Article │ Received 26 July 2024; Accepted 1 January 2025; Published 7 February 2025
https://doi.org/10.55092/blockchain20250002

Leveraging blockchain technology for carbon footprint information sharing

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Highlights:

- The information sharing strategies of green supply chains, greenwashing, and blockchain technology.
- The sharing of carbon footprint information via blockchain platforms serves to eliminate the negative influence of the “greenwashing” phenomenon.
- The information sharing decisions of carbon footprints of manufacturers and retailers, as well as the revenue situations of supply chain members under the sharing structure.

Abstract: This paper investigates the information sharing strategies of green supply chains, greenwashing, and blockchain technology. The unobservable green activities in the manufacturing process references to those aspects of logistics activities that are imperceptible to consumers. To ensure that consumers perceive authentic green information without being influenced by greenwashing, the retailer and manufacturer can collaborate on establishing a blockchain platform for sharing the manufacturer’s carbon footprint data. The research findings indicate that the manufacturer may be motivated to share its carbon footprint information to stimulate consumer demand for green products. Additionally, the retailer may proactively invest in constructing a blockchain platform to facilitate the sharing of the manufacturer’s carbon footprint data and enhance sales profitability. Analysis indicates that when consumers possess a higher anticipated level of unobservable greenness and exhibit greater sensitivity to green issues, there is an enhanced motivation for both manufacturers and retailers to implement blockchain technology. Interestingly, due to the construction costs associated with implementing the blockchain platform, the manufacturer and retailer are more likely to collaborate on this endeavor. However, this shift in the information sharing structure benefits all members of the supply chain, resulting in a mutually beneficial outcome. Furthermore, the dominant blockchain strategy is influenced by factors such as cost and market strategy.

Keywords: information sharing; greenwashing; blockchain; green supply chain

1. Introduction

The deterioration of the global environment has garnered significant worldwide attention due to the increasing awareness of environmental preservation. As a result, consumers are more inclined to purchase ecofriendly products for their additional ecological benefits [1]. In response to government regulations and consumer demand, businesses have begun producing green products and adopting environmentally conscious practices in order to conserve energy, mitigate emissions, and establish a presence in the burgeoning green market.

However, because manufacturers do not fully disclose their information, consumers and retailers lack access to comprehensive carbon footprint data covering the entire process from raw material procurement through production, manufacturing, and transportation. Additionally, some companies may engage in deceptive practices known as ‘greenwashing’ by failing to implement the environmentally friendly measures they advertise. As an example of this issue, Beijing Shounong Animal Husbandry Development Co., Ltd., a subsidiary of Sanyuan Food (a well-known company specializing in sustainable food products) was discovered discharging sewage into multiple seepage pits in an attempt to avoid regulatory oversight, which resulted in environmental pollution [2]. The Japanese company Oji Paper was indefinitely suspended due to opposition from environmentally conscious individuals, as there is no empirical evidence supporting the feasibility of its claimed zero-emission discharge into the sea. Therefore, due to the prevailing environmental consciousness among the general public, Oji Paper’s project discharging pollutants into the sea has been indefinitely suspended [3].

The lack of transparency in information is the root cause of greenwashing [4]. Retailers and consumers expect information platforms to effectively monitor manufacturers' carbon footprint, validate the sustainability of products throughout their life cycle, and enhance consumer awareness regarding the environmental impact of products. The implementation of blockchain technology has the potential to enhance supply chain transparency and traceability. By leveraging the decentralized, distributed, and immutable information architecture of blockchain, carbon footprint data can be shared to provide consumers with authentic green activity information [5]. For instance, as a strategic retailer, JD Zhizhen Chain can access source information from suppliers. JD Zhizhen Chain enhances the transparency and traceability of its supply chain, thereby delivering safe and reliable products to consumers [6]. BYD established a blockchain-based ecosystem known as Vechain to meticulously document carbon footprint data and disseminate low-carbon information to interested consumers [7].

However, the willingness of manufacturers to disclose carbon footprint information plays a crucial role. By leveraging blockchain technology for sharing such information, the issue of greenwashing can be effectively addressed [8]. Additionally, the decision to share these data is influenced by the construction cost associated with implementing a blockchain platform. If manufacturers choose to disclose their carbon footprint information, consumers will have access to more accurate measures of environmental sustainability, and retailers can adapt their marketing strategies accordingly.

Based on the aforementioned discussion, this paper investigates the issue of sharing carbon footprint information and distinguishes between scenarios led by manufacturers and retailers. Specifically, we propose an alternative perspective regarding green information that manufacturers are unable to observe as private data. We adopt a model featuring asymmetric information between the manufacturer and retailer to address this problem. Initially, both the manufacturer and retailer establish commitments for sharing or concealing carbon footprint information. Subsequently, if information sharing is chosen, a collaborative decision is made regarding whether the manufacturer or retailer takes the lead in establishing a blockchain platform to facilitate such sharing. Based on this outcome, the retailer determines the retail profit margin, while the manufacturer determines both the greeness level and wholesale price of its product.

In this paper, we address the following research questions:

How does the sharing of carbon footprint information by manufacturers impact the profitability of supply chain members?

Who should take the lead in establishing a blockchain platform when manufacturers choose to share carbon footprint information?

To accurately answer these questions, we present a supply chain consisting of manufacturers and dominant retailers. In the non-sharing scenario, the retailer determines retail profit margins, while the manufacturer sets wholesale prices and product greenness. As consumers cannot directly the green activities during raw material procurement, production, and transportation, they constitute the unobservable greenness of products, which is also the carbon footprint information that consumers want shared. In the information-sharing scenario, the member responsible for leading blockchain platform construction bears the implementation costs, while the other party pays usage fees. By utilizing blockchain technology, the manufacturer can record its carbon footprint information on the platform and facilitate sharing.

We demonstrate that in equilibrium, when the manufacturer's latent greenness is relatively high, information sharing facilitates a mutually beneficial profit outcome. Specifically, a higher level of unobservable greenness leads to enhanced consumer perceptions of product sustainability through carbon footprint disclosure, thereby stimulating product demand and augmenting supply chain members' profits. However, while determining the decision to share information does not impact the product price based on the leading blockchain-constructing member within the supply chain, it primarily depends on factors such as blockchain usage costs, unobservable greenness, and consumers' sensitivity to environmental concerns. The aforementioned observation also offers a novel theoretical explanation and decision-making foundation for the establishment of a blockchain platform aimed at achieving information sharing.

The remaining sections of the paper are organized as follows: Section 2 provides a comprehensive literature review and identifies existing research gaps. Section 3 presents an asymmetric information game model involving manufacturers and dominant retailers to determine the decision-making process involved in establishing a blockchain platform for sharing carbon footprint information. Section 4 introduces the equilibrium analysis of this game model. In Section 5, a comparative analysis is conducted on the decisions made within the game to examine manufacturers' choices concerning carbon footprint information sharing and their subsequent impact on supply chain members. Finally, Section 6 concludes by summarizing the key findings and contributions of this study. All the proofs are given in the Appendix.

2. Literature

Our paper is related to three streams of literature: greenwashing, blockchain adoption, and information sharing.

2.1. Greenwashing

An empirical comparison conducted by Nygaard & Silkoset [8] revealed that blockchain information offers superior consumer protection against greenwashing in comparison to an authentication system. He, Gan & Zhong [9] conducted a study on the greenwashing strategies employed by enterprises, which utilize environmental information to communicate their desired environmental image to external stakeholders, in alignment with the green credit policy. The findings of this study indicate that when the green credit policy targets enterprises operating in regions with low levels of environmental supervision and economic underdevelopment, these enterprises are more inclined to adopt transparent and environmentally focused information. However, such practices may have detrimental effects on financial, environmental, and social performance. The positive and negative aspects of corporate greenwashing were examined by Wu, Zhang & Xie [10] from the perspective of social responsibility. Their study revealed that adequate transparency can effectively eradicate greenwashing practices and provide incentives for socially responsible companies to make additional investments in environmentally friendly initiatives.

Our study builds upon the aforementioned research findings and examines the influence of greenwashing behavior on consumer demand.

2.2. Blockchain adoption

The blockchain is essentially a distributed ledger that possesses the characteristics of immutability, decentralization, and transparency [11,12]. Hastig & Sodhi [13] demonstrated that the implementation of blockchain-based traceability systems can enhance sustainability performance, optimize operational efficiency, and bolster supply chain coordination. Zhang *et al.* [14] revealed that retailers can leverage blockchain technology to enhance information transparency, thereby appealing to consumers. Biswas *et al.* [5] developed a supply chain model comprising a manufacturer and a retailer, integrating blockchain technology to enhance the traceability of the supply chain in response to consumer demand for traceability. The research findings indicated that a lower level of distrust can positively impact the profitability of the supply chain, particularly when the cost associated with implementing blockchain is minimal. Dong *et al.* [15] conducted a study on the application of blockchain technology in mitigating greenwashing practices within logistics enterprises based on their prevalent occurrence.

The findings indicate that despite the potential risks involved, logistics enterprises may still engage in greenwashing when the adoption cost of blockchain is prohibitively high. Hence, our research endeavors to enhance supply chain traceability and transparency through the implementation of blockchain technology. In contrast to prior studies, this paper introduces blockchain as a means to facilitate the sharing of carbon footprint information, enabling consumers to gain insights into manufacturers' genuine environmental practices.

2.3. Information sharing

The focus of our research lies within the realm of supply chain information sharing. Li *et al.* [16] and Huang *et al.* [17] both established an information asymmetrical supply chain comprising suppliers and retailers, wherein they discovered that altering the structure of information sharing in various scenarios resulted in unforeseen advantages. Li & Zhang [18] proposed a novel wholesale pricing mechanism that facilitates information exchange between retailers with relatively limited bargaining power and manufacturers with stronger market positions, thereby mutually enhancing their performance. The study conducted by Ha *et al.* [19] focused on the information sharing dynamics between a supplier and agent on an online platform. Specifically, it examined the sequence of decision-making processes in which information sharing decisions preceded appropriation decisions. Furthermore, this research investigated how the interplay between channel structure and information sharing behaviour shapes various aspects of the relationship, including commission rates, channel substitutability, and information accuracy.

The present study builds upon the classical asymmetric information model to address a novel issue. In light of the greenwashing practices adopted by certain enterprises, consumer demand becomes uncertain, while some manufacturers possess private information regarding their green activities. Our research aims to investigate how manufacturers' decisions on information sharing and the implementation of blockchain technology within the supply chain impact the profits of its members.

3. Model decision

Consider a supply chain in which a manufacturer procures green products for a retailer. Consumers can perceive certain aspects of green products, such as adherence to green standards and the utilization of new energy sources. However, there are also unobservable greenness levels that consumers cannot discern, including the use of recycled raw materials and environmentally friendly practices during warehousing and transportation processes. In line with Dong [15], this distinction highlights two categories of greenness: observable and unobservable. Due to the lack of transparency in information, retailers are unable to accurately observe the unobservable green activities of manufacturers or effectively communicate this hidden green information to consumers. Consequently, enterprises may engage in deceptive practices known as greenwashing, which creates uncertainty about the unobservable greenness level. Consumers are sceptical of green practices that lack direct visibility in the manufacturing process due to manufacturers' greenwashing behavior. Consequently, when manufacturers withhold carbon footprint information, consumers perceive the expected level of unobservable greenness. Conversely, when manufacturers disclose carbon footprint information, consumers perceive the actual level of unobservable greenness. Based on this, we denote the enterprise’s observable and unobservable greenness levels as g and θ, respectively, where θ is uniformly distributed within $[0,2d]$ [15,17]. As such, we can use d to denote the expectation of an unobservable greenness level. While consumer environmental awareness has grown, products with higher levels of sustainability inspire greater demand from consumers. The sensitivity of consumers to the degree of sustainability is represented by λ. Thus, the consumer's utility derived from unobservable green information can be represented by its expected value λd. Let p denote the retail price of the green product. Consequently, consumer utility U can be expressed as follows.

$$U = v - p + (g + E_{\theta})\lambda.$$

Market size is normalized to one. Consumers will buy the product when their utility is positive, $U > 0$. We can deduce that the product demand D is:

$$D = 1 - p + (g + E_{\theta})\lambda.$$

We consider the price leadership structure led by a dominant retailer, as it possesses the capability to spearhead the establishment of a blockchain platform. For instance, Walmart relies on the IBM blockchain platform to track food traceability across its supply chain [20]. In retail decision-making, both Walmart and Tesco require manufacturers and suppliers to ensure profit margins [21]. Consequently, based on the relevant literature, Gao *et al.* [22], Fan *et al.* [23], retailers under this structure determine their retail profit margins prior to manufacturers selecting wholesale prices. The timeline depicting this process can be found in Figure 1.

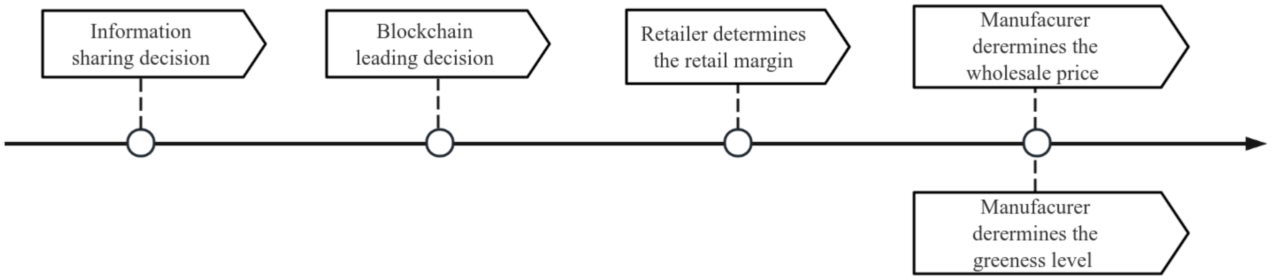

Figure 1. Timeline of retail profit margin determination and wholesale price selection.

A lack of transparency in supply chain information is the fundamental cause of greenwashing. To address this issue, we propose leveraging blockchain technology to enhance information transparency within the supply chain, ensuring the reliability and observability of greenness data. The decision to share carbon footprint information between the manufacturer and retailer plays a pivotal role. If they opt to establish a collaborative decision-making process, both parties must jointly determine the leader responsible for building the blockchain platform dedicated to sharing carbon footprint information. Once the establishment of the blockchain platform is confirmed, both manufacturers and retailers are obligated to uphold their commitments. Failure to do so would result in only manufacturers having access to unobservable greenness data, while retailers remain uncertain about the extent of unobservable sustainable practices, thus impeding accurate communication with consumers. Notably, such predetermined decisions regarding information sharing have been widely adopted in the relevant literature. After receiving (or not receiving) unobservable greenness information, the retailer chooses the retail margin r. Then, the manufacturer establishes the wholesale price w and the observable greenness level g. Finally, the manufacturer goes into production.

We assume that the costs of the greenness levels g and θ for the manufacturer are $\frac{1}{2}mg^2$ and $\frac{1}{2}m\theta^2$, respectively. We normalize both the manufacturer's production cost and the retailer's sales cost to zero. When the manufacturer (retailer) dominates the construction of the blockchain platform, it needs to invest the blockchain construction cost tb, and the retailer (manufacturer) pays the platform use cost cb. All players in the supply chain are risk neutral and seek to maximize their expected payoffs. Let π_m, π_R denote the profits of the manufacturer and retailer. A summary of the major notations is listed in Table 1.

Table 1. Overview of notations.

Notation	Description
Indices	
p	Retailer's unit retail price in the final market
q	Quantity of product demand
θ	Product's unobservable greenness level
v	Consumers reservation unit price
λ	Sensitivity of customers to the greenness level
m	Green technology investment cost per unit level
tb	Blockchain platform implementation cost
cb	Blockchain platform usage cost
e	Carbon emission per unit product
Decision variables	
w	Manufacturer's unit wholesale price
r	Retailer's retail margin, r=p-w
g	Product's observable greenness level
Outputs	
$\Pi_{m,}\Pi_r$	Manufacturer's profit, retailer's profit
Em	Carbon emissions of the manufacturer

3.1. Analysis

In this section, we investigate the supplier's carbon footprint information sharing strategy among different members leading to the establishment of a blockchain platform. Initially, we address optimal decisions and expected profits for suppliers and retailers when carbon footprint information is not shared. Subsequently, we explore scenarios in which either the retailer or supplier leads in establishing a blockchain platform for carbon footprint information sharing and compare expected revenues between the information-sharing and non-sharing cases.

3.2. Carbon footprint information non-sharing cases

When suppliers do not share carbon footprint information, this model becomes a retailer-led Stackelberg model setting featuring asymmetric information. Only manufacturers possess these data, rendering them unobservable to retailers and consumers. Retailers determine the retail profit margin based on anticipated profits, while manufacturers establish wholesale prices and observable greenness levels of products based on expected profits. The superscript "NS" denotes the scenario in which the manufacturer does not share carbon footprint information. The payoff function is given by:

$$\Pi_m^{NS} = E_\theta\{wq\} - \frac{1}{2}mg^2 - \frac{1}{2}m\theta^2,$$

$$\Pi_r^{NS} = E_\theta\{(p-w)q\}.$$

Proposition 1. In the carbon footprint information non-sharing cases, if $\frac{\lambda^2}{2} < m < \frac{3+6d\lambda+19d^2\lambda^2}{32d^2}$, the optimal values for the observable greenness level, wholesale price, retail profit margin, manufacturer's expected profit, and retailer's expected profit are:

$$g^{NS*} = \frac{\lambda(1+d\lambda)}{4m-2\lambda^2}, w^{NS*} = \frac{m+dm\lambda}{4m-2\lambda^2}, r^{NS*} = \frac{1}{2}(1+d\lambda)$$

$$\Pi_m^{NS*} = \frac{m(3+6d\lambda+d^2(-32m+19\lambda^2))}{48m-24\lambda^2}, \Pi_r^{NS*} = \frac{m(1+d\lambda)^2}{8m-4\lambda^2}$$

The analytical solution is obtained through the inverse solution method and all proofs are provided in the Appendix. The condition $\frac{\lambda^2}{2} < m < \frac{3+6d\lambda+19d^2\lambda^2}{32d^2}$ ensures an optimal value for the retail profit margin. Thus, advancements in green technology require a certain investment cost, which may lead to instances of unobservable green activities being misrepresented as environmentally friendly.

Corollary 1. The retailer’s expected profit increases in the expected unobservable greenness level. On the other hand, the manufacturer’s expected profit increases consistently by either reducing the investment cost per greenness level or accepting higher investment costs per greenness level but with a lower expected unobservable greenness level:

$$\frac{\partial \Pi_r^{NS*}}{\partial d} > 0, if\ m > \frac{\lambda^2}{2}, \mathrm{d} > 0$$

$$\frac{\partial \Pi_m^{NS*}}{\partial d} > 0, if\ \frac{\lambda^2}{2} < m < \frac{19\lambda^2}{32} or\ m > \frac{19\lambda^2}{32}, 0 < \mathrm{d} < \frac{3\lambda}{32m-19\lambda^2}$$

$$\frac{\partial \Pi_m^{NS*}}{\partial d} < 0, if\ m > \frac{19\lambda^2}{32}, \mathrm{d} > \frac{3\lambda}{32m-19\lambda^2}$$

According to Corollary 1, the retailer can benefit from improvements in the unobservable greenness level that the manufacturer is unable to observe, while the manufacturer may not reap the same benefits. When the investment in greenness-level units and the unobservable greenness level are high, the manufacturer’s high unobservable greenness costs do not result in higher revenue but rather reduce profits due to their elevated expenses. Consequently, we posit that the cost of investment per greenness level constrains a manufacturer’s ability to achieve higher greenness.

3.3. Carbon footprint information sharing cases (retailer-led blockchain)

After the manufacturer decides to share carbon footprint information, the retailer and manufacturer collaborate to determine who will establish the blockchain system. By investing in building a blockchain platform that enables the manufacturer to share its carbon footprint data, the retailer enables both itself and consumers to access previously unobservable green information. As a result, both the retailer and manufacturer have symmetric information when making decisions regarding the retail profit margin, wholesale price, and observable greenness. The superscript “SR” denotes the scenario where the retailer dominates the establishment of a blockchain platform sharing the manufacturer’s carbon footprint information. The payoff function is given by:

$$\Pi_m^{SR} = (w-cb)q - \frac{1}{2}mg^2 - \frac{1}{2}m\theta^2,$$

$$\Pi_r^{SR} = (p-w)q - tb.$$

Proposition 2. In the carbon footprint information sharing cases (retailer-led blockchain), if $0 < cb < 1+\theta\lambda,$, the optimal values for observable greenness, wholesale price, retail profit margin, manufacturer's expected profit, and retailer's expected profit are:

$$g^{SR*}=\frac{\lambda(1-\mathrm{cb}+\theta\lambda)}{4m-2\lambda^2},w^{SR*}=\frac{m+3\mathrm{cb}m+m\theta\lambda-2\mathrm{cb}\lambda^2}{4m-2\lambda^2},r^{SR*}=\frac{1}{2}(1-\mathrm{cb}+\theta\lambda)$$

$$\Pi_m^{SR*}=\frac{m\big(3+3\mathrm{cb}^2+6d\lambda-6\mathrm{cb}(1+d\lambda)+4d^2(-8m+5\lambda^2)\big)}{48m-24\lambda^2}$$

$$\Pi_r^{SR*}=\frac{3m((-1+\mathrm{cb})^2-8\mathrm{tb})-6(-1+\mathrm{cb})dm\lambda+4(d^2m+3\mathrm{tb})\lambda^2}{24m-12\lambda^2}$$

Corollary 2. The enterprise's profit exhibits a monotonically decreasing trend as the cost of utilizing the blockchain platform decreases. Conversely, the profit demonstrates a monotonically increasing trend as the cost increases:

$$\frac{\partial\Pi_r^{SR*}}{\partial cb}>0,\frac{\partial\Pi_{\mathrm{m}}^{SR*}}{\partial cb}>0,if\ 1+\mathrm{d}\lambda<cb<1+\theta\lambda,(\theta>d)$$

$$\frac{\partial\Pi_r^{SR*}}{\partial cb}<0,\frac{\partial\Pi_{\mathrm{m}}^{SR*}}{\partial cb}<0,if\ 0<cb<\min\{1+\mathrm{d}\lambda,1+\theta\lambda\}$$

According to Corollary 2, the utilization of blockchain technology by manufacturers generally leads to an increase in costs and a decrease in enterprise profits. Interestingly, when the manufacturer's cost of utilizing blockchain is high ($cb>1+\mathrm{d}\lambda$) and the unobservable greenness level exceeds the expected value ($\theta>d$), the enterprise's profit increases with an increase in the cost of using blockchain. The introduction of blockchain technology in the supply chain leads to greater green utility for consumers, resulting in increased demand. As a result, manufacturers reduce their observable greenness and wholesale price due to the elevated cost of utilizing blockchain, which subsequently lowers retail prices and further stimulates demand, ultimately resulting in increased enterprise profit.

3.4. Carbon footprint information sharing cases (manufacturer-led blockchain)

In this case, the manufacturer invests in building the blockchain platform and shares carbon footprint information. The retailer pays for platform use to obtain carbon footprint information to perceive unobserved green information. As a result, both the retailer and manufacturer have symmetric information when making decisions regarding the retail profit margin, wholesale price, and observable greenness. The superscript "SM" denotes the scenario where the manufacturer dominates the establishment of a blockchain platform sharing the manufacturer’s carbon footprint information. The payoff function is given by:

$$\Pi_m^{SM}=wq-\frac{1}{2}mg^2-\frac{1}{2}m\theta^2-\mathrm{tb},$$

$$\Pi_r^{SM}=(p-w-cb)q.$$

Proposition 3. In the carbon footprint information sharing cases (manufacturer-led blockchain), if $0<\mathrm{tb}<\frac{3m-6\mathrm{cb}m+3\mathrm{cb}^2m-32d^2m^2+6dm\lambda-6\mathrm{cb}dm\lambda+20d^2m\lambda^2}{48m-24\lambda^2},0<cb<1+\theta\lambda,\frac{\lambda^2}{2}<m<\frac{3-6\mathrm{cb}+3\mathrm{cb}^2+6d\lambda-6\mathrm{cb}d\lambda+20d^2\lambda^2}{32d^2}$, the optimal values for the observable greenness, wholesale price, retail profit margin, manufacturer’s expected profit, and retailer's expected profit are:

$$g^{SM*}=\frac{\lambda(1-\mathrm{cb}+\theta\lambda)}{4m-2\lambda^2},w^{SM*}=\frac{m(1-\mathrm{cb}+\theta\lambda)}{4m-2\lambda^2},r^{SM*}=\frac{1}{2}(1+\mathrm{cb}+\theta\lambda)$$

$$\Pi_m^{SM*}=\frac{m(3+3(-2+\mathrm{cb})\mathrm{cb}-32d^2m-48\mathrm{tb})-6(-1+\mathrm{cb})dm\lambda+4(5d^2m+6\mathrm{tb})\lambda^2}{48m-24\lambda^2}$$

$$\Pi_r^{SM*}=\frac{m\big(3+3\mathrm{cb}^2-6\mathrm{cb}(1+d\lambda)+2d\lambda(3+2d\lambda)\big)}{24m-12\lambda^2}$$

Corollary 3. The enterprise's profit exhibits a monotonically decreasing trend as the cost of utilizing the blockchain platform decreases. Conversely, the profit demonstrates a monotonically increasing trend as the cost increases:

$$\frac{\partial \Pi_r^{SM*}}{\partial cb} > 0, \frac{\partial \Pi_{\mathrm{m}}^{SM*}}{\partial cb} > 0, if\ 1 + \mathrm{d}\lambda < cb < 1 + \theta\lambda, (\theta > d)$$
$$\frac{\partial \Pi_r^{SM*}}{\partial cb} < 0, \frac{\partial \Pi_{\mathrm{m}}^{SM*}}{\partial cb} < 0, if\ 0 < cb < \min\{1 + \mathrm{d}\lambda, 1 + \theta\lambda\}$$

Corollary 2 and Corollary 3 yield consistent findings, suggesting that the impact of blockchain adoption on supply chain members' profitability remains unchanged in scenarios characterized by retailer dominance or supplier dominance. Through the calculation of Proposition 2 and Proposition 3, it becomes evident that $p^{SR*} = p^{SM*} = \frac{m(3+\mathrm{cb}+3\theta\lambda)-\lambda^2(1+\mathrm{cb}+\theta\lambda)}{4m-2\lambda^2}$. Although optimal wholesale prices and retail profit margins for manufacturers may vary across different scenarios where different supply chain members implement blockchain, consumer demand is determined by shared carbon footprint information and consumers' certain perceptions of green credentials. At this point, internal coordination within the supply chain establishes the best product retail prices. As various members dominate blockchain implementation across different supply chains, they incur varying costs associated with blockchain technology. Hence, differences exist in terms of wholesale prices and retail profit margins.

Furthermore, through the calculation of Proposition 2 and Proposition 3, it becomes evident that $g^{SR*} = g^{SM*} = \frac{\lambda(1-\mathrm{cb}+\theta\lambda)}{4m-2\lambda^2}$. This indicates that the manufacturer's decision regarding the level of environmental sustainability is independent of the dominant power in blockchain platform construction but rather influenced by the associated costs. Even if the manufacturer invests in establishing a blockchain platform and charges retailers for its usage, retailers hold a dominant position in determining retail profit margins, thereby impacting the manufacturer's decision-making process with regard to incorporating blockchain technology.

4. Discussion

In this section, we compare the profitability of a sharing strategy model with that of a no-sharing strategy model, analyse the blockchain platform sharing decisions made by manufacturers and retailers, and subsequently examine the environmental impact of carbon footprint sharing based on optimal enterprise decisions regarding carbon emissions.

To provide a clear demonstration, we define:

$$\mathrm{cb}_1 = 1 + d\lambda - A, \mathrm{cb}_2 = 1 + d\lambda + \mathrm{A}, \mathrm{cb}_3 = 1 + d\lambda - \mathrm{B}, \mathrm{cb}_4 = 1 + d\lambda + B$$
$$\mathrm{cb}_5 = 1 + d\lambda - C, \mathrm{cb}_6 = 1 + d\lambda + C$$
$$tb_1 = \frac{d^2m\lambda^2}{24m - 12\lambda^2}, tb_2 = \frac{d^2m\lambda^2 - 3m - 6dm\lambda - 6dm\theta\lambda^2 + 3m\theta^2\lambda^2}{24m - 12\lambda^2}$$
$$tb_3 = \frac{3m - 6\mathrm{cb}m + 3\mathrm{cb}^2m - 32d^2m^2 + 6dm\lambda - 6\mathrm{cb}dm\lambda + 20d^2m\lambda^2}{48m - 24\lambda^2}$$
$$\lambda_1 = \frac{3d}{d^2 - 6d\theta + 3\theta^2} + \sqrt{3}\sqrt{\frac{4d^2 - 6d\theta + 3\theta^2}{(d^2 - 6d\theta + 3\theta^2)^2}}$$
$$A = \sqrt{1 + 2d\lambda + \frac{2d^2\lambda^2}{3}}, B = \frac{\sqrt{m\left(-12\mathrm{tb}\lambda^2 + m(3 + 24\mathrm{tb} + 6d\lambda + 2d^2\lambda^2)\right)}}{\sqrt{3}m},$$

$$C = \frac{\sqrt{m(-24\mathrm{tb}\lambda^2 + m(3 + 48\mathrm{tb} + 6d\lambda + 2d^2\lambda^2))}}{\sqrt{3}m}$$

4.1. Sharing carbon footprint data

4.1.1 Retailer-led blockchain implementation

By leveraging blockchain technology, the manufacturer can effectively track carbon footprint information, enabling consumers to observe previously unobservable green activities. This transparency has the potential to drive higher demand and increased profits for supply chain members. By comparing the profits subsequent to the retailer-led blockchain for sharing carbon footprint information, both in cases where sharing occurs and when sharing does not occur, an analysis is conducted on enterprises' decisions regarding information sharing.

Proposition 4. Retailer-led blockchain implementation enhances profitability for both the retailer and manufacturer when the following conditions hold:

(1) $0 < \mathrm{cb} < \mathrm{cb}_3, \frac{\theta}{2} < d < \theta, 0 < \lambda < 1, 0 < tb < tb_1$,

(2) $\mathrm{cb}_4 < cb < 1 + \theta\lambda, \theta > 6 + 4\sqrt{3}, \frac{\theta}{2} < d < 3(1+\theta) - \sqrt{6}\sqrt{2 + 3\theta + \theta^2}, \lambda_1 < \lambda < 1, 0 < tb < tb_2$.

As supported by Proposition 4, the utilization of blockchain technology can result in a mutually beneficial outcome for the manufacturer and retailer. Specifically, the manufacturer's unobservable greenness surpasses the consumer's expected value, while the investment cost for the blockchain platform remains within a reasonable range. Furthermore, when the cost of using blockchain is high, it becomes particularly suitable for consumers with heightened environmental consciousness. This result obtained aligns with Corollary 2, illustrating how corporate profits are sensitive to the expenses linked to utilizing blockchain technology.

When the manufacturer possesses a high level of unobservable green practices, consumers lack access to such information, and due to enterprises' greenwashing behaviour, the perceived expected level of unobservable green practices is lower than the actual level of the manufacturer. The manufacturer's green investment does not receive enough positive feedback. In the SR scenario, when the construction cost of implementing blockchain technology falls within a certain range, the manufacturer can share carbon footprint information through a blockchain platform, enabling consumers to perceive the true extent of unobservable green practices. This enhances the environmental value proposition of products and increases consumer willingness to pay higher prices for them, leading to an increase in product demand and enterprise profitability.

4.2. Manufacturer-led blockchain implementation

The manufacturer can enhance the transparency of its carbon footprint information by establishing a blockchain platform, enabling the retailer and consumers to gain comprehensive insights into the environmental sustainability of products. By comparing the profits subsequent to the manufacturer-led blockchain for sharing carbon footprint information, both in cases where sharing occurs and when sharing does not occur, an analysis is conducted on enterprises' decisions regarding information sharing.

Proposition 5. Manufacturer-led blockchain implementation enhances profitability for both the retailer and manufacturer when the following conditions hold:

(1) $0 < cb < \mathrm{cb}_5, 0 < d < 3 + 2\sqrt{3}, d < \theta < 2d, 0 < \lambda < 1, 0 < tb < tb_1$,

(2) $0 < cb < 1 + \theta\lambda, d > 3 + 2\sqrt{3}, 0 < \theta < d - \frac{\sqrt{3+6d+2d^2}}{\sqrt{3}}, \lambda_1 < \lambda < 1, 0 < tb < tb_2$.

Proposition 5(1) demonstrates that in scenarios where the anticipated value of the imperceptible greenness level is low and the cost of blockchain construction falls within a reasonable range, if the actual imperceptible greenness of an enterprise is high, then when the cost of utilizing blockchain technology is minimal, manufacturers take charge of constructing the blockchain platform. The utilization of the blockchain platform enables consumers to perceive heightened levels of unobservable greenness, thereby fostering increased product demand and generating enhanced profits for all participants within the supply chain.

The finding of Proposition 5 (2) reveals an intriguing insight: even if a manufacturer’s actual green performance is low, enterprises can achieve higher profits by allowing suppliers to take the lead in establishing a blockchain platform for sharing carbon footprint information. Sharing carbon footprint information enables the supplier to assess the environmental sustainability of the manufacturer and consumers. While it may diminish the utility value of consumers, misinformation stemming from the high initial expected level can be seen as a reflection of corporate greenwashing. Consequently, product pricing aligns more closely with functionality and eco-friendliness, facilitated by the implementation of a blockchain platform that provides consumers with enhanced transparency and prevents inferior products from overshadowing superior products. The sharing of carbon footprint information benefits all stakeholders in the supply chain.

4.3. Not sharing carbon footprint data

4.3.1 Retailer-led blockchain implementation

Proposition 6. The manufacturer is willing to share carbon footprint information; however, the retailer is reluctant to take the initiative to establish a blockchain platform when the following conditions hold:

(1) $0 < \mathrm{cb} < \mathrm{cb}_1, \frac{\theta}{2} < d < \theta, 0 < \lambda < 1, tb_1 < tb < tb_3$,

(2) $\mathrm{cb}_3 < \mathrm{cb} < \mathrm{cb}_1, \frac{\theta}{2} < d < \theta, 0 < \lambda < 1, 0 < tb < tb_1$,

(3) $\mathrm{cb}_2 < \mathrm{cb} < 1 + \theta\lambda, \theta > 6 + 4\sqrt{3}, \frac{\theta}{2} < d < 3(1+\theta) - \sqrt{6}\sqrt{2 + 3\theta + \theta^2}, \lambda_1 < \lambda < 1,$
$tb_1 < tb < tb_3$,

(4) $\mathrm{cb}_2 < \mathrm{cb} < \min\{\mathrm{cb}_4, 1 + \theta\lambda\}, \theta > 6 + 4\sqrt{3}, \frac{\theta}{2} < d < 3(1+\theta) - \sqrt{6}\sqrt{2 + 3\theta + \theta^2},$
$0 < \lambda < 1, 0 < tb < tb_1$.

As indicated by Proposition 6(1)(3), the retailer may be disinclined to take the lead in blockchain adoption due to the high costs associated with its implementation. Consequently, even if the supplier expresses a willingness to share carbon footprint data, the expense of investing in blockchain technology outweighs any potential profits derived from obtaining such information, thereby dissuading the retailer from assuming a leadership role.

However, as indicated by Proposition 6(2)(4), even if the investment cost of blockchain falls within the retailer's acceptable range, deviations in the use cost of blockchain can impact its willingness to invest in constructing a blockchain platform. As demonstrated by Lemma 3, the manufacturer allocates the use cost of blockchain to the retailer through the wholesale price, thereby reducing the retailer's profit margins. When the use cost of blockchain is excessively low, minimal changes are observed in product greenness, wholesale prices and retail profit margins; however, the retailer incurs higher expenses for platform construction costs, which discourages its leadership role. Conversely, when the use cost of blockchain is exceedingly high and under supply chain coordination mechanisms, it significantly affects its retail profit margins, leading to a decrease in overall retail profits.

Proposition 7. The retailer is inclined to take the initiative in establishing a blockchain platform for achieving shared carbon footprint management in manufacturing, whereas the manufacturer is reluctant when the following conditions hold:

$$\begin{aligned}&\mathrm{cb}_4 < \mathrm{cb} < 1 + \theta\lambda\\ &d > 2\sqrt{3} + 3, d + \frac{\sqrt{3 + 6d + 2d^2}}{\sqrt{3}} < \theta < 2d,\\ &\lambda_1 < \lambda < 1, 0 < tb < tb_{2.}\end{aligned}$$

Proposition 6 reveals that in scenarios where the cost of utilizing blockchain technology is high and the actual unobservable greenness level exceeds consumers' expectations, the retailer is willing to spearhead the establishment of a blockchain platform, while the manufacturer exhibits reluctance towards information sharing.

An enhanced unobservable greenness attributes facilitates information sharing, thereby enabling consumers to attain elevated levels of product green utility and allowing the retailer to generate greater revenue in increasing product demand. Consequently, the retailer is motivated to spearhead the establishment of the blockchain platform. However, the excessive cost of utilizing blockchain technology impedes the manufacturer's motivation to share information. Although this cost can be partially transferred to the retailer through supply chain coordination and wholesale pricing, note that platform sharing necessitates maintaining a higher level of unobservable green practices. This inclination towards investing in unobservable green activities may adversely affect observable greenness levels and subsequently impact overall product sustainability. Furthermore, apart from incurring additional costs for information sharing purposes, the manufacturer does not derive any profit from engaging in such behaviour.

Proposition 8. In the SR scenario, both the manufacturer and retailer refrain from sharing carbon footprint information when the following conditions hold:

$$\begin{aligned}&\mathrm{cb}_1 < \mathrm{cb} < \min\{\mathrm{cb}_2, 1 + \theta\lambda\}\\ &\frac{\theta}{2} < d < \theta,\\ &0 < \lambda < 1, 0 < tb < tb_{1.}\end{aligned}$$

Proposition 8 indicates that in the context of retailer-led blockchain implementation, when the cost of utilizing blockchain technology is high, the manufacturer's unobservable greenness exceeds the expected value. Furthermore, even if the investment in blockchain is not substantial, neither the manufacturer nor the retailer achieve profits comparable to those in the NS scenario.

At present, consumers have heightened green expectations and there is a limited increase in the environmental value of sharing the manufacturer's carbon footprint information, coupled with the relatively low cost-effectiveness of implementing blockchain technology to enhance profitability for supply chain members. It becomes evident that enterprises do not necessarily need to invest in blockchain technology to bolster consumer trust when their greenwashing practices are minimal and industry standards are stringent.

4.4. Manufacturer-led blockchain implementation

Proposition 9. The retailer urges the manufacturer to take the lead in implementing blockchain technology and sharing carbon footprint information; however, the manufacturer remains hesitant when the following conditions hold:

(1) $d > 3(1+\theta)+\sqrt{6}\sqrt{2+3\theta+\theta^2}, \lambda_1 < \lambda < 1, tb_1 < tb < tb_3$

(2) $\mathrm{cb}_5 < cb < 1+\theta\lambda, d > 3(1+\theta)+\sqrt{6}\sqrt{2+3\theta+\theta^2}, \lambda_1 < \lambda < 1, tb_2 < tb < tb_1$

(3) $0 < cb < \mathrm{cb}_1, \mathrm{d} < \theta < 2d, 0 < \lambda < 1, tb_1 < tb < tb_3$

(4) $\mathrm{cb}_2 < cb < 1+\theta\lambda, \theta > 6+4\sqrt{3}, \frac{\theta}{2} < d < 3(1+\theta)-\sqrt{6}\sqrt{2+3\theta+\theta^2}, \lambda_1 < \lambda < 1,$

$tb_2 < tb < tb_3$, where $tb_2 < tb_1$

Proposition 9 suggests that a high cost of implementing blockchain may hinder the manufacturer's motivation to lead its development. As demonstrated in Proposition 9(1)(3), when consumers anticipate a relatively high but underestimated greenness relative to the actual value of the manufacturer's unobservable level, regardless of the cost of implementing blockchain technology, the manufacturer is hesitant to invest and disclose carbon footprint information due to high construction costs. Under these circumstances, sharing carbon footprint information can enhance consumer awareness regarding product sustainability; however, its impact may be limited. Therefore, the profitability of investing in a blockchain platform for the manufacturer is primarily influenced by construction costs.

As demonstrated in Proposition 9(2), if the disparity in the unobservable greenness level between consumers' expectations and the manufacturer's actual value is significant and the cost of implementing blockchain technology is low, the retailer may be willing to invest in improving product utility. However, manufacturers may be hesitant to disclose carbon footprint information due to the associated costs of utilizing a blockchain platform.

When the level of blockchain adoption is high, as shown in Proposition 9(4), the retailer will also seek information sharing from the manufacturer if the unobservable greenness level and consumers' green sensitivity are both high. However, in this scenario, the manufacturer's enthusiasm for blockchain implementation is more influenced by the cost of constructing a blockchain platform than in cases (1) and (2). This is due to the manufacturer's high investment costs in achieving a given level of greenness, resulting in limited resources being available for blockchain construction.

Proposition 10. In the SM scenario, both the manufacturer and retailer refrain from sharing carbon footprint information when the following conditions hold:

(1) $\mathrm{cb}_1 < cb < \mathrm{cb}_2, \theta < 6+4\sqrt{3}, \frac{\theta}{2} < d < \theta, 0 < \lambda < 1, tb_1 < tb < tb_3$

(2) $\mathrm{cb}_1 < cb < min\{\mathrm{cb}_2, 1+\theta\lambda\}, \theta > 6+4\sqrt{3}, \frac{\theta}{2} < d < 3(1+\theta)-\sqrt{6}\sqrt{2+3\theta+\theta^2},$

$0 < \lambda < 1, tb_1 < tb < tb_3,$

(3) $\mathrm{cb}_5 < cb < \mathrm{cb}_6, \theta > 6+4\sqrt{3}, \frac{\theta}{2} < d < 3(1+\theta)-\sqrt{6}\sqrt{2+3\theta+\theta^2}, \lambda_1 < \lambda < 1,$

$$0 < tb < tb_2$$

Proposition 10(1)(3) demonstrate that when the usage cost of blockchain falls within a higher range, the construction cost of blockchain also increases significantly. Moreover, if the unobservable greenness level surpasses the expected value, the manufacturer and retailer exhibit reluctance to share carbon footprint information through the blockchain platform. As the manufacturer is unable to account for the substantial green cost, investing in blockchain technology would impose an excessive financial burden on them. Moreover, due to supply chain coordination, a portion of these high costs will be shared by the manufacturer. Consequently, this may impede its investment in sustainable practices and diminish the demand for green products.

Interestingly, even when the cost of blockchain implementation is low, the manufacturer and retailer are reluctant to share carbon footprint information under certain conditions. Under such circumstances, the actual unobservable greenness level achieved by the manufacturer tends to be relatively high but falls slightly below consumers' expectations due to their heightened sensitivity to green practices. Despite incurring significant costs for maintaining their unobservable green activities, the manufacturer is recognized for its efforts by consumers who possess a strong awareness and recognition of them. However, upon disclosure of carbon footprint information by the manufacturer, consumers experience a reduction in their green utility. Furthermore, the introduction of blockchain technology imposes an additional financial burden on supply chain members, which further prevents them from embracing this solution to achieve seamless information sharing.

4.5. Win-win decisions

According to the findings from the SR and SM scenarios, this section focuses on analysing the manufacturer's carbon footprint information sharing strategy and the supply chain members' blockchain-led approach.

Proposition 11. Through a comparison between the two scenarios SR and SM, it is evident that, the supply chain members experience lower profitability when they hitchhike, $\Pi_m^{SR*} > \Pi_m^{SM*}, \Pi_r^{SM*} > \Pi_r^{SR*}$. The win-win area of carbon foot information sharing:

Retailer-led: $\{0 < \mathrm{cb} < \mathrm{cb}_3, \frac{\theta}{2} < d < \theta, 0 < \lambda < 1, 0 < tb < tb_1\}$ and $\{\mathrm{cb}_4 < cb < 1 + \theta\lambda, \theta > 6 + 4\sqrt{3}, \frac{\theta}{2} < d < 3(1+\theta) - \sqrt{6}\sqrt{2 + 3\theta + \theta^2}, \lambda_1 < \lambda < 1, 0 < tb < tb_{2\}}$,

Manufacture-led:

$\{0 < cb < \mathrm{cb}_5, 0 < d < 3 + 2\sqrt{3}, d < \theta, 0 < \lambda < 1, 0 < tb < tb_1\ \}$, $\{0 < cb < 1 + \theta\lambda, d > 3 + 2\sqrt{3}, 0 < \theta < d - \frac{\sqrt{3 + 6d + 2d^2}}{\sqrt{3}}, \lambda_1 < \lambda < 1, 0 < tb < tb_{2\}}$,

Not share: $\{\mathrm{cb}_1 < \mathrm{cb} < \min\{\mathrm{cb}_2, 1 + \theta\lambda\}, \frac{\theta}{2} < d < \theta, 0 < \lambda < 1, 0 < tb < tb_1\}$ and $\{\mathrm{cb}_1 < cb < \mathrm{cb}_2, \theta < 6 + 4\sqrt{3}, \frac{\theta}{2} < d < \theta, 0 < \lambda < 1, tb_1 < tb < tb_3\}$ and $\{\mathrm{cb}_1 < cb < min\{\mathrm{cb}_2, 1 + \theta\lambda\}, \theta > 6 + 4\sqrt{3}, \frac{\theta}{2} < d < 3(1+\theta) - \sqrt{6}\sqrt{2 + 3\theta + \theta^2}, 0 < \lambda < 1, tb_1 < tb < tb_3\}$ and $\{\mathrm{cb}_5 < cb < \mathrm{cb}_6, \frac{\theta}{2} < d < 3(1+\theta) - \sqrt{6}\sqrt{2 + 3\theta + \theta^2}, \theta > 6 + 4\sqrt{3}, \lambda_1 < \lambda < 1, 0 < tb < tb_2\}$.

The analysis of Proposition 11 reveals that when a supply chain member dominates the blockchain, profitability is influenced by the construction cost of the blockchain, resulting in lower profits than when the other party dominates the construction of the blockchain platform. Nevertheless, it still derives benefits from information sharing. By integrating Proposition 4 and Proposition 5, it can be inferred that the dissemination of carbon footprint information fosters mutually beneficial outcomes among supply chain members. By integrating Proposition 8 and Proposition 10, it can be inferred that the dissemination of carbon footprint information fosters mutually beneficial outcomes among supply chain members.

It is evident that there are scenarios where both manufacturer-led and retailer-led scenarios can achieve a win–win result. In this context, in conjunction with Proposition 10, both parties aspire for the other party to dominate the blockchain to attain higher profits while also acknowledging their own dominance due to the increased profitability associated with information sharing. This proposition is further supported by Figure 2, where we set $\lambda = 0.6, m = 0.2, \mathrm{tb} = 0.5$.

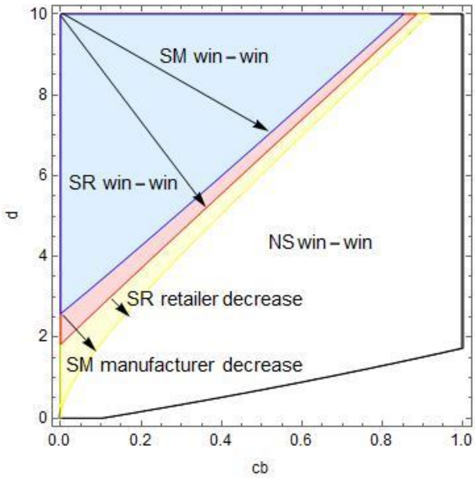

Figure 2. Firms' win-win decisions.

The blue area represents a win–win situation for the manufacturer-led mode, while the combined blue and red areas represent a win–win situation for the retailer-led mode. The yellow area depicts a scenario where the manufacturer desires information sharing but the retailer is unwilling to take charge. The combined yellow and red areas illustrate a situation where the retailer seeks information sharing but the manufacturer is reluctant to lead. Last, in the white area, both the manufacturer and retailer attain higher profits when information is not shared. As depicted in Figure 1, when consumers' expectations are high, establishing a blockchain platform to share carbon footprint information facilitates the attainment of mutually beneficial profits. During such instances, consumers have elevated expectations regarding unobservable greenness levels. If information sharing is achieved, it ensures that the actual unobservable greenness level of the manufacturer does not fall below consumers' expected level. Consequently, this also indicates that a higher manufacturer's unobservable greenness leads to a greater inclination towards information sharing when consumers' sensitivity is slightly heightened. Note that determining who should take the lead is a complex issue since both parties would incur profit losses. However, neither scenario results in joint profit loss.

As shown in Figure 1, when the manufacturer dominates the blockchain, the cost of using the blockchain by the retailer will be partly transferred to the manufacturer. Therefore, at the same level of unobservable greenness, the acceptable cost of using blockchain is lower in the SM scenario than in the SR scenario. The decision-making process for information sharing is increasingly influenced by higher levels of unobservable green factors as the cost of utilizing blockchain technology increases.

Given that the manufacturer possesses carbon footprint information, failure to invest in a blockchain platform may prompt the retailer to establish the blockchain platform. Additionally, the retailer often encounters multiple manufacturers and suppliers. By constructing a blockchain platform, the retailer can facilitate the sharing of carbon footprint information among all participants in the retail channel, fostering mutual benefits and win–win outcomes. Consequently, when a retailer has a significant market presence, taking the lead becomes more advantageous.

When the retailer lacks strength, the manufacturer gains a competitive edge due to its possession of proprietary information and greater decision-making authority regarding information sharing. The manufacturer willingly shares its carbon footprint data to enhance product understanding for both retailers and consumers. Moreover, the manufacturer may engage in multichannel distribution by selling to multiple retailers and establishing direct sales channels. By developing a blockchain platform, the manufacturer enables consumers to directly access product information, thereby enhancing their purchasing intention. Consequently, the manufacturer's inclination towards market dominance becomes more pronounced.

Therefore, the carbon footprint information sharing decisions of supply chain members are primarily determined by consumers’ expectations of unobservable greenness levels and the costs of blockchain platforms. The leadership role and potential success in this context hinge upon both the investment cost related to blockchain implementation and the market strategies pursued by the manufacturer and retailer.

5. Conclusion

The objective of the manufacturer sharing carbon footprint information is to enable consumers to access data on the environmental impact of products, enhancing their perception of green utility and stimulating demand. Consequently, both the manufacturer and retailer aspire to achieve carbon footprint information sharing. This study investigates the interactive relationship between a manufacturer's dissemination of carbon footprint information and supply chain members' decision-making facilitated by blockchain technology.

We deduce that the sharing decisions regarding carbon footprint information entail two conflicting effects, which have unexpected repercussions on the equilibrium decisions and anticipated benefits of supply chain members. On the one hand, information sharing enhances consumer trust in the manufacturer’s imperceptible environmentally friendly activities, thereby improving their perception of sustainability. On the other hand, information sharing increases costs for supply chain members. The dominant member responsible for constructing the blockchain platform incurs construction expenses, while the other member bears usage costs. Notably, retail coordination within the supply chain can be achieved by adjusting profit margins (and manufacturers can increase wholesale prices) to equitably distribute blockchain usage costs. Consequently, when information is shared, product prices rise, and consumer utility diminishes.

When making decisions regarding information sharing, supply chain members anticipate that the establishment of a blockchain platform by the other party will yield greater benefits to their own profitability. In such scenarios, decisions driven by blockchain technology offer more possibilities: if the leading blockchain’s profitability is compromised, supply chain members may opt out of information sharing. Conversely, when the leading blockchain’s profitability can enhance expected returns, leadership is contingent upon proprietary information advantages and market strategies. Manufacturers hold a dominant position in decision-making on information sharing due to their possession of proprietary carbon footprint data. Additionally, supply chain members' willingness to assume leadership roles fluctuates based on market strategies. Consequently, decisions pertaining to carbon footprint information sharing within supply chains have the potential to generate mutually beneficial outcomes for enterprises.

In this study, we employ blockchain technology as a means of sharing carbon footprint information, enabling decision-making based on anticipated profits in both symmetric and asymmetric information scenarios. It would be intriguing to explore the establishment models of blockchain platforms, such as collaborative efforts among supply chain members for profit sharing or the initiation of blockchain platforms by third parties such as government agencies and nonprofit organizations to promote environmental sustainability. This aspect warrants further discussion in future research endeavours. Additionally, note that the level of blockchain traceability is not fixed; hence, investigating the endogenous level of traceability within blockchains could shed light on the associated costs and consumer perception effects. Further research in this direction holds potential for yielding fruitful outcomes.

Authors' contribution

Conceptualization, S.H.Z., W.L.; methodology, P.W.H., W.L.; software, W.L.; validation, W.L.; formal analysis, W.L.; investigation, S.H.Z.; resources, P.W.H.; data curation, W.L.; writing—original draft preparation, W.L.; writing—review and editing, W.L.; visualization, W.L.; supervision, W.L.; project administration, S.H.Z.; funding acquisition, S.H.Z. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest

The authors declared that they have no conflicts of interests.

Appendix

Proof of Proposition 1.

Through the reverse solving method, the demand expression is substituted into the profit expression, so as to obtain the analytical solution. The consumer's utility can be represented as the expected value.

Proof of Proposition 2. & 3.

Through the reverse solving method, the demand expression is substituted into the profit expression, so as to obtain the analytical solution. The consumer's utility is validated.

Proof of Proposition 4.

We have $\frac{\partial^2(\Pi_m^{SR*}-\Pi_m^{NS*})}{\partial cb^2}=\frac{m}{8m-4\lambda^2}>0$, as $cb\in(0,1+\theta\lambda)$, we get $\frac{\partial(\Pi_m^{SR*}-\Pi_m^{NS*})}{\partial cb}\in(-\frac{m+dm\lambda}{8m-4\lambda^2},\frac{m(-d+\theta)\lambda}{8m-4\lambda^2}),-\frac{m+dm\lambda}{8m-4\lambda^2}<0$. When $d>\theta$, $\frac{m(-d+\theta)\lambda}{8m-4\lambda^2}<0$, when $\frac{\theta}{2}<d<\theta$, $\frac{m(-d+\theta)\lambda}{8m-4\lambda^2}>0$. When $cb=0$, we get $\Pi_m^{SR*}-\Pi_m^{NS*}=\frac{d^2m\lambda^2}{48m-24\lambda^2}>0$, when $cb=1+\theta\lambda$, we get $\Pi_m^{SR*}-\Pi_m^{NS*}=\frac{m(-3+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{48m-24\lambda^2}$. When $\frac{m(-d+\theta)\lambda}{8m-4\lambda^2}<0,\frac{m(-3+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{48m-24\lambda^2}>0$, $\Pi_m^{SR*}-\Pi_m^{NS*}>0$, we get $\lambda_1<\lambda<1,d>3(1+\theta)+\sqrt{6}\sqrt{2+3\theta+\theta^2}$. We solve $\Pi_m^{SR*}-\Pi_m^{NS*}=0$, and get cb_1,cb_2. When $\frac{m(-d+\theta)\lambda}{8m-4\lambda^2}>0,\frac{m(-3+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{48m-24\lambda^2}<0$, if $cb<cb_1$, we have $\Pi_m^{SR*}-\Pi_m^{NS*}>0$. When $\frac{m(-d+\theta)\lambda}{8m-4\lambda^2}>0,\frac{m(-3+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{48m-24\lambda^2}>0$, if $cb<cb_1$ or $cb>cb_2$, we have $\Pi_m^{SR*}-\Pi_m^{NS*}>0$. We have $\frac{\partial^2(\Pi_r^{SR*}-\Pi_r^{NS*})}{\partial cb^2}=\frac{m}{4m-2\lambda^2}>0$, as $cb\in(0,1+\theta\lambda)$, we get $\frac{\partial(\Pi_r^{SR*}-\Pi_r^{NS*})}{\partial cb}\in$

$(-\frac{m+dm\lambda}{4m-2\lambda^2},\frac{m(-d+\theta)\lambda}{4m-2\lambda^2}), -\frac{m+dm\lambda}{4m-2\lambda^2}<0$. When $d>\theta$, $\frac{m(-d+\theta)\lambda}{4m-2\lambda^2}<0$, when $\frac{\theta}{2}<d<\theta$, $\frac{m(-d+\theta)\lambda}{4m-2\lambda^2}>0$. When $cb=0$, we get $\Pi_r^{SR*}-\Pi_r^{NS*}=\frac{-24m\mathrm{tb}+d^2m\lambda^2+12\mathrm{tb}\lambda^2}{24m-12\lambda^2}$, when $cb=1+\theta\lambda$, we get $\Pi_r^{SR*}-\Pi_r^{NS*}=\frac{12\mathrm{tb}\lambda^2+m(-3-24\mathrm{tb}+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{24m-12\lambda^2}$. When $\frac{m(-d+\theta)\lambda}{4m-2\lambda^2}<0,\frac{-24m\mathrm{tb}+d^2m\lambda^2+12\mathrm{tb}\lambda^2}{24m-12\lambda^2}>0$, $\Pi_r^{SR*}-\Pi_r^{NS*}>0$, we get $\lambda_1<\lambda<1, d>3(1+\theta)+\sqrt{6}\sqrt{2+3\theta+\theta^2}, \mathrm{tb}<\mathrm{tb}_2$. We solve $\Pi_r^{SR*}-\Pi_r^{NS*}=0$, and get cb_3, cb_4. If $\frac{m(-d+\theta)\lambda}{4m-2\lambda^2}>0,\frac{-24m\mathrm{tb}+d^2m\lambda^2+12\mathrm{tb}\lambda^2}{24m-12\lambda^2}>0,\frac{12\mathrm{tb}\lambda^2+m(-3-24\mathrm{tb}+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{24m-12\lambda^2}<0$,when $cb<cb_3$, we have $\Pi_r^{SR*}-\Pi_r^{NS*}>0$. If $\frac{m(-d+\theta)\lambda}{4m-2\lambda^2}>0,\frac{-24m\mathrm{tb}+d^2m\lambda^2+12\mathrm{tb}\lambda^2}{24m-12\lambda^2}>0,\frac{12\mathrm{tb}\lambda^2+m(-3-24\mathrm{tb}+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{24m-12\lambda^2}<0$,when $cb<cb_3$ or $cb>cb_4$, we have $\Pi_r^{SR*}-\Pi_r^{NS*}>0$. By comparison we get $cb_3<cb_1<cb_2<cb_4$. Subsequently, we proceed to determine the intersection.

Proof of Proposition 5.

We have $\frac{\partial^2(\Pi_m^{SM*}-\Pi_m^{NS*})}{\partial cb^2}=\frac{6m}{48m-24\lambda^2}>0$, as $cb\in(0,1+\theta\lambda)$, we get $\frac{\partial(\Pi_m^{SR*}-\Pi_m^{NS*})}{\partial cb}\in(-\frac{m+dm\lambda}{8m-4\lambda^2},\frac{m(-d+\theta)\lambda}{8m-4\lambda^2}), -\frac{m+dm\lambda}{8m-4\lambda^2}<0$. When $d>\theta$, $\frac{m(-d+\theta)\lambda}{8m-4\lambda^2}<0$, when $\frac{\theta}{2}<d<\theta$, $\frac{m(-d+\theta)\lambda}{8m-4\lambda^2}>0$. When $cb=0$, we get $\Pi_m^{SM*}-\Pi_m^{NS*}=\frac{-48m\mathrm{tb}+d^2m\lambda^2+24\mathrm{tb}\lambda^2}{48m-24\lambda^2}$, when $cb=1+\theta\lambda$, we get $\Pi_m^{SR*}-\Pi_m^{NS*}=\frac{24\mathrm{tb}\lambda^2+m(-3-48\mathrm{tb}+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{48m-24\lambda^2}$. When $\frac{m(-d+\theta)\lambda}{8m-4\lambda^2}<0,\frac{24\mathrm{tb}\lambda^2+m(-3-48\mathrm{tb}+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{48m-24\lambda^2}>0$, $\Pi_m^{SM*}-\Pi_m^{NS*}>0$, we get $\lambda_1<\lambda<1, tb<tb_3, d>3(1+\theta)+\sqrt{6}\sqrt{2+3\theta+\theta^2}$. We solve $\Pi_m^{SM*}-\Pi_m^{NS*}=0$, and get cb_5, cb_6. When $\frac{m(-d+\theta)\lambda}{8m-4\lambda^2}<0,\frac{-48m\mathrm{tb}+d^2m\lambda^2+24\mathrm{tb}\lambda^2}{48m-24\lambda^2}>0,\frac{24\mathrm{tb}\lambda^2+m(-3-48\mathrm{tb}+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{48m-24\lambda^2}<0$, we get $cb<cb_5, \Pi_m^{SM*}-\Pi_m^{NS*}>0$. When $\frac{m(-d+\theta)\lambda}{8m-4\lambda^2}>0,\frac{-48m\mathrm{tb}+d^2m\lambda^2+24\mathrm{tb}\lambda^2}{48m-24\lambda^2}>0,\frac{24\mathrm{tb}\lambda^2+m(-3-48\mathrm{tb}+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{48m-24\lambda^2}<0$, we get $cb<cb_5, \Pi_m^{SM*}-\Pi_m^{NS*}>0$. When $\frac{m(-d+\theta)\lambda}{8m-4\lambda^2}>0,\frac{-48m\mathrm{tb}+d^2m\lambda^2+24\mathrm{tb}\lambda^2}{48m-24\lambda^2}>0,\frac{24\mathrm{tb}\lambda^2+m(-3-48\mathrm{tb}+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{48m-24\lambda^2}>0$, we get $cb<cb_5$ or $cb>cb_6$, we have $\Pi_m^{SM*}-\Pi_m^{NS*}>0$. We have $\frac{\partial^2(\Pi_r^{SM*}-\Pi_r^{NS*})}{\partial cb^2}=\frac{m}{4m-2\lambda^2}>0$, as $cb\in(0,1+\theta\lambda)$, we get $\frac{\partial(\Pi_r^{SM*}-\Pi_r^{NS*})}{\partial cb}\in(-\frac{m+dm\lambda}{4m-2\lambda^2},\frac{m(-d+\theta)\lambda}{4m-2\lambda^2}), -\frac{m+dm\lambda}{4m-2\lambda^2}<0$. When $d>\theta$, $\frac{m(-d+\theta)\lambda}{4m-2\lambda^2}<0$, when $\frac{\theta}{2}<d<\theta$, $\frac{m(-d+\theta)\lambda}{4m-2\lambda^2}>0$. When $cb=0$, $\Pi_r^{SM*}-\Pi_r^{NS*}=\frac{d^2m\lambda^2}{24m-12\lambda^2}>0$, when $cb=1+\theta\lambda$, $\Pi_r^{SM*}-\Pi_r^{NS*}=\frac{m(-3+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{24m-12\lambda^2}$. When $\frac{m(-d+\theta)\lambda}{4m-2\lambda^2}<0,\frac{m(-3+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{24m-12\lambda^2}>0$, $\Pi_r^{SM*}-\Pi_r^{NS*}>0$, we get $\lambda_1<\lambda<1, d>3(1+\theta)+\sqrt{6}\sqrt{2+3\theta+\theta^2}$. We solve $\Pi_r^{SM*}-\Pi_r^{NS*}=0$, and get cb_7, cb_8. If $\frac{m(-d+\theta)\lambda}{4m-2\lambda^2}<0,\frac{m(-3+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{24m-12\lambda^2}<0$, when $cb<cb_7$, we have $\Pi_r^{SM*}-\Pi_r^{NS*}>0$. If $\frac{m(-d+\theta)\lambda}{4m-2\lambda^2}>0,\frac{m(-3+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{24m-12\lambda^2}>0$,when $cb<cb_7$ or $cb>cb_8$, we have $\Pi_r^{SR*}-\Pi_r^{NS*}>0$. By comparison we get $cb_5<cb_7<cb_8<cb_6$. Subsequently, we proceed to determine the intersection.

Proof of Proposition 6.

When $\frac{m(-d+\theta)\lambda}{4m-2\lambda^2}<0,\frac{-24m\mathrm{tb}+d^2m\lambda^2+12\mathrm{tb}\lambda^2}{24m-12\lambda^2}<0$, we have $\Pi_r^{SR*}-\Pi_r^{NS*}<0$, getting $0<\lambda<1, d>\theta, tb>tb_1$. If $\frac{12\mathrm{tb}\lambda^2+m(-3-24\mathrm{tb}+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{24m-12\lambda^2}<0,\frac{m(-d+\theta)\lambda}{4m-2\lambda^2}>0$, $\frac{-24m\mathrm{tb}+d^2m\lambda^2+12\mathrm{tb}\lambda^2}{24m-12\lambda^2}>0$, when $cb>cb_3$, we have $\Pi_r^{SR*}-\Pi_r^{NS*}<0$. If $\frac{m(-d+\theta)\lambda}{4m-2\lambda^2}>0,\frac{-24m\mathrm{tb}+d^2m\lambda^2+12\mathrm{tb}\lambda^2}{24m-12\lambda^2}>$

$0, \frac{12\mathrm{tb}\lambda^2+m(-3-24\mathrm{tb}+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{24m-12\lambda^2} < 0$, when $cb_3 < cb < cb_4$, we have $\Pi_r^{SR*} - \Pi_r^{NS*} < 0$. Take the intersection of the range where $\Pi_m^{SR*} - \Pi_m^{NS*} > 0$ in proof of proposition 4 and $\Pi_r^{SR*} - \Pi_r^{NS*} < 0$.

Proof of Proposition 7.

When $\frac{m(-d+\theta)\lambda}{8m-4\lambda^2} > 0, \frac{m(-3+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{48m-24\lambda^2} < 0$, if $cb > cb_1$, we have $\Pi_m^{SR*} - \Pi_m^{NS*} < 0$. When $\frac{m(-d+\theta)\lambda}{8m-4\lambda^2} > 0, \frac{m(-3+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{48m-24\lambda^2} > 0$, if $cb_1 < cb < cb_2$, we have $\Pi_m^{SR*} - \Pi_m^{NS*} < 0$. Take the intersection of the range where $\Pi_r^{SR*} - \Pi_r^{NS*} > 0$ in proof of proposition 4 and $\Pi_m^{SR*} - \Pi_m^{NS*} < 0$.

Proof of Proposition 8.

If $\frac{m(-d+\theta)\lambda}{4m-2\lambda^2} < 0, \frac{m(-3+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{24m-12\lambda^2} < 0$, when $cb > cb_7$, we have $\Pi_r^{SM*} - \Pi_r^{NS*} < 0$. If $\frac{m(-d+\theta)\lambda}{4m-2\lambda^2} > 0, \frac{m(-3+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{24m-12\lambda^2} > 0$, when $cb_7 < cb < cb_8$, we have $\Pi_r^{SM*} - \Pi_r^{NS*} < 0$. Take the intersection of the range where $\Pi_m^{SM*} - \Pi_m^{NS*} > 0$ in proof of proposition 5 and $\Pi_r^{SM*} - \Pi_r^{NS*} < 0$.

Proof of Proposition 9.

When $\frac{m(-d+\theta)\lambda}{8m-4\lambda^2} < 0, \frac{-48m\mathrm{tb}+d^2m\lambda^2+24\mathrm{tb}\lambda^2}{48m-24\lambda^2} > 0$, $\Pi_m^{SM*} - \Pi_m^{NS*} < 0$, we get $0 < \lambda < 1, tb > tb_1, d > \theta$. When $\frac{24\mathrm{tb}\lambda^2+m(-3-48\mathrm{tb}+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{48m-24\lambda^2} < 0, \frac{m(-d+\theta)\lambda}{8m-4\lambda^2} < 0, \frac{-48m\mathrm{tb}+d^2m\lambda^2+24\mathrm{tb}\lambda^2}{48m-24\lambda^2} > 0$, we get $cb > cb_5, \Pi_m^{SM*} - \Pi_m^{NS*} < 0$. When $\frac{m(-d+\theta)\lambda}{8m-4\lambda^2} > 0, \frac{-48m\mathrm{tb}+d^2m\lambda^2+24\mathrm{tb}\lambda^2}{48m-24\lambda^2} > 0, \frac{24\mathrm{tb}\lambda^2+m(-3-48\mathrm{tb}+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{48m-24\lambda^2} < 0$, we get $cb > cb_5, \Pi_m^{SM*} - \Pi_m^{NS*} < 0$. When $\frac{24\mathrm{tb}\lambda^2+m(-3-48\mathrm{tb}+d^2\lambda^2+3\theta^2\lambda^2-6d\lambda(1+\theta\lambda))}{48m-24\lambda^2} > 0, \frac{m(-d+\theta)\lambda}{8m-4\lambda^2} > 0, \frac{-48m\mathrm{tb}+d^2m\lambda^2+24\mathrm{tb}\lambda^2}{48m-24\lambda^2} > 0$, we get $cb_5 < cb < cb_6$, we have $\Pi_m^{SM*} - \Pi_m^{NS*} < 0$. Take the intersection of the range where $\Pi_r^{SM*} - \Pi_r^{NS*} > 0$ in proof of proposition 5 and $\Pi_m^{SM*} - \Pi_m^{NS*} < 0$.

Proof of Proposition 10.

Take the intersection of the range where $\Pi_m^{SR*} - \Pi_m^{NS*} < 0$ in proof of proposition 7 and $\Pi_r^{SR*} - \Pi_r^{NS*} < 0$ in proof of proposition 6. Take the intersection of the range where $\Pi_m^{SM*} - \Pi_m^{NS*} < 0$ in proof of proposition 9 and $\Pi_r^{SM*} - \Pi_r^{NS*} < 0$ in proof of proposition 8. Then, take the union of the two scopes.

Proof of Proposition 11.

Take the union of the bounds presented in Proposition 4 and Proposition 5.

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