d)p-2ted\right)te}{4k(p+2\delta)-2t^2e^2d}$;

*(ii) otherwise,* $x^{R*} = \frac{te\sqrt{(p+2\delta)\left((2p^2+2A^2+4A(d-p)+4d(d-p))\delta+p(A-p)^2\right)}}{2k(p+2\delta)}$, where $\delta_1$ is the only positive root of the equation

$$\begin{aligned}&\left(t^2d-2k\left(p+2\delta\right)\right)\sqrt{\left(p+2\delta\right)\left(\left(2p^2+2A^2+4A\left(d-p\right)+4d\left(d-p\right)\right)\delta+p(A-p)^2\right)}\\&+k\left(2\delta\left(A+d\right)-p^2+\left(A-2\delta+2d\right)p-2td\right)\left(p+2\delta\right)=0.\end{aligned}$$

Proposition 1 elaborates on the relationship between the optimal greenness level of a manufacturer's product and regret level. We find that the greenness of the product shows a non-monotonic change as the regret level increases. When the retailer's regret level is low, it indicates that they are not very concerned about the potential negative consequence of their procurement decision, such as excess or insufficient inventory. In this situation, a manufacturer believes that a retailer is unlikely to regret their procurement decision due to environmental concern. Therefore, a manufacturer feels less environmental pressure from a retailer and does not need to overly consider producing more environmentally friendly products. In such a situation, a manufacturer may choose to lower the green threshold of its product to minimize investment in green research and development. Obviously, this decision is driven by the manufacturer's expectation, that is, in cases where a retailer has a low level of regret, a manufacturer may prioritize cost-saving measure over environmental sustainability effort, as there is less demand for more environmentally friendly product in the market. Conversely, when the regret level is already elevated, an increase in the retailer's regret further prompts the manufacturer to enhance the sustainability of their products (*i.e.*, greeness level). This choice arises from the manufacturer's expectation that a retailer facing intensified regret would prioritize avoiding sales losses due to insufficient procurement, potentially resulting in higher sales of environmentally friendly products. Thus, the influence of the retailer's anticipated regret on the optimal sustainability level demonstrates a non-monotonic pattern.

Next, we will analyze the impact of the retailer anticipated regret on the expected profit of the upstream manufacturer in the supply chain.

**Proposition 3.** *There exists a threshold $\delta_2$ such that if $\delta \le \delta_2$, $\mathrm{E}\Pi_M^{R*} \ge \mathrm{E}\Pi_M^{N*}$; Otherwise, $\mathrm{E}\Pi_M^{R*} < \mathrm{E}\Pi_M^{N*}$, where $\delta_2$ is a positive root of the equation*

$$\begin{aligned}&\frac{1}{4e^2t^2d^2}\left(4k\left(2d\left(p+\delta-et\right)+\left(p+2\delta\right)\left(A-p\right)\right)\times\sqrt{\left(p+2\delta\right)\left(\left(2p^2+2A^2+4A\left(d-p\right)+4d\left(d-p\right)\right)\delta+p(A-p)^2\right)}\right.\\&-m^2\left(36\delta^2+\left(24p-8et\right)\delta+4(p-et)^2\right)-4d\left(p+2\delta\right)\left(p+5\delta-et\right)\left(A-p\right)\\&\left.-5k(p+2\delta)^2(A-p)^2+2de^2t^2\left(4\delta d^2+4\delta d\left(A-p\right)+\left(A-p\right)^2\left(p+2\delta\right)\right)\right)-\frac{k(p\left(A-p\right)+2d\left(p-et\right))^2}{d\left(8kp-4dt^2e^2\right)}=0.\end{aligned}$$

*Proof.* We let $\Delta\Pi_M = \mathrm{E}\Pi_M^{R*} - \mathrm{E}\Pi_M^{N*}$. Then we have if $\delta \le \delta_1$, then

$$\begin{aligned}\Delta\Pi_M &= \frac{k(2d(p+\delta-et)+(p+2\delta)(A-p))^2}{d\left(8k(p+2\delta)-4de^2t^2\right)}-\frac{k(p(A-p)+2d(p-et))^2}{d\left(8kp-4dt^2e^2\right)}\\&=\frac{k\delta\begin{pmatrix}\left(A+d-p\right)^2\left(2kp-e^2t^2d\right)\delta\\-\left(2d\left(p-et\right)+p\left(A-p\right)\right)\left(d^2t^2e^2+et\left(Aet-pet-2k\right)d+kp\left(A-p\right)\right)\end{pmatrix}}{\left(2k\left(p+2\delta\right)-e^2t^2d\right)\left(2kp-e^2t^2d\right)d}.\end{aligned}$$

For a sufficiently large $k$, if $\delta \le \delta_1$, it always holds that $\Delta\Pi_M > 0$. And if $\delta > \delta_1$, then

$$\begin{aligned}\Delta\Pi_M = {} & \tfrac{1}{4e^2t^2d^2}\,(4k\,(2d\,(p+\delta-et)+(p+2\delta)\,(A-p))\\ & \times\sqrt{\begin{aligned}&(p+2\delta)\left((2p^2+2A^2+4A\,(d-p)+4d\,(d-p))\,\delta+p(A-p)^2\right)\\ &-m^2\left(36\delta^2+(24p-8et)\,\delta+4(p-et)^2\right)-4d\,(p+2\delta)\,(p+5\delta-et)\,(A-p)\\ &-5k(p+2\delta)^2(A-p)^2+2de^2t^2\left(4\delta d^2+4\delta d\,(A-p)+(A-p)^2\,(p+2\delta)\right)\end{aligned}}\;\Bigg)\\ & -\tfrac{k(p(A-p)+2d(p-et))^2}{d(8kp-4dt^2e^2)}.\end{aligned}$$

□

We assume that $A=1$, $e=1$, $t=0.4$, $k=0.8$, $d=0.4$, $p=1$. Then there exists $\delta_2=0.3178361722$ is a positive root of $\Delta\Pi_M=0$. Therefore, if $\delta_1<\delta\le\delta_2$, $\Delta\Pi_M\ge 0$; otherwise, $\Delta\Pi_M<0$.

Proposition 4 indicates that the impact of the retailer's regret level on the manufacturer's expected profit is non-monotonic. When the regret level is low, *i.e.*, $\delta<\delta_2$, the retailer's anticipated regret can increase the manufacturer's expected profit, while conversely, it can reduce the manufacturer's profit. Our explanation is as follows. When the regret level is low enough, *i.e.*, $\delta<\delta_2$, the retailer's anticipated regret can cause the manufacturer to increase the wholesale price, benefiting the manufacturer. However, this price increase results in a decrease in retailer orders, which negatively affects the manufacturer. Conversely, a decrease in the wholesale price leads to an increase in retail purchases, benefiting the manufacturer. When the regret level meets $\delta<\delta_2$, the positive impact of anticipated regret on the manufacturer prevails, resulting in increased expected profit. On the other hand, when the regret level is high enough, *i.e.*, $\delta\ge\delta_2$, the negative impact on the manufacturer dominates, leading to a decrease in expected profit.

In addition, we explore the influence of the retailer's anticipated regret on her own outcomes. Intuitively, one might assume that decision-making bias for the business manager would hinder the growth of their enterprises, leading to more harm than good. However, in the following proposition, we present a significant finding from our research: the retailer's anticipated regret can benefit her.

**Proposition 4.** *There exists a threshold $\delta_3>0$ such that if $\delta<\delta_3$, $\mathrm{E}\Pi_R^{R*}(\delta)\le\mathrm{E}\Pi_R^{N*}$; Otherwise, $\mathrm{E}\Pi_R^{R*}(\delta)>\mathrm{E}\Pi_R^{N*}$, where $\delta_3$ is a positive root of the equation*

$$\begin{aligned}&\tfrac{1}{d(p+2\delta)}\,(((p-A-d)\\ &\times\sqrt{(p+2\delta)\left((2p^2+2A^2+4A\,(d-p)+4d\,(d-p))\,\delta+p(A-p)^2\right)}\\ &+p^3-(2A+2\delta-d)\,p^2+\left(A^2+Ad+d^2-4\delta\,(A+d)\right)p+2\delta\left(A^2+2dA+2d^2\right))\,\delta)\\ &-\frac{\begin{aligned}&p\left(d\left(et\,(Aet+2k)-p\left(e^2t^2+2k\right)\right)-3kp\,(A-p)\right)\\ &\times\left(kp\,(A-p)+d\left(2ket-ae^2t^2+\left(e^2t^2-2k\right)p\right)\right)\end{aligned}}{4d(2kp-de^2t^2)}=0.\end{aligned}$$

*Proof.* We let $\Delta\Pi_R=\mathrm{E}\Pi_R^{R*}-\mathrm{E}\Pi_R^{N*}$. Then we have

(i) If $\delta\le\delta_1$, then

$$\begin{aligned}\Delta\Pi_R = {} & \tfrac{1}{8d(2k(p+2\delta)-de^2t^2)}\left(8t^2\delta\,(p+\delta-et)\,km^3\right.\\ & -\begin{pmatrix}-4\left(p^2+(\delta-et)\,p-4\delta\,(et+\delta)\right)(p+\delta-et)\,k^2-4\delta\,(A-p)\,t^2\,(3p-2et+4\delta)\,k\\ +pe^4t^4(A-p)^2\end{pmatrix}m^2\\ & +4k\left(\left(k-e^2t^2\right)p^2+\left(et\,(Aet-k)-\left(k+e^2t^2\right)\delta\right)p+\delta Ae^2t^2-4\delta^2k\right)(A-p)\,(p+2\delta)\,m\\ & \left.-(3p+4\delta)\,(p+2\delta)^2k^2(A-p)^2\right)\\ & -\tfrac{p\left(d\left(et(Aet+2k)-p\left(e^2t^2+2k\right)\right)-3kp(A-p)\right)\left(kp(A-p)+d\left(2ket-ae^2t^2+\left(e^2t^2-2k\right)p\right)\right)}{4d(2kp-de^2t^2)}.\end{aligned}$$

In terms of

$$\begin{aligned}
&\mathrm{E}\Pi_R^{R*} = \tfrac{1}{8d(2k(p+2\delta)-de^2t^2)}\left(8t^2\delta\left(p+\delta-et\right)km^3\right.\\
&-\begin{pmatrix} -4\left(p^2+\left(\delta-et\right)p-4\delta\left(et+\delta\right)\right)\left(p+\delta-et\right)k^2-4\delta\left(A-p\right)t^2\left(3p-2et+4\delta\right)k \\ +pe^4t^4(A-p)^2 \end{pmatrix} m^2\\
&+4k\left(\left(k-e^2t^2\right)p^2+\left(et\left(Aet-k\right)-\left(k+e^2t^2\right)\delta\right)p+\delta Ae^2t^2-4\delta^2k\right)\left(A-p\right)\left(p+2\delta\right)m\\
&\left.-\left(3p+4\delta\right)\left(p+2\delta\right)^2k^2(A-p)^2\right)
\end{aligned}$$

, then we have

$$\begin{aligned}
&\tfrac{\partial \mathrm{E}\Pi_R^{R*}(\delta)}{\partial\delta} = -\tfrac{1}{4\left(k(p+2\delta)-\frac{e^2t^2d}{2}\right)^3 d}\left(k\left(8k^2(A+d-p)^2\delta^3+6k\left(2kp-e^2t^2m\right)\left(A+d-p\right)^2\ \delta^2\right.\right.\\
&+\left(\left(\left(10p^2-12pet+8e^2t^2\right)d^2+\left(2\left(p\left(3p-2et\right)\right)\left(A-p\right)+8p^2\left(A-p\right)\right)d+6p^2(A-p)^2\right)k^2\right.\\
&+\left(\tfrac{3e^2t^2\left(-2p-\frac{8et}{3}\right)d^3}{2}-\tfrac{5\left(\frac{16p}{5}+\frac{8et}{5}\right)(A-p)e^2t^2d^2}{2}-\left(2p(A-p)^2t^2+\left(3A-3p\right)e^2t^2\left(A-p\right)p\right)d\right)k\\
&\left.+2d^4e^4t^4+4e^4t^4\left(A-p\right)d^3+2d^2e^4t^4(A-p)^2\right)\delta+\left(\left(p\left(A-p\right)+2d\left(p-et\right)\right)p^2\left(A+d-p\right)\right)k^2\\
&+\left(\tfrac{3e^2t^2\left(-\frac{2}{3}p^2-\frac{2}{3}pet+\frac{4}{3}e^2t^2\right)d^3}{2}-\tfrac{5\left(p^2-\frac{2}{5}pet\right)(A-p)e^2t^2d^2}{2}-p^2(A-p)^2e^2t^2d\right)k\\
&\left.\left.+e^4t^4\left(p-et\right)d^4+\tfrac{3e^4t^4(A-p)\left(p-\frac{2et}{3}\right)d^3}{2}+\tfrac{d^2pe^4t^4(A-p)^2}{2}\right)\right).
\end{aligned}$$

We observe that $\frac{\partial \mathrm{E}\Pi_R^{R*}(\delta)}{\partial\delta}<0$ when $k$ is sufficiently large. In this case, $\mathrm{E}\Pi_R^{R*}(\delta)$ is decreasing in $\delta$. Thus, $\mathrm{E}\Pi_R^{R*}(\delta)\le \mathrm{E}\Pi_R^{R*}(0)=\mathrm{E}\Pi_R^{N*}$ when $0\le\delta\le\delta_1$ and $k$ is sufficiently large. In this case, it always holds that $\Delta\Pi_R<0$.

(ii) If $\delta>\delta_1$, then

$$\begin{aligned}
&\Delta\Pi_R = \tfrac{1}{d(p+2\delta)}\left(\left(\left(p-A-d\right)\right.\right.\\
&\times\sqrt{(p+2\delta)\left(\left(2p^2+2A^2+4A\left(d-p\right)+4d\left(d-p\right)\right)\delta+p(A-p)^2\right)}\\
&\left.+p^3-\left(2A+2\delta-d\right)p^2+\left(A^2+Ad+d^2-4\delta\left(A+d\right)\right)p+2\delta\left(A^2+2dA+2d^2\right)\right)\delta\Big)\\
&-\frac{\begin{array}{l} p\left(d\left(et\left(Aet+2k\right)-p\left(e^2t^2+2k\right)\right)-3kp\left(A-p\right)\right)\\ \times\left(kp\left(A-p\right)+d\left(2ket-ae^2t^2+\left(e^2t^2-2k\right)p\right)\right)\end{array}}{4d(2kp-de^2t^2)}.
\end{aligned}$$

□

We let $\delta_3$ is a positive root of $\Delta\Pi_R=0$. In this case, there exists $\delta_3>0$ such that $\Delta\Pi_R\le 0$ if $\delta\le\delta_3$; otherwise, $\Delta\Pi_R>0$. For an example, we set these parameters by, $e=1$, $t=0.4$, $k=0.8$, $d=0.4$, $p=1$, then $\delta_3=0.1821078458$. According to the above analysis, the proposition follows.

Obviously, the anticipated regret of the retailer can directly affect her purchasing decisions. When considering the price of products, the retailer's expected profit is primarily influenced by the wholesale price and sales volume. If the retailer has a low level of regret, *i.e.*, $\delta<\delta_3$, she tends to adopt an aggressive procurement strategy. In this case, the manufacturer sets a higher wholesale price, which negatively affects the retailer. Conversely, when the regret level is high enough, *i.e.*, $\delta\ge\delta_3$, the retailer prefers a more conservative procurement approach. Consequently, the manufacturer reduces the wholesale price to encourage the retailer to order more products. The decrease in the wholesale price has a positive impact on the retailer's expected profit. Therefore, a lower regret level leads to a decrease in the retailer's expected profit, whereas a higher regret level increases it.

## 5. Numerical experiment and sensitivity analysis

In this section, building upon the optimal solutions and equilibrium expected profits derived in Section 4, we initially explore the influence of various parameters on the optimal decision. Subsequently, we investigate how these parameters affect the expected profits of both the manufacturer and the retailer.

Table 3. Data statistics on the impact of regret on profits.

| Category | Percentage |
|---|---|
| Percentage Positive $\left(\frac{N\left(\Pi_M^{R*}-\Pi_M^{N*}\right)^+}{N}\right)$ | 13.9475% |
| Percentage Negative $\left(\frac{N\left(\Pi_M^{R*}-\Pi_M^{N*}\right)^-}{N}\right)$ | 86.0525% |
| Percentage Positive $\left(\frac{N\left(\Pi_R^{R*}-\Pi_R^{N*}\right)^+}{N}\right)$ | 96.1362% |
| Percentage Negative $\left(\frac{N\left(\Pi_R^{R*}-\Pi_R^{N*}\right)^-}{N}\right)$ | 3.8638% |

**Notes.** Total Cases: $N(\cdot)^+$, $N(\cdot)^-$, and $N$ respectively indicate that the difference in profit between the retailer without and without regret is positive, negative, and the total number of cases, where $N = 17910$.

## 5.1. The effect of anticipated regret

In this subsection, building upon extant research findings, we scrutinize the impact of anticipated regret on decision-making and anticipated profits within the context of supply chain enterprises. To assess the robustness of the results from Propositions 3 and 4, we conducted simulation tests involving the allocation of pertinent parameters. Some key experiments were executed using MATLAB R2022b on a LAPTOP-HH353THN equipped with an AMD Ryzen 7 4800U operating at 1.80 GHz and 16.0 GB of memory. The relevant data will be documented in Excel in Appendix B.

Specifically, we assigned values to the market size ($A$), expected market demand ($d$), carbon tax rate ($t$), price ($p$), regret level ($\delta$), and cost coefficient ($k$), with $e$ set to 1. We took $A$ values of 0.1, 0.4, 0.7, 1, 1.3, and 1.6, respectively. For $d$, we considered 0.1, 0.2, 0.3, 0.4, 0.5, and 0.6, respectively. The values for $t$ were 0.1, 0.2, 0.3, 0.4, and 0.5, respectively. Likewise, $p$ took on values of 0.1, 0.3, 0.6, and 0.9, and $\delta$ assumed values of 0.1, 0.2, 0.3, 0.4, and 0.5. Finally, we varied $k$ with values of 0.1, 0.3, 0.5, 0.7, and 0.9. This yielded a total of 18,000 sets of values. Excluding those where $k$ was greater than $\frac{de^2t^2}{2(p+2\delta)}$, we retained 17,910 sets of values. Through a comparative analysis of a manufacturer's and a retailer's profits in different scenarios, we derived the results outlined in Table 3.

From the statistical data in Table 3, it is evident that in the majority of cases, the anticipated regret behavior of both manufacturers and retailers is disadvantageous for the manufacturer but advantageous for the retailer. Specifically, in over eighty percent of scenarios, the anticipated regret behavior of the retail manager tends to decrease the expected profit of the manufacturer. Additionally, in over ninety percent of cases, the anticipated regret behavior of the retail manager tends to increase the expected profit of the retailer. Building upon the insights gleaned from Table 3, we can confidently reinforce the numerical validity of Propositions 3 and 4. In a setting marked by demand uncertainty and shaped by carbon tax policies, the retailer's regret consistently wields a dual impact on the profits of both upstream and downstream entities within the supply chain. The superscript data illustrates that, across the majority of scenarios, the retailer's anticipated regret (or regret bias) tends to diminish the manufacturer's profit while concurrently enhancing her own.

In this following, we will numerically examine the effects of relevant parameters on the optimal decisions and expected profits of the manufacturer and the retailer.

### *5.1.1. The impacts on the optimal decisions*

Further research and analysis find that the carbon tax rate has a non-monotonic impact on the optimal greenness level. In this subsection, we present these results.

However, as illustrated in Figure 3 (with $A = 1$, $t = 0.5$, $d = 0.4$, $p = 0.9$), it becomes evident that the greenness level of the product exhibits a non-monotonic variation with the escalation of regret level. Here is our rationale for this observation.

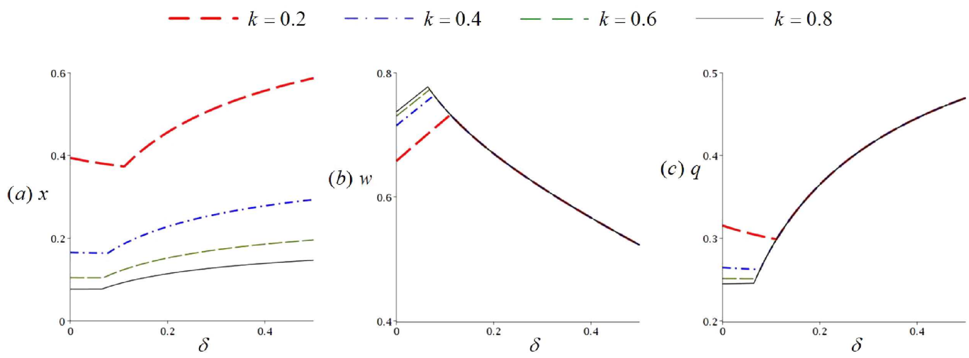


FIGURE 3. The impacts of regret level $\delta$ on the optimal decisions.

In contexts characterized by demand uncertainty, the anticipated losses arising from supply-demand imbalances exert a dual psychological effect on the retailer. On one hand, if the market faces a supply shortage, the retailer might incur partial losses in expected earnings due to inadequate procurement, leading to a feeling of underpurchase regret. On the other hand, an oversupply in the market could lead to cost losses for the retailer due to excess procurement of raw materials, triggering a sense of overpurchase regret.

As regret levels increase, the retailer's ordering decisions are influenced by the dual regret factors mentioned earlier. At lower levels of regret, the retailer tends to experience a stronger sense of underpurchase regret compared to overpurchase regret. This tendency stems from the retailer's inclination, even amidst demand uncertainty, to lean towards more rational procurement practices by sourcing larger quantities from upstream suppliers. Consequently, as regret levels gradually rise, the manufacturer anticipates the retailer's heightened motivation to increase procurement, leading to an elevation in wholesale prices and a reduction in investment in green research and development. Paradoxically, this results in a decrease in the actual order quantities placed by the retailer.

Conversely, at higher regret levels, the retailer experiences a stronger sense of overpurchase regret compared to underpurchase regret. Consequently, as the regret level gradually increases, the manufacturer reduces the wholesale price to encourage the retailer to procure more products, resulting in an increase in the retailer's order quantity. Simultaneously, the diminishing marginal returns compel the retailer to allocate more resources towards green research and development in order to mitigate carbon tax costs.

*5.1.2. The impacts on the manufacturer and the retailer*

In this section, we delve into the impact of retailer anticipated regret on the upstream and downstream segments of a sustainable supply chain. Taking values $k = 0.2$, $k = 0.4$, $k = 0.6$, $k = 0.8$ in the interval $\left[\frac{e^2t^2d}{2(p+2\delta)}, 1\right]$, we illustrate this graphically as depicted below, where $A = 1$, $t = 0.5$, $d = 0.4$, $p = 0.9$. We observe that with the escalation of retailer regret levels, the anticipated profits in both upstream and downstream segments of the supply chain exhibit non-monotonic fluctuations. A detailed analysis is presented below.

In Figure 4, when the regret level is relatively low, employing managers with a higher degree of regret to operate the business may benefit the manufacturer but potentially harm the retailer. Specifically, when the regret level falls below a certain threshold, an increase in regret intensity leads to an increase in the manufacturer's expected profit while simultaneously reducing those of the retailer. At a lower regret level, as regret intensity escalates, despite a decrease in retailer procurement volume, the manufacturer tends to set a higher wholesale price and a lower green standard. This elevates the manufacturer's anticipated profits but diminishes those of the retailer.

At a higher regret level, an increase in regret intensity leads to a reduction in the product wholesale price. However, the manufacturer allocates more resources towards green costs to mitigate carbon tax expenses. While

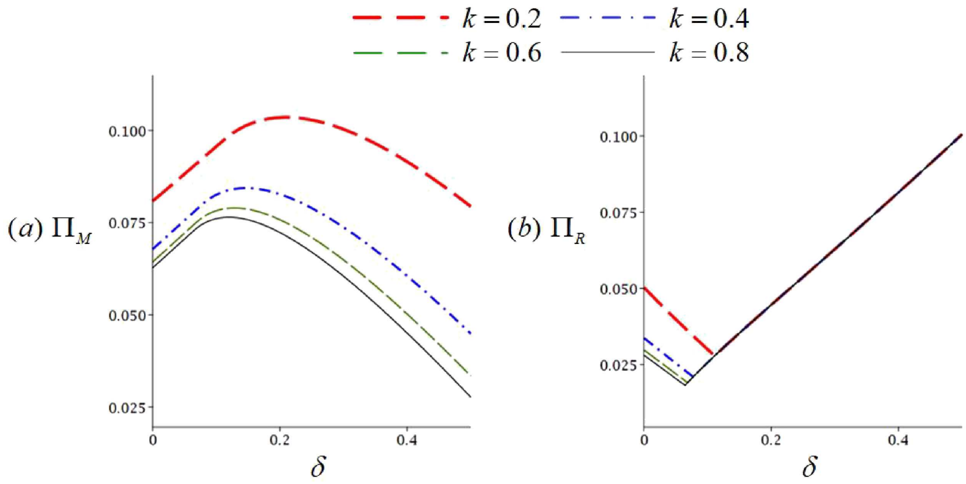


FIGURE 4. The impacts of regret level $\delta$ on the firms' expected profits.

this results in a decrease in the manufacturer's expected profit, the reduction in the wholesale price benefits the downstream retailer, thereby augmenting her expected profit.

## 5.2. The effects of the expected demand

In this section, we also investigate the impact of market expectations on the upstream and downstream segments of the sustainable supply chain under demand uncertainty. By constraining the regret level parameter $\delta$ within the interval $[0, 1]$, and setting specific values for $\delta = 0.1$, $\delta = 0.2$, $\delta = 0.3$, and $\delta = 0.4$ respectively, we delve into this analysis. Meanwhile, we set the parameter $A = 1$, $t = 0.5$, $k = 1$, $p = 0.9$, and draw Figure 5 as follows. Based on this, we will analyze the impact of market expected demand on the manufacturer and the retailer' expected profits under different levels of regret.

Intuitively, one might expect that higher anticipated market demand would result in greater expected profits for both the manufacturer and the retailer in the face of demand uncertainty. In our study, this holds true for the retailer's expected profit. Interestingly, we find that for the manufacturer, the relationship between expected profit and expected market demand is non-monotonic when market demand expectations are relatively low. In other words, with lower anticipated market demand, an increase in expected demand levels leads to non-monotonic shifts in the manufacturer's expected profit. We offer the following explanation for this phenomenon.

When the overall market expectation for demand is not high, even though the upstream manufacturer may implement a series of promotional strategies, the retailer with anticipated regret does not have a compelling incentive to significantly increase her product orders. Consistent with the earlier analysis, which indicates that when regret levels are high, the retailer's overpurchase regret outweighs underpurchase regret, it follows, as depicted in Figure 5(a), that the higher the set level of regret, the more profit a manufacturer stands to lose from a retailer's overpurchase regret. Consequently, as the anticipated market demand level increases, the higher the bias level of the retailer, the greater the profit loss incurred by the manufacturer. Conversely, when the retailer possesses a higher regret level, as market demand expectations rise, the expected profit loss for a manufacturer will be less pronounced.

In such circumstances, a more rational suggestion would be for manufacturers to proactively seek strategic collaborations with downstream enterprises, especially emphasizing the need for heightened rational communication at the managerial level. This approach aims to foster more reasoned decision-making within the management of downstream companies, particularly in times when market expectations are less favorable.

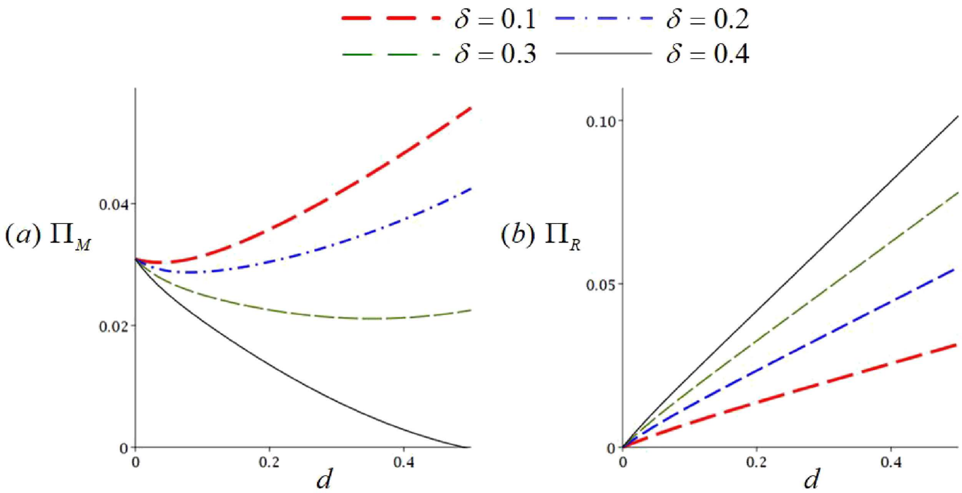


FIGURE 5. The impacts of the expected demand $d$ on firms' expected profits.

## 5.3. The effects of environmental tax rate

In this section, we further investigate the impact of environmental tax rates on supply chain enterprises. In line with industry practices, we assume that the carbon tax rate falls within the interval $(0, 0.5)$. By dynamically considering market pricing, we illustrate in Figure 5 the trends of the product wholesale price, the procurement quantity, as well as the expected profits of the manufacturer and the retailer, in response to variations in environmental carbon tax rates, where $A = 1$, $k = 0.1$, $d = 0.4$, $\delta = 0.1$. Intuitively, it's expected that higher environmental tax rates imposed on the manufacturing sector would lead to an overall reduction in a profit for businesses. However, as depicted in Figure 6(c–d), we are surprised to discover that with an increase in the carbon tax rate, it may be a win-win situation for both upstream and downstream enterprises in the sustainable supply chain. We outline the explanation for this phenomenon below.

Intuitively, as the carbon tax rate increases, manufacturers tend to elevate their green standards to mitigate the burden of the carbon tax, while simultaneously shifting the carbon tax costs downstream by raising wholesale prices for retailers. However, in situations where the environmental carbon tax rate is high, if a manufacturer continues to raise the wholesale price, the downstream retailer may drastically reduce their product orders due to the imposition of exorbitant wholesale costs. Under such circumstances, it appears that both upstream and downstream entities in the supply chain would incur losses.

In an environment of uncertain market demand, the retailer's exhibited anticipated regret amplifies their procurement motivation. Specifically, when the environmental tax rate is high, a manufacturer, influenced by a retailer with anticipated regret, chooses a lower wholesale price as the retailer demonstrates a heightened purchasing drive. In turn, when the retailer observes this reduction in wholesale price, they place an order in quantity higher than what would be expected under rational circumstances (see Fig. 6(a–b)). Consequently, propelled by the anticipated regret of the retailer, the overall profitability of the supply chain enterprises increases in response to the elevation of the carbon tax rate.

However, it's worth noting that, as illustrated in Figure 5(c), an increase in the carbon tax rate doesn't always guarantee an enhancement in the expected profits for both upstream and downstream enterprises. This is contingent on whether the product pricing is appropriate. Moreover, when the carbon tax rate is relatively low, the manufacturer lacks the incentive to lower the wholesale price, as, at this juncture, obtaining a high marginal profit through increasing the wholesale price proves more advantageous for him. Hence, for scenarios with low carbon tax rates, a manufacturer, with the rise in the carbon tax rate, is inclined to set a higher wholesale

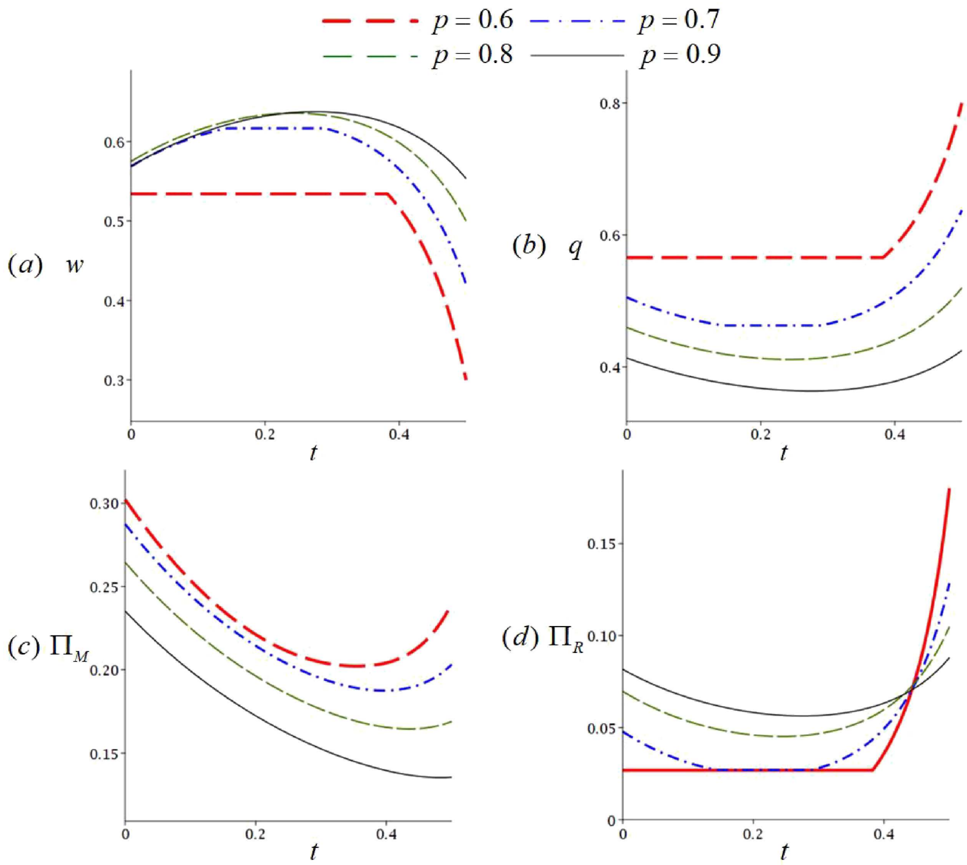


FIGURE 6. The impact of the tax rate $t$ on the decisions and profits in equilibrium.

price, potentially leading the downstream enterprise to decrease their procurement quantity. Consequently, this scenario may result in a lose-lose situation for both upstream and downstream enterprises.

From the perspective of policymakers, finding the right balance in determining the magnitude of the environmental carbon tax rate is crucial. This requires skillfully adjusting the environmental carbon tax rate in a timely and moderate manner, considering various factors within the product market, such as product pricing, to enhance the overall sustainability of the entire supply chain.

Furthermore, as depicted in Figure 6, we observe that with an increase in exogenous pricing, the manufacturer consistently experiences a decline in profit, while the retailer's expected profit initially increases, followed by a decrease. The rationale behind this finding is quite intuitive. With an escalation in product market pricing, market sales volume inevitably decreases, thereby reducing the manufacturer's anticipated profit as the retailer curtails her product orders. However, as long as the market price is not exceptionally high, the positive impact of elevated margins resulting from higher product pricing outweighs the negative impact of reduced sales volume for the retailer, leading to an increase in her profit. However, when the market price becomes overly exorbitant, the negative impact on the retailer's expected profit stemming from the decline in product sales volume predominates, resulting in a subsequent decrease in her expected profit.

## 6. Management implications

This paper explores the impact of the retailer's anticipated regret on the expected profits of both the manufacturer and the retailer and studies the influence of the tax rate on the environment. Our analysis of these results has revealed crucial insights.

- The impact of anticipated regret by a retail manager on supply chain decision-making.
  The anticipated regret behavior of a retail manager has far-reaching effects on supply chain decision-making. This anticipation may prompt a manufacturer to adjust the green level and pricing strategies of a product, thereby influencing the purchasing decision of a retailer. It is noteworthy that this influence is not monotonous but rather exhibits complex and variable characteristics. Particularly, when the regret emotion of a retail manager is high, it may hinder the green transformation process of a manufacturer. Therefore, a manufacturer should actively engage in strategic cooperation with a downstream retailer while promoting green transformation to mitigate the potential negative impact of anticipated regret by a retail manager on green investments.
- The impact of the market expectation on manufacturer decisions.
  The optimism of market expectations has a significant impact on a manufacturer's decisions. However, this optimism is not always favorable to a manufacturer, as its effectiveness is closely related to the degree of regret of a retail manager. When a manufacturer holds optimistic views on future markets, they should carefully evaluate production decisions and fully consider the anticipated regret behavior of a downstream retail manager. This finding further confirms the non-monotonic impact of decision biases on supply chain enterprise profits, reminding us to comprehensively consider various factors in the decision-making process.
- Rational approach to the anticipated regret of a retail manager.
  Although the anticipated regret of a retail manager may bring some negative effects, it does not always harm business profits. Under certain conditions, this anticipated regret may even benefit both a manufacturer and a retailer. Therefore, a supply chain retail company does not need to deliberately exclude managers with decision preferences when hiring. Instead, companies should establish an open and inclusive cultural atmosphere, encouraging communication and collision of different styles. Through training and guidance, help managers rationally assess risks and returns to make wiser decisions.
- Improving decision-making mechanism and process.
  To ensure the scientificity and effectiveness of decisions, a company should perfect decision-making mechanisms and processes. This includes clarifying decision goals, standardizing decision procedures, and strengthening decision supervision. By perfecting these mechanisms, decisions can conform to corporate strategic goals and overall interests, avoiding personal preferences from interfering with decisions. In this way, a company can fully utilize the advantages of different managers, promote innovation and competitiveness enhancement, and achieve sustainable development.
- Cautious formulation of the government environmental tax rate.
  The carbon tax increases production costs, complicating procurement decisions and amplifying the downstream retailer's anticipated regret by heightening financial risks and the challenge of balancing profitability with environmental sustainability. Given the complex impact of environmental tax rates on a manufacturer and a retailer, a government must exercise particular caution in setting environmental tax rates. Low tax rates not only fail to effectively promote a company's transition to green production but may also result in a lack of environmental motivation, making it difficult to achieve the ultimate goal of controlling carbon emissions and protecting the environment. Therefore, when setting environmental tax rates, a government should fully consider the actual situation of a company and market reactions to ensure that the tax rates not only encourage companies to take proactive environmental measures but also avoid imposing excessive economic burdens on them. Additionally, a government should strengthen supervision and enforcement efforts to ensure that companies strictly comply with environmental regulations, jointly promoting green sustainable development.

## 7. Conclusions

Manager decision-making bias plays a crucial role in supply chain management, especially from a sustainable perspective. In this paper, we delve into how anticipated regret behavior of retail manager influences the decision-making process of supply chain procurement and manufacturer. To do so, we constructed a sustainable supply chain model comprising green manufacturer and retailer, with the manufacturer committed to investing in green technology. Through comparative analysis, we examined equilibrium solution of game model under two scenarios: one where retail manager experiences anticipated regret and another where they do not. Building upon this, we further investigate the impact of anticipated regret behavior of retail manager on upstream and downstream enterprise in the supply chain, as well as on the overall environment. To validate the reliability and stability of these key finding, we conducted numerical simulation experiment. Through numerical simulation testing, we confirm the robustness of these conclusion.

### 7.1. Findings

Through in-depth research, it has been found that the anticipated regret behavior of a retail manager exerts a restraining effect on the green investment of a manufacturer and has complex and non-monotonic effects on the profit of upstream and downstream enterprises in the supply chain.

Specifically, when the regret emotion of a retail manager remains at a relatively low level, their anticipated regret behavior can, to some extent, enhance the profitability of a manufacturer, albeit at the cost of sacrificing the retailer's own profit. However, once the regret emotion of a retail manager intensifies, rising to a higher degree, this anticipated regret behavior instead leads to a decline in the profit of a manufacturer, while the profit of a retailer may receive a certain boost. Therefore, for a manufacturer's manager upstream in the supply chain, they need to remain vigilant and closely monitor the potential anticipated regret behavior of a retail manager to promptly formulate response strategies. Additionally, a carbon tax increases production and transportation costs, leading to higher wholesale prices, which in turn raises the anticipated regret for the downstream retailer by complicating profitability and procurement decisions. When the market's expected demand increases or carbon tax rates rise, a manufacturer needs to exercise greater caution in decision-making. Because these changes not only have a negative impact on enterprise profit but may also impact the stability of the entire supply chain. Therefore, a manufacturer needs to consider multiple factors such as market demand, environmental policies, and anticipated regret behavior of supply chain partners comprehensively to develop more rational and effective business strategies.

### 7.2. Research limitations

In this study, we present a sustainable supply chain model comprising a green manufacturer and a retailer with anticipated regret when making decisions. We examine the influence of anticipated regret on sustainable supply chains, but there are certain limitations that should be addressed in future research.

Firstly, although our model is based on the government's carbon tax policy, assuming it drives sustainable operations of enterprises, the environmental awareness of consumers plays an equally pivotal role in reality and should not be overlooked. Secondly, while our investigation primarily focuses on the anticipated regret of the retailer under the backdrop of carbon tax policy, we have overlooked the specific quantitative analysis of carbon emission levels, which is an aspect worthy of further exploration. Lastly, it is worth noting that while most studies exploring demand uncertainty related to inventory assume product prices are exogenous variables, *i.e.*, not controlled by enterprises, we also adopt this assumption in this article. However, in the actual business environment, enterprises often dynamically adjust the retail prices of their products based on changes in external market conditions to achieve better market adaptation and maximize profits.

### 7.3. Recommendations for future research

Given the many shortcomings of this article, we will endeavor to address the following issues to deepen our research in the future. Firstly, recognizing the crucial role played by consumers in environmental awareness, we plan to delve into the impact mechanism of retailer's anticipated regret behavior on sustainable supply chains under the impetus of consumer environmental consciousness in future studies. Secondly, due to the current lack of sufficient exploration into the determination of carbon emission levels, we will strive to incorporate the upstream manufacturer's endogenous determination of carbon emission levels into the scope of our research to more comprehensively reveal its impact on supply chain operations. Lastly, considering that enterprises often dynamically adjust product retail prices based on external market conditions in actual operations, we plan to treat product prices as endogenous variables in future research and further explore the specific impact of retailer's anticipated regret behavior on supply chain operations in this context.

## Appendix A.

In this study, to circumvent trivial scenarios, we introduce the assumption that the cost coefficient $k$ is significantly large, ensuring the existence of all equilibrium outcomes, *i.e.*, $k > \frac{de^2t^2}{2p}$. In the game model between the upstream manufacturer (referred to as "he") and the downstream retailer (referred to as "she"), the manufacturer assumes the role of the Stackelberg game leader, while the retailer acts as the follower.

*Scenario $R\,(\delta > 0)$: the retailer hires a manager with anticipated regret*

When the retailer hires a regretful manager, the manufacturer's and the retailer's objective functions are

$$\max_{x,w>0} \mathrm{E}\Pi_M = (w - t\,(1-x)\,e)\,q - kx^2, \quad \text{s.t.}, U_R \geq 0. \tag{A.1}$$

$$\begin{aligned}&\max_{q>0} U_R = \mathrm{E}\left[p\cdot\min\{D,q\} - wq - \delta\,|D-q|\right] = \int_0^{p+q-A} \tfrac{1}{2d}\,(p\cdot D - w\cdot q - \delta\,(q-D))\,d\varepsilon \\ &+ \int_{p+q-A}^{2d} \tfrac{1}{2d}\,((p-w)\cdot q - \delta\,(D-q))\,d\varepsilon.\end{aligned} \tag{A.2}$$

Given the manufacturer's role as the Stackelberg game leader and the retailer as the follower, we employ the backward induction method for resolution.

First, for any specified wholesale price $w$, maximizing the objective function (A.1) of the retailer enables us to derive the optimal order response function of the retailer under demand uncertainty. The retailer's objective function can be reformulated as follows:

$$\begin{aligned}&\max_{q>0} U_R = -\tfrac{(p+2\delta)q^2}{4d} + \tfrac{\left(4(A+d)\delta - 4dw + (2A-4\delta+4d)p - 2p^2\right)q}{4d} \\ &+ \tfrac{-p^3+2(A-\delta)p^2+\left(4(A+d)\delta - A^2\right)p + \left(-2A^2-4Ad-4d^2\right)\delta}{4d}.\end{aligned} \tag{A.3}$$

Clearly, the $U_R$ a is concave function. Thus, the optimal solution of the optimization problem is $q\,(w) = \frac{2\delta(A+d-p)+(A+2d)p-p^2-2dw}{p+2\delta}$.

Secondly, for any specified greenness level $x$, maximizing the objective function (A.2) of the manufacturer allows us to derive the optimal wholesale price response function of the manufacturer under demand uncertainty. It's worth noting that the constraint $U_R \geq 0$, also referred to as the participation constraint (IR), ensures the downstream retailer's acceptance of the upstream manufacturer's contract. Regarding $U_R \geq 0$, we have

$$\begin{aligned}&w \leq \tfrac{1}{2d}\left((A+2d-2\delta)\,p + 2\delta\,(A+d) - p^2\right. \\ &\left.-\sqrt{(p+2\delta)\left(\left(2p^2+2A^2+4A\,(d-p)+4d\,(d-p)\right)\delta + p(A-p)^2\right)}\right)\end{aligned}$$

Therefore, the manufacturer's objective function is rewritten as

$$\max_{x,w>0} \mathrm{E}\Pi_M = \frac{1}{p+2\delta}\left(w-t\left(1-x\right)e\right)\left(2\delta\left(A+d-p\right)+\left(A+2d\right)p-p^2-2dw\right)-kx^2, \quad \text{s.t.},$$

$$\begin{aligned} w \le \tfrac{1}{2d}\Big(&\left(A+2d-2\delta\right)p+2\delta\left(A+d\right)-p^2 \\ &-\sqrt{\left(p+2\delta\right)\left(\left(2p^2+2A^2+4A\left(d-p\right)+4d\left(d-p\right)\right)\delta+p(A-p)^2\right)}\Big). \end{aligned} \tag{A.4}$$

Because of $\frac{\partial^2 \mathrm{E}\Pi_M}{\partial w^2} = -\frac{4d}{p+2\delta} < 0$, $\mathrm{E}\Pi_M$ is concave in $w$. In this case, the Lagrangean and the KKT optimality conditions for the manufacturer's optimization problem are

$$\begin{aligned} L_1 = &\tfrac{1}{p+2\delta}\left(w-t\left(1-x\right)e\right)\left(2\delta\left(A+d-p\right)+\left(A+2d\right)p-p^2-2dw\right)-kx^2 \\ &+\lambda_1\Big(\tfrac{1}{2d}\Big(\left(A+2d-2\delta\right)p+2\delta\left(A+d\right)-p^2 \\ &-\sqrt{\left(p+2\delta\right)\left(\left(2p^2+2A^2+4A\left(d-p\right)+4d\left(d-p\right)\right)\delta+p(A-p)^2\right)}\Big)-w\Big), \end{aligned} \tag{A.5}$$

$$\frac{\partial L_1}{\partial w} = \frac{\left(p+2\delta\right)\left(A-p\right)+2d\left(p+\delta+et\left(1-x\right)\right)-4dw}{p+2\delta}-\lambda_1 = 0, \tag{A.6}$$

$$\begin{aligned} &\lambda_1\Big(\tfrac{1}{2d}\Big(\left(A+2d-2\delta\right)p+2\delta\left(A+d\right)-p^2 \\ &-\sqrt{\left(p+2\delta\right)\left(\left(2p^2+2A^2+4A\left(d-p\right)+4d\left(d-p\right)\right)\delta+p(A-p)^2\right)}\Big)-w\Big) = 0, \end{aligned} \tag{A.7}$$

$$\begin{aligned} w \le \tfrac{1}{2d}\Big(&\left(A+2d-2\delta\right)p+2\delta\left(A+d\right)-p^2 \\ &-\sqrt{\left(p+2\delta\right)\left(\left(2p^2+2A^2+4A\left(d-p\right)+4d\left(d-p\right)\right)\delta+p(A-p)^2\right)}\Big). \end{aligned} \tag{A.8}$$

We consider the following two scenarios to examine because the multiplier $\lambda_1$ can be zero or positive.

Scenario (i) $\lambda_1 = 0$: substituting $\lambda_1 = 0$ into equation (A.8), for a given $x$, we have $w\left(x\right) = \frac{2(p+\delta+(1-x)te)d+(p+2\delta)(A-p)}{4d}$. According to the equation (A.10), we have

$$x \ge \frac{\begin{array}{c}2\sqrt{\left(p+2\delta\right)\left(\left(2p^2+2A^2+4A\left(d-p\right)+4d\left(d-p\right)\right)\delta+p(A-p)^2\right)} \\ -\left(p+2\delta\right)A+p^2+2\left(\delta+d\right)p+2d\left(te-\delta\right)\end{array}}{2dte}.$$

Scenario (ii) $\lambda_1 > 0$: in terms of equation (A.6), we have

$$w\left(x\right) = \frac{\begin{array}{c}2\delta\left(A+d\right)-p^2+\left(A-2\delta+2d\right)p \\ -\sqrt{\left(p+2\delta\right)\left(\left(2p^2+2A^2+4A\left(d-p\right)+4d\left(d-p\right)\right)\delta+p(A-p)^2\right)}\end{array}}{2d}.$$

The multiplier $\lambda_1 > 0$ requires $x < \frac{\begin{array}{c}2\sqrt{\left(p+2\delta\right)\left(\left(2p^2+2A^2+4A\left(d-p\right)+4d\left(d-p\right)\right)\delta+p(A-p)^2\right)} \\ -\left(p+2\delta\right)A+p^2+2\left(\delta+d\right)p+2d\left(te-\delta\right)\end{array}}{2dte}$.

Finally, based on the above optimal responsible functions, we can obtain the manufacturer's optimal greenness level.

(1) When $x < \frac{\begin{array}{c}2\sqrt{\left(p+2\delta\right)\left(\left(2p^2+2A^2+4A\left(d-p\right)+4d\left(d-p\right)\right)\delta+p(A-p)^2\right)} \\ -\left(p+2\delta\right)A+p^2+2\left(\delta+d\right)p+2d\left(te-\delta\right)\end{array}}{2dte}$, the manufacturer's objective function is

$$\max_{x>0} \mathrm{E}\Pi_M = \left( \frac{\begin{array}{l} 2\delta(A+d) - p^2 + (A - 2\delta + 2d)p \\ -\sqrt{(p+2\delta)\left((2p^2+2A^2+4A(d-p)+4d(d-p))\delta + p(A-p)^2\right)} \end{array}}{2d} - t(1-x)e \right) q - kx^2$$

. Clearly, the optimal solution is $x^{R*} = \frac{te\sqrt{(p+2\delta)\left((2p^2+2A^2+4A(d-p)+4d(d-p))\delta+p(A-p)^2\right)}}{2k(p+2\delta)}$. The inequality $x < \frac{\begin{array}{l} 2\sqrt{(p+2\delta)\left((2p^2+2A^2+4A(d-p)+4d(d-p))\delta+p(A-p)^2\right)} \\ -(p+2\delta)A + p^2 + 2(\delta+d)p + 2d(te-\delta) \end{array}}{2dte}$ requires $\delta < \delta_1$, where $\delta_1$ is a positive root of the equation

$$\begin{array}{l} \left(t^2 d - 2k(p+2\delta)\right)\sqrt{(p+2\delta)\left((2p^2+2A^2+4A(d-p)+4d(d-p))\delta+p(A-p)^2\right)} \\ +k\left(2\delta(A+d) - p^2 + (A-2\delta+2d)p - 2td\right)(p+2\delta) = 0 \end{array}.$$

(2) When $x \geq \frac{\begin{array}{l} 2\sqrt{(p+2\delta)\left((2p^2+2A^2+4A(d-p)+4d(d-p))\delta+p(A-p)^2\right)} \\ -(p+2\delta)A + p^2 + 2(\delta+d)p + 2d(te-\delta) \end{array}}{2dte}$, the manufacturer's objective function is $\max_{x>0} \mathrm{E}\Pi_M = \left(\frac{2(p+\delta+(1-x)te)d+(p+2\delta)(A-p)}{4d} - t(1-x)e\right)q - kx^2$. Obviously, $\mathrm{E}\Pi_M$ is concave in $x$. Thus, the optimization problem's interior solution is $x^{R*} = \frac{\left(2\delta(A+d)-p^2+(A-2\delta+2d)p-2ted\right)te}{4k(p+2\delta)-2t^2e^2d}$. The inequality $x \geq \frac{\begin{array}{l} 2\sqrt{(p+2\delta)\left((2p^2+2A^2+4A(d-p)+4d(d-p))\delta+p(A-p)^2\right)} \\ -(p+2\delta)A + p^2 + 2(\delta+d)p + 2d(te-\delta) \end{array}}{2dte}$ requires $\delta \leq \delta_1$. Clearly, the optimization problem's corner solution is $x^{R*} = \frac{te\sqrt{(p+2\delta)\left((2p^2+2A^2+4A(d-p)+4d(d-p))\delta+p(A-p)^2\right)}}{2k(p+2\delta)}$ when $\delta > \delta_1$.

According to (1) and (2), we can obtain the manufacture's optimal greenness level is

(i) if $\delta > \delta_1$, then $x^{R*} = \frac{te\sqrt{(p+2\delta)\left((2p^2+2A^2+4A(d-p)+4d(d-p))\delta+p(A-p)^2\right)}}{2k(p+2\delta)}$;
(ii) otherwise, $x^{R*} = \frac{\left(2\delta(A+d)-p^2+(A-2\delta+2d)p-2ted\right)te}{4k(p+2\delta)-2t^2e^2d}$.

Substituting the optimal greenness level into optimal responsible functions, we have

(i) if $\delta > \delta_1$, then $w^{R*} = \frac{\begin{array}{l} (A+2d-2\delta)p + 2\delta(A+d) - p^2 \\ -\sqrt{(p+2\delta)\left((2p^2+2A^2+4A(d-p)+4d(d-p))\delta+p(A-p)^2\right)} \end{array}}{2d}$.
(ii) otherwise, $w^{R*} = \frac{2(p+\delta+(1-x)te)d+(p+2\delta)(A-p)}{4d}$. Based on the optimal wholesale price and $q(w) = \frac{2\delta(A+d-p)+(A+2d)p-p^2-2dw^{R*}}{p+2\delta}$, we can obtain the optimal order quantity $q^{R*} = \frac{2\delta(A+d)+(A+2d-2\delta)p-p^2-2dte(1-x)}{2(p+2\delta)}$ when $\delta \geq \delta_1$; otherwise, $q^{R*} = \frac{\sqrt{(p+2\delta)\left((2p^2+2A^2+4A(d-p)+4d(d-p))\delta+p(A-p)^2\right)}}{p+2\delta}$.

According to these optimal decisions, we can obtain the manufacturer's and the retailer's expected profits are

(i) if $\delta > \delta_1$, then

$$\begin{aligned}
&\mathrm{E}\Pi_M^{R*} = \tfrac{1}{4e^2t^2d^2}\left(4k\left(2d\left(p+\delta-et\right)+\left(p+2\delta\right)\left(A-p\right)\right)\right.\\
&\times\sqrt{\begin{aligned}&\left(p+2\delta\right)\left(\left(2p^2+2A^2+4A\left(d-p\right)+4d\left(d-p\right)\right)\delta+p(A-p)^2\right)\\ &-d^2\left(36\delta^2+\left(24p-8et\right)\delta+4(p-et)^2\right)-4d\left(p+2\delta\right)\left(p+5\delta-et\right)\left(A-p\right)\end{aligned}}\\
&\left.-5k(p+2\delta)^2(A-p)^2+2de^2t^2\left(4\delta d^2+4\delta d\left(A-p\right)+\left(A-p\right)^2\left(p+2\delta\right)\right)\right)
\end{aligned}$$

, and

$$\begin{aligned}
&\mathrm{E}\Pi_R^{R*} = \tfrac{1}{d(p+2\delta)}\left(\left(\left(p-A-d\right)\right.\right.\\
&\times\sqrt{\left(p+2\delta\right)\left(\left(2p^2+2A^2+4A\left(d-p\right)+4d\left(d-p\right)\right)\delta+p(A-p)^2\right)}\\
&\left.\left.+p^3-\left(2A+2\delta-d\right)p^2+\left(A^2+Ad+d^2-4\delta\left(A+d\right)\right)p+2\delta\left(A^2+2dA+2d^2\right)\right)\delta\right).
\end{aligned}$$

(ii) otherwise, $\mathrm{E}\Pi_M^{R*} = \frac{k(2d(p+\delta-et)+(p+2\delta)(A-p))^2}{d(8k(p+2\delta)-4de^2t^2)}$, and

$$\begin{aligned}
&\mathrm{E}\Pi_R^{R*} = \tfrac{1}{8d(2k(p+2\delta)-de^2t^2)}\left(8t^2\delta\left(p+\delta-et\right)kd^3\right.\\
&-\begin{pmatrix}-4\left(p^2+\left(\delta-et\right)p-4\delta\left(et+\delta\right)\right)\left(p+\delta-et\right)k^2-4\delta\left(A-p\right)t^2\left(3p-2et+4\delta\right)k\\ +pe^4t^4(A-p)^2\end{pmatrix}d^2\\
&+4k\left(\left(k-e^2t^2\right)p^2+\left(et\left(Aet-k\right)-\left(k+e^2t^2\right)\delta\right)p+\delta Ae^2t^2-4\delta^2k\right)\left(A-p\right)\left(p+2\delta\right)d\\
&\left.-\left(3p+4\delta\right)\left(p+2\delta\right)^2k^2(A-p)^2\right).
\end{aligned}$$

*Scenario $N$ ($\delta = 0$): the retailer hires a manager without anticipated regret*

In this section, when $\delta = 0$ in Scenario $R$, it transforms into Scenario $N$. Here, we denote the absence of retailer regret-biased behavior with the superscript "NR". When the retailer employs a realistic manager, the objective functions of both the manufacturer and the retailer are

$$\max_{x,w>0} \mathrm{E}\Pi_M = \left(w - t\left(1-x\right)e\right)q - kx^2, \tag{A.9}$$

$$\begin{aligned} U_R &= \mathrm{E}\left[p\cdot\min\left\{D,q\right\}-wq\right]\\ &= \int_0^{p+q-A}\tfrac{1}{2d}\left(p\cdot D - w\cdot q\right)d\varepsilon + \int_{p+q-A}^{2d}\tfrac{1}{2d}\left(\left(p-w\right)\cdot q\right)d\varepsilon. \end{aligned} \tag{A.10}$$

According to backward induction, we can obtain the optimal decisions of the manufacturer and the retailer are $x^{N*} = \frac{\left((A+2d)p-p^2-2dte\right)et}{4kp-2de^2t^2}$, $w^{N*} = \frac{p\left(kp(A-p)+\left(\left(e^2t^2+2k\right)p-Ae^2t^2+2ket\right)d-2d^2e^2t^2\right)}{(4kp-2e^2t^2d)d}$, and $q^{N*} = \frac{k\left((A+2d)p-2dte-p^2\right)}{2kp-e^2t^2d}$.

Based on these optimal decisions, we can obtain the decision makers' expected profits are $\mathrm{E}\Pi_M^{N*} = \frac{k(p(A-p)+2d(p-et))^2}{d(8kp-4dt^2e^2)}$, and $\mathrm{E}\Pi_R^{N*} = \frac{p\left(d\left(et\left(Aet+2k\right)-p\left(e^2t^2+2k\right)\right)-3kp\left(A-p\right)\right)\times\left(kp\left(A-p\right)+d\left(2ket-ae^2t^2+\left(e^2t^2-2k\right)p\right)\right)}{4d(2kp-de^2t^2)}$.

*The Proof of Lemmas 1–2, Proposition 1–2*

According to the equilibrium outcome we obtained above under different scenarios, the Lemmas 1, 2, Propositions 1 and 2 are easy to be proved, we thus omit them.

## Appendix B.

The statistical data involved in the table in the article can be found in an Excel file called "profit_results. xlsx". We will offer these parameter sting in MATLAB code as follows:

```
% parameters
a_values = [0.1, 0.4, 0.7, 1, 1.3, 1.6];
m_values = [0.1, 0.2, 0.3, 0.4, 0.5, 0.6];
e = 1;
```

t_values = [0.1, 0.2, 0.3, 0.4, 0.5];
p_values =[0.1, 0.3, 0.6, 0.9];
delta_values =[0.1, 0.2, 0.3, 0.4, 0.5];
k_values = [0.1, 0.3, 0.5, 0.7, 0.9];
% Initialize result matrix
result_table = zeros(1, 9);
% Initialize counter
positive_diff_M = 0;
negative_diff_M = 0;
positive_diff_R = 0;
negative_diff_R = 0;

## Funding

Research of this paper is supported by 2024 Chongqing Education Commission Humanities and Social Sciences Research Youth Project (24SKGH099) and the National Natural Science Foundation of China (General Program, 12271071).

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