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Blockchain's Role in Low-Carbon Supply Chain Decisions with Game Model Insights

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Abstract

As the demand for sustainable supply chain management grows, companies are increasingly adopting low-carbon transition strategies. To cater to diverse consumer needs, manufacturers offer both low-carbon and conventional products. However, consumer acceptance of low-carbon products remains limited due to a lack of trust. Many companies are now leveraging blockchain technology to bridge this trust gap, addressing information asymmetry in the supply chain and building consumer confidence in low-carbon products. This paper introduces a game model to investigate the conditions for implementing blockchain from various perspectives, considering consumer preferences for low-carbon products, product competition, and the associated costs of blockchain implementation. The findings suggest that consumer preferences for low-carbon products and the dynamics of product competition significantly influence the conditions for blockchain adoption. Additionally, as the interplay between these preferences and competition evolves, an increase in blockchain implementation costs can lead to higher prices for low-carbon products.

Introduction

Low-carbon supply chains have become a crucial strategy for enterprises seeking development, particularly due to escalating global environmental issues and the increasing environmental consciousness of consumers (Zhang et al., 2020). In low-carbon supply chains, low-carbon production is of paramount importance (Li et al., 2016). Therefore, to promote the further growth of low-carbon supply chains, there is a pressing need to emphasize and expand the production of green products (Watkins et al., 2016).

Numerous firms are transitioning to low-carbon production (Mo et al., 2017). The enhancement of the eco-friendliness of the manufacturing process and the advancement of the sustainability of green supply chains can be achieved through the implementation of low-carbon technologies and the development of products that meet the low-carbon demands of consumers (Ranjan and Jha, 2019). For instance, Adidas is committed to mitigating its environmental footprint by utilizing more eco-friendly manufacturing and packaging materials for its products (Adidas, 2023). Similarly, PepsiCo mandates its suppliers to incorporate green technologies into their operations to minimize carbon emissions (Raj et al., 2018). However, manufacturers often still produce standard products due to various constraints such as technology, raw materials, and economic pressures. Additionally, while studies have shown that consumers are willing to pay a premium for low-carbon products (Shuai et al., 2014), some consumers may still be financially restricted from purchasing such products. Therefore, during the transition, manufacturers may not immediately produce exclusively low-carbon products; they may simultaneously produce ordinary products, which consumers will still purchase. Consequently, low-carbon products and ordinary products coexist and contend within the market (Jamali and Rasti-Barzoki, 2018).

Low-carbon products encounter competitive disadvantages due to consumer distrust stemming from information asymmetry (Meng et al., 2021; Xu & Duan, 2022). Establishing a trustworthy, traceable system for these products across their production, processing, and sales stages is vital. With the rapid development of technology, RFID (Radio Frequency Identification) and DPP (Digital Product Passport) technologies have been widely applied in the field of product traceability and source identification, which have improved consumer trust to some extent. However, the risks of information tampering and forgery cannot be ignored. The introduction of

blockchain technology, with its unique features of decentralization, data immutability, and high degree of transparency (Niu et al., 2021b; Saurabh & Dey, 2021), has been deeply integrated with RFID to build a more stable framework for product traceability, as in the case of the luxury brands Prada and Cartier (Wu et al., 2022), and has also begun to explore the integration of the DPP integration into their products. Within this framework, data is encrypted and stored in a distributed manner on the blockchain, where any unauthorized modifications are quickly detected and blocked by the network, ensuring the authenticity and integrity of the information. This innovative combination not only significantly enhances consumer trust but also drives the sustainable development of low-carbon supply chains (Fan et al., 2020; Xu, X. et al., 2021).

Given this context, this paper seeks to address the following questions:

(1) In a competitive environment, what are the optimal decisions for manufacturers and retailers when manufacturers have not implemented blockchain?

(2) How would a manufacturer's implementation of blockchain affect the optimal decisions of both manufacturers and retailers?

(3) What are the specific conditions that would encourage manufacturers to embrace blockchain from various perspectives?

To answer these questions, this paper focuses on manufacturers undergoing a low-carbon transition, producing both low-carbon and ordinary products, which are sold to consumers by the same retailer. Considering the factors that influence consumers' preference for low-carbon products, their trust in these products, and the intensity of product competition, we construct supply chain game models for manufacturers both with and without blockchain. We then analyze the conditions under which blockchain technology should be applied from various perspectives. Additionally, we explore the impact of blockchain technology on the optimal decision-making processes of manufacturers and retailers regarding competing products, as well as its influence on the level of carbon emission reduction for products.

The paper is organized as follows: Section 2 provides a literature review. Section 3 introduces four different models to study and address the problem. Section 4 discusses the results in further details. Section 5 offers a numerical analysis, and

Section 6 concludes with a summary of our findings.

Section snippets

Literature Review

This research is closely connected to two existing bodies of literature. The first examines the green product supply chain, while the second focuses on the application of blockchain technology in the supply chain. …

Problem description and assumptions

Consider a two-tier supply chain comprising a single dominant manufacturer and a follower retailer. Within the Stackelberg game framework, the manufacturer and retailer engage in competition, offering both low-carbon and ordinary products to consumers through the same retailer. Both the manufacturer and retailer act as rational agents, each aiming to maximize their respective profits. Notably, the retailer prices the low-carbon products higher to reflect consumers' preferences for eco-friendly …

Comparisons and Analyses

The optimal decisions for the two scenarios mentioned above are summarized in Table 2.

In this section, we begin by conducting a comparative analysis of the optimal decisions presented in Table 2. Subsequently, we explore the thresholds of blockchain costs from economic and environmental perspectives, which leads us to the following proposition: …

Numerical analyses

In this section, we will further investigate the sufficient conditions for supply chains to implement blockchain, analyze the optimal decisions before and after blockchain implementation, and examine the changes in market demand and prices for supply

chain agents through numerical examples. This will allow us to fully consider the relationship between blockchain costs and the wholesale and retail prices of low-carbon products.

To facilitate comparisons and enhance managerial insights, it is …

Conclusions

The integration of blockchain with technologies such as RFID and DPP forms an essential system for modern supply chain management, delivering vital support for product traceability, transparency, and trust. As a result, blockchain has evolved into a fundamental infrastructure in the era of the digital economy.

Using Unilever as a case study, the company produces both low-carbon products (e.g., a personal care line made with sustainably sourced palm oil) and ordinary products (such as …

Declaration of Competing Interest

☑ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: None …

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