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RESEARCH ARTICLE

Certifying Greenness: Blockchain's Impact on Eco-Friendly Products in a Competitive Market

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ABSTRACT The competitive dynamics between conventional and environmentally conscious goods have been transformed by the implementation of blockchain technology to authenticate the environmental sustainability of different products. Using game theory, we explore the influence of blockchain integration on the rivalry between eco-friendly and non-eco-friendly products sold by two retailers, respectively. We introduce duopoly pricing models to address this concern. One model is designed for an environmentally conscious product firm that utilizes blockchain technology to authenticate the sustainability attributes of its offers. The other model is applicable to a traditional product firm. To evaluate the reliability of our findings, we expand our models to encompass two critical variables, i.e., the cost of blockchain adoption and exogenous decisions concerning product quality. Our analysis reveals that the eco-friendly product firm that embraces blockchain does not enjoy the advantages of expanding its eco-conscious customer base. Paradoxically, an increase in such consumers intensifies the competition between two products. Additionally, our research indicates that although blockchain implementation can alleviate this competition, the use of blockchain for certification does not necessarily enhance the competitiveness of the eco-friendly product. To secure a competitive edge over the non-eco-friendly product through blockchain adoption, the eco-friendly product firm must possess substantial bargaining power.

INDEX TERMS Blockchain, greenness certification, competitive pricing, green product, supply chain.

I. INTRODUCTION

Blockchain technology has emerged as a transformative force, permeating various sectors and industries, including supply chains and environmental sustainability [1], [2]. One area where blockchain technology has been increasingly applied is in the validation and certification of eco-friendly products, fundamentally reshaping the competitive landscape between environmentally conscious and traditional product offerings [3], [4]. For example, H&M, a prominent international clothing brand, employs blockchain to trace the origins of the organic cotton and recycling materials used in its products. The World Wide Fund for Nature has introduced a blockchain-powered supply chain monitoring system known as OpenSC, enabling consumers to track the provenance and origins of organic food products. However, firms face challenges in assessing the benefits brought to their businesses by green products equipped with blockchain technology when entering the market competition. This is particularly true as consumers exhibit cautious attitudes towards blockchain-based products [5], [6], [7].

In addition, as eco-consciousness surges globally, consumers actively seek products that align with their environmental values [8], [9]. This shift has created a competitive battleground, prompting firms to portray their products as eco-friendly, often through blockchain technology. Such a practice not only assures consumers of their eco-friendly claims but also amplifies competition within the

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industry [10], as rival firms are compelled to adopt similar strategies to increase competitiveness.

The motivation behind this research also stems from the intrinsic complexities associated with this evolving landscape. These intricate dynamics warrant a comprehensive examination. As discussed above, one motivating factor is our observation that adopting blockchain by eco-friendly product firms does not necessarily translate into a straightforward competitive advantage, particularly concerning expanding their eco-conscious customer base. As a result, this paper is intrigued by the profound implications this technological shift holds for businesses and consumers. We aim to investigate the intricate interplay of competition between eco-friendly and non-environmentally friendly products in the context of blockchain adoption.

Given the context outlined above, this paper focuses on investigating the competition dynamics between eco-friendly and non-eco-friendly products during the blockchain revolution. Our primary research objectives can be succinctly summarized as follows:

(i) In what manner does blockchain technology influence the rivalry between eco-friendly and non-eco-friendly products?

(ii) Can integrating blockchain technology offer advantages to the eco-friendly product when competing with the non-environmentally friendly product? What avenues drive the transformation of the eco-friendly product into a more competitive market player through blockchain implementation?

(iii) What factors affect the eco-friendly firm's decision of blockchain adoption? Given the different cost structures of blockchain adoption, how can blockchain help the eco-friendly product firm win the competition? How do the optimal outcomes vary when endogenous quality decision is considered?

To address the aforementioned inquiries, we analyze the rivalry between eco-friendly and non-ecofriendly products. While there are items in the market lacking blockchain certification, their ecological credentials might raise concerns among consumers. Therefore, our primary focus centres on assessing the influence of blockchain technology on the certification of environmentally friendly products. Consequently, we exclude eco-friendly products lacking blockchain certification, as consumers often perceive them as non-environmentally friendly due to trust-related issues. Furthermore, we segment the consumer base into two distinct categories: eco-friendly consumers who prefer environmentally friendly products and those who favour non-environmentally friendly options. To assess the influence of blockchain technology on the market of ecologically friendly items, we examine the potential of blockchain to boost customer's perceived belief for the product. Initially, we examine the competitive pricing strategies and profits for both environmentally friendly and non-environmentally friendly products, followed by a comparative analysis of optimal results to gain insights into the rivalry between the two firms. Additionally, we investigate the model extensions by including two critical elements: (i) Blockchain costs, exploring optimal results with both exogenous and endogenous blockchain cost considerations, and (ii) exogenous quality decision, where blockchain is employed to certify the quality standards of green products.

This paper presents several intriguing findings. Firstly, we unveil an unexpected outcome wherein a higher presence of sustainability-focused consumers amplifies market competition, leading to a reduction in prices and profits for both products. However, adopting blockchain technology can mitigate the losses incurred by both firms in the face of intense competition. Secondly, the market's composition of eco-friendly consumers plays a pivotal role. When there is a significant presence of eco-friendly consumers, the eco-friendly product outperforms the non-eco-friendly product. In contrast, when eco-friendly consumers are in the minority, the value added by blockchain becomes limited. This implies that blockchain-enabled certification does not necessarily boost the competitiveness of eco-friendly products in all scenarios. Thirdly, for the eco-friendly product to gain an edge over the non-eco-friendly product through blockchain adoption, the former must possess substantial bargaining power to control the costs associated with blockchain implementation. Numerical analyses indicate that a smaller population of sustainability-focused consumers has a more pronounced impact on pricing and profitability for both product categories.

This paper contributes to the field in three key ways. Firstly, to the extent of our current understanding, we give the initial theoretical examination of the rivalry involving eco-friendly and eco-friendly items within the framework of blockchain technology. We argue that blockchain technology does not guarantee an automatic boost in competitiveness for the eco-friendly product. Furthermore, we delve into how the eco-friendly product can strategically harness blockchain technology to gain a competitive advantage. Secondly, our research yields a significant and thought-provoking insight into how different blockchain cost structures influence the rivalry dynamics among eco-friendly and non-eco-friendly items. This underscores the inherent value of blockchain for both products. Finally, our findings reveal some counterintuitive outcomes. For instance, even if blockchain adoption diminishes the demand for non-eco-friendly products, it is still likely to lead to an increase in pricing and profitability.

II. LIERATURE REVIEW

A. BLOCKCHAIN ADOPTION IN SUPPLY CHAIN OPERATIONS

Initial research examines the utilization of blockchain technology in enhancing traceability inside supply chain systems. These studies not only underscore the potential advantages of blockchain technology but also explore its relationships with different factors such as task technology fit, user self-efficacy, competitive environments, and its potential applications in addressing global health crises [11]. For example, Shahzad et al. [12] focus on the role of blockchain in mobile food delivery applications. This research highlights the pivotal role of blockchain in the mobile food delivery industry. Chen et al. [13] investigate traceability strategy choice in competitive supply chains using blockchain technology. They argue that blockchain can improve supply chain traceability, especially in competitive environments. Wan et al. [14] examine the value of blockchain-enabled supply chain traceability in competitive environments. They find that blockchain technology can deliver more value, especially in highly competitive supply chains. Xu et al. [15] focus on ordering and supply chain traceability for addressing global health crises, particularly COVID-19 vaccine procurement. While the primary focus of the paper is vaccine ordering, it mentions the potential of using information updates and blockchain technology to improve supply chain transparency in the digital age. This study underscores the importance of blockchain during times of crisis.

In conclusion, the aforementioned articles showcase the vast scope of blockchain technology in facilitating transparency inside supply chain systems, whether in mobile food delivery, competitive supply chains, or crisis management, such as in the context of global health crises. It not only enhances the reliability of traceability but also offers added value, emphasizing its critical role in achieving supply chain transparency and traceability in various contexts.

In addition, recent studies explore the implementation of blockchain technology in the realm of e-commerce for the retail industry. These papers collectively investigate various aspects of blockchain's impact, including supply chain management, authentication technology, coordination in the marketplace, environmental considerations, and its role in agricultural and cold supply chains. Saxena and Sarkar [16] investigate how the retailing industry can optimize replenishment strategies with blockchain technology. This research addresses the practical applications of blockchain in managing supply chain operations for retail businesses. Choi [17] and Li et al. [18] delve into the selection of a verification solution plan for luxurious online retailers in the blockchain age. These studies focus on how blockchain can enhance security and trust in luxury e-commerce, offering insights into adopting blockchain-based authentication systems. The study conducted by Ma et al. [19] investigate the synchronization of warehouses that operate based on IoT and blockchain technologies. The researchers specifically focus on analyzing the operational strategies and the use of blockchain technology in these supply chains. This research provides valuable insights into how blockchain enhances supply chain coordination. Zhou et al. [20] explore consumer scepticism in the context of blockchain and the fashion industry. Cao et al. [21] provide an analysis of the role of blockchain-based platforms in agricultural supply chains. This paper explores how blockchain technology can improve transparency and traceability in the agricultural sector. The study by Zhang et al. [22] examine the effects of using blockchain technology in cold supply chains, specifically focusing on the role of TPL.

In summary, these studies collectively shed light on the diverse applications of blockchain technology in the retail e-commerce industry. They demonstrate the versatility of blockchain in enhancing supply chain management, security, sustainability, and traceability across various retail sectors.

Importantly, some recent studies focus on applying blockchain technology in operations, particularly addressing deceptive counterfeits and improving supply chain operations [23], [24], [25], [26], [27]. These papers collectively explore various aspects of blockchain's impact on these areas, highlighting both similarities and differences in their approaches and findings. Specifically, these studies suggest that blockchain can enhance supply chain transparency and trust and reduce risks, particularly in situations of information asymmetry. They emphasize that the application of blockchain technology can improve the credibility and reliability of transactions, thereby encouraging greater participation in the market.

B. BLOCKCHAIN SUPPORTED SUSTAINABLE OPERATIONS

The application of blockchain technology in green products is studied extensively. These studies provide unique insights into the role of blockchain in promoting sustainability and environmental consciousness in different sectors, from sustainable supply chains to online retailing and fashion industries. For example, Li et al. [28] concentrate on the role of blockchain and fairness in green investment within sustainable supply chains. Their findings emphasize how blockchain technology enhances transparency and fairness, contributing to greener and more sustainable supply chain operations. Liu et al. [29] investigate the influence of blockchain technology on online purchasing behaviour, specifically for green agricultural products. The study highlights how blockchain can instil trust and transparency in online green product markets, thus encouraging environmentally conscious purchasing behaviour. Guo et al. [4] and Quayson et al. [30] investigate the coordination of a supply chain with an online platform, particularly considering green technology in the blockchain era. The research highlights the pivotal role of blockchain in enhancing supply chain efficiency while promoting sustainability and green technology adoption.

In addition, prior studies investigate the application of blockchain technology in the context of remanufacturing and the circular economy. For example, Meier et al. [31] focus on circular supply chain management with blockchain technology from a dynamic capabilities perspective. Their research underscores how blockchain can enable dynamic capabilities in remanufacturing, enhancing sustainability and efficiency in the circular supply chain. Yang et al. [32] investigate the dynamic between competition and cooperation in a remanufacturing supply chain, with a focus on the role of blockchain. Their findings offer insights into the decision-making processes in remanufacturing supply

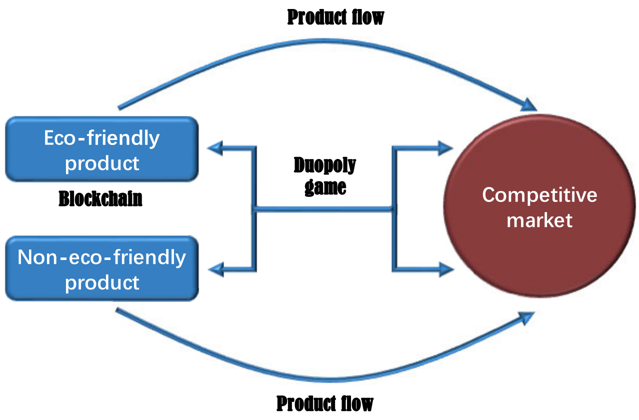

FIGURE 1. Illustration of the market competition.

chains and the impact of blockchain on collaboration and competition. Mohammed et al. [33] examine how blockchain technology can create win-win scenarios in a remanufacturing supply chain, particularly when dealing with consumer risk aversion and quality concerns. Klöckner et al. [34] investigate the strategic considerations of using blockchain for platform operations.

C. RESEARCH GAPS

In summary, these studies highlight the diverse applications of blockchain technology in the field of remanufacturing and the circular economy. It is concluded that the increased transparency enables consumers and businesses to make more informed choices about recycled and remanufactured products, fostering trust and supporting the principles of the circular economy. Blockchain not only lowers operational costs but also facilitates the adoption of sustainable practices by making it easier to manage and optimize the use of resources, ultimately contributing to the goals of the circular economy by reducing waste and promoting resource efficiency.

III. PRELIMINARY MODELS

A. MODEL SETUPS AND METHODS

In this paper, we examine a competitive scenario involving two different firms. One of them is a firm specializing in eco-friendly products that utilizes blockchain technology to certify the environmental credentials of their offerings. In contrast, the second company is engaged in producing non-eco-friendly products, and both companies produce items with similar functionalities, with the primary distinction being the eco-logical attributes, as shown in Figure 1. To address the issue of competition between two firms, we use duopoly game theory to derive some analytical results. This method is appropriate because our model reflects the competitive landscape between two firms, and by investigating the game between two firms, we can find the competitive pricing strategies, which are important operational decisions.

1) THE PRODUCT

The eco-friendly product is symbolized as q, serving as the degree of sustainability of the eco-friendly product. Let θ $(0 < \theta \leq 1)$ represents the extent to which consumers are willing to pay for the green attributes of this product. As a result, consumers' perceived value of the eco-friendly product equates to θq. Initially, consumers' valuation of the green attributes is shrouded in uncertainty. However, with the implementation of blockchain technology, this uncertainty dissipates [7], [9], [11]. We introduce γ $(0 < \gamma \leq 1)$ as the factor that enhances a consumer's perceived belief in the eco-friendly product enabled by blockchain.

Nevertheless, consumers also harbour reservations regarding potential data breaches associated with blockchain technology [7]. In light of this, we assume that consumers purchasing blockchain-enabled products must contend with a privacy-related cost, denoted as c.

Furthermore, beyond the green attributes, there exists a fundamental value v representing how consumers perceive the product. In the meantime, for the non-eco-friendly product, consumers merely have a fundamental perceived value v. Since both products possess identical functionality, the key differentiating factor lies in their ecological qualities. Consequently, it can be inferred that customers view the fundamental value of both products to be equivalent.

2) CONSUMERS' UTILITY

Within the marketplace, consumers exhibit diverse stances concerning the eco-friendly product. A segment, denoted as α, consists of environmentally-conscious individuals, which we categorize as eco-friendly consumers. They are willing to embrace the eco-friendly product, yet they exhibit significant heterogeneity in their θ values. Previous research highlights that consumers within these eco-friendly categories display variations in their attitudes towards eco-friendly product acquisition and their corresponding perceived belief for it [35]. Consequently, it is judicious to introduce the notion of consumer heterogeneity in terms of their perceived belief in the eco-friendly product. This approach represents an advancement over past analytical models that traditionally assumed sustainable consumers as the exclusive purchasers of the eco-friendly product. In this context, we assume that θ follows a uniform distribution across the interval $[0, 1]$, aligning with the conventional probability density function employed in consumer preference studies [36], [37].

In parallel, there exists a complementary fraction of consumers, accounting for $1 - \alpha$, who do not prioritize environmental considerations. We refer to this segment as non-eco-friendly consumers. They distinctly favour the non-eco-friendly product due to the limited appeal of eco-friendly features to their preferences.

As discussed above, non-eco-friendly consumers will only purchase the non-eco-friendly product, while the eco-friendly consumers' purchase decision depends on comparing the utilities of purchasing both products.

As a result, for the eco-friendly consumers, the utility of purchasing both products is:

$$U_{NE} = v - p_n \tag{1}$$

$$U_E = v + (1+\gamma)\theta q - p_e \tag{2}$$

Solving $U_{NE} = U_E$ for θ, we derive the marginal point $\tilde{\theta} = \frac{p_e - p_n}{1+\gamma} q$, where the eco-friendly consumers are indifferent in purchasing both products. Moreover, the eco-friendly consumers will purchase the non-eco-friendly product when $U_{NE} > U_E$ and $U_E > 0$.

3) THE DEMAND AND PROFIT

According to the above analysis, the demands of both products are as follows, respectively:

$$D_{NE} = \alpha \int_0^{\tilde{\theta}} f(\theta) d\theta + (1-\alpha), \tag{3}$$

$$D_E = \alpha \int_{\tilde{\theta}}^1 f(\theta) d\theta. \tag{4}$$

In (3), the demand consists of two parts: The demand from eco-friendly consumers, and the second term is the demand from non-eco-friendly consumers.

Then, the profits of both products are as follows, respectively:

$$\pi_{NE} = p_n D_{NE}, \tag{5}$$

$$\pi_E = p_e D_E. \tag{6}$$

B. RESULTS AND ANALYSIS

In the competitive landscape of these two firms, pricing decisions are made simultaneously, and each firm lacks the ability to access or foresee the pricing strategies of its competitor. In the subsequent sections, we have compiled the equilibrium outcomes, which can be found in detail in Table 1 (Appendix A). Our analysis of these equilibrium outcomes will shed light on the ramifications of implementing blockchain technology.

Proposition 3.1:

(i) *More eco-friendly consumers, i.e., an increased α, reduce both firms' prices and profits.*

(ii) *A higher enhanced perceived belief for the product due to blockchain implementation, i.e., an increased γ, increases both firms' prices and profits.*

The blockchain-enabled green product will snatch demand from the non-eco-friendly product because a portion of non-eco-friendly consumers will transfer to eco-friendly consumers (an increasing α). Also, some non-eco-friendly consumers will purchase the eco-friendly product instead of the non-eco-friendly one. Common sense suggests that more eco-friendly consumers will enhance the eco-friendly product's profit and reduce the non-eco-friendly product's profit in a unit market. However, this proposition shows that more eco-friendly consumers can potentially decrease the prices of both products.

From Proposition 3.1(i), we see that the price and profit of the non-eco-friendly product decrease with α. But why do the price and profit of the eco-friendly product also decrease with α? We explain this counter-intuitive result as follows: Since the demand decreases, the non-eco-friendly product will inevitably lower its price (as shown in Proposition 3.1, that a higher α leads to a lower price) to regain some demand. Thus, the price competition between the non-eco-friendly and eco-friendly products intensifies, leading to a price war between the firms. As a result, the eco-friendly product reduces its price and makes less profit.

Proposition 3.1 also implies that the utilization of blockchain technology holds significant value in both the context of non-environmentally friendly items as well as environmentally favourable products. Both products can benefit from blockchain adoption, which implies that a stronger γ diminishes the competition between the two firms. In essence, the integration of blockchain technology is seen as favourable, provided that it yields a substantial enhancement in consumer usefulness. This phenomenon can be attributed to the fact that a higher γ incentivizes the eco-friendly product firm to set a higher price without seeing a significant decline in their user base (note that a higher γ leads to a higher U_E).

IV. COMPETITION LANDSCAPE WHERE BLOCKCHAIN IS EMPLOYED

Here, we delve into the scenario where blockchain technology has the potential to enhance the profitability of the eco-friendly product. Our analysis involves a comprehensive examination of the profits and pricing strategies of two competing firms to gain insights into their competitive dynamics. Through this analysis, we aim to pinpoint the specific conditions under which blockchain proves to be advantageous for the eco-friendly product. To facilitate our study, we introduce the following key parameters:

$$\Delta\pi^* = \pi_E^* - \pi_{NE}^*, \tag{7}$$

$$\Delta p^* = p_e^* - p_n^*. \tag{8}$$

Then, we have the following interesting outcomes.

Proposition 4.1: If $\alpha > 0.5$,

(i) *the price of the eco-friendly product is relatively elevated, i.e., $p_e^* > p_n^*$;*

(ii) *The profitability of eco-friendly products is evident, i.e., $\pi_E^* > \pi_{NE}^*$.*

This result elucidates the competitive dynamics involving firms that sell two products respectively. In the event that a significant proportion of consumers, namely $\alpha > 0.5$, exhibit eco-friendly purchasing behaviour, it may be observed that the price of eco-friendly products surpasses that of non-eco-friendly alternatives. In Proposition 4.1, we establish an essential value of α to determine the potential success of one product in outperforming another product in rivalry.

This result visually and reasonably suggests that blockchain helps the eco-friendly product achieve sustainable operations. Consumer segments affect the profits of the eco-friendly and non-eco-friendly products. Without blockchain, the non-eco-friendly consumers segment has no motivation to buy the eco-friendly product. In addition, the result is straightforward because blockchain adoption increases the eco-friendly product's demand while decreasing the non-eco-friendly product's demand in the unit market. Thus, the non-eco-friendly product is prompted to reduce its price to grab more consumers, i.e., $p_e^* > p_n^*$. Consequently, consumer segments are a determining factor for the rivalry landscape between two products when advanced blockchain technology is used to confirm the degree of sustainability of the eco-friendly product.

Interestingly, we find that only α impacts the competition between two types of products, whereas γ has no impact on the margins and prices of them (see the expressions of $\Delta\pi^*$ and Δp^* in Appendix B). This finding suggests that even a modest influence of blockchain technology on consumers' perceived trust is sufficient for an eco-friendly product to generate profits. The inherent characteristics of blockchain technology lend themselves to effective measures against fraud and manipulation. The outcome is driven by the level of trust that consumers place in blockchain security technology.

Finally, suppose the eco-friendly consumer segment is small (when $\alpha < 0.5$), implementing blockchain-enabled certification is unprofitable. The reason is that the sustainability degree information disclosure comes at a cost, meaning that blockchain adoption requires the firm to control the cost of using blockchain. With lower demand, i.e., when $\alpha < 0.5$, the benefits of low demand hardly offset the costs of blockchain implementation. Thus, the eco-friendly product cannot reap the benefits of blockchain-enabled green-level information disclosure.

V. EXTENSION

A. THE COST OF BLOCKCHAIN

In this sub-section, we consider the cost of blockchain implementation in the eco-friendly product. Specifically, we consider two scenarios as follows: (i) exogenous blockchain cost (Model C_exo) and (ii) endogenous blockchain cost (Model C_end). Both situations are common in practice. For example, IBM in the USA provides its customers (manufacturers or retailers) with blockchain platforms to help them achieve digital traceability and certify product quality, while some firms choose to build their own blockchain platforms, such as JD.com in China, which also provides third-party blockchain services.

In Case (i), the firm producing the eco-friendly product serves as the game leader and makes its pricing decision first. In Case (ii), the blockchain technology provider first charges the firm a unit cost of using blockchain c_b. The firm pays the unit usage cost to receive information certification for its products that cannot be tampered with and then decides its own price p_e^C.

We also consider that all the firms seek to maximize their profits. Thus, the profit under Model C_exo and Model C_end are as follows:

$$\pi_{NE}^C = p_n^C D_{NE}, \tag{9}$$

$$\pi_E^C = (p_e^C - c_b) D_E. \tag{10}$$

In addition, the blockchain platform's profit function in Case (ii) is as follows:

$$\pi_B^C = c_b D_E. \tag{11}$$

The optimal results are in Table 1 in Appendix A. Besides, under Model C_exo and Model C_end, the optimal decisions' sensitivity analysis yields results that are consistent with those of the basic models. See Table 2 for the details.

We derive the following results by comparing the optimal results between Cases (i) and (ii).

Proposition 5.1: When the eco-friendly product is profitable,

(i) *(under the endogenous blockchain cost case) the performance of the eco-friendly product is inferior to that of the non-eco-friendly product;*

(i) *(under the exogenous blockchain cost case) there exists $\alpha > \alpha_L$ or $\gamma > \gamma_L$ that enables the eco-friendly product to win the competition with the non-eco-friendly product.*

Where $\alpha_L = \frac{q\gamma(1+\gamma)}{2q\gamma(1+\gamma)-2c_b}$ *and* $\gamma_L = \frac{2\alpha c_b - q\gamma(2\alpha-1)}{q\gamma(2\alpha-1)}$

Recall that the case of endogenous blockchain cost means that a third-party blockchain firm decides the price of blockchain usage. The eco-friendly product firm decides the price after receiving the unit blockchain usage price c_b, whereas in the case of exogenous blockchain cost, the firm has the pricing power for using blockchain, which means that the firm is the game leader. Proposition 5.1 shows that only the eco-friendly product firm as the game leader can benefit from blockchain adoption. This finding is exciting and vital. It highlights that the eco-friendly product must have the bargaining power to benefit from using blockchain. It must be the case that the profit of the eco-friendly product should be higher than the rivals since there is no reason for the eco-friendly product to adopt blockchain technology provided by a third party if it generates a lower profit than the non-eco-friendly product.

In addition, Proposition 5.1 gives the thresholds, i.e., α_L and γ_L, beyond which the eco-friendly product benefits from using blockchain and wins the competition with the non-eco-friendly product. For the eco-friendly product, blockchain adoption depends on having enough eco-friendly consumers. This interesting result shows that blockchain does not always benefit the eco-friendly product. We explain this phenomenon by considering the threshold γ_L. Note that $\gamma > \gamma_L$ means that the impact of blockchain adoption, i.e., increasing consumers' trust in green products, must be high enough to benefit the eco-friendly product. However, all the parameters cause γ to fall, i.e., $\frac{\partial \gamma_L}{\partial q} < 0$ and $\frac{\partial \gamma_L}{\partial \alpha} < 0$, which implies that the eco-friendly product firm lacks the incentive to enhance the blockchain-enabled certification level. As a result, blockchain is not necessarily beneficial due to a lack of incentive for the eco-friendly product firm to go all out to adopt blockchain.

B. THE DEGREE OF SUSTAINABILITY DECISION

In this sub-section, we consider the exogenous green-level decision for the eco-friendly product (Model Q) to validate the robustness of the main results. We assume that the cost for achieving the degree of sustainability q is $cq^2/2$, where c is the cost coefficient. The literature on operations management makes extensive use of this quadratic function.

Thus, under Model Q, the profit functions are as follows:

$$\pi_{NE}^{Q} = p_n^Q D_{NE}, \tag{12}$$

$$\pi_{E}^{Q} = p_e^Q D_E - \frac{cq^2}{2}. \tag{13}$$

Under Model Q, we consider a two-stage game. In stage 1, the eco-friendly product firm decides the quality of the eco-friendly product with blockchain certification. In stage 2, after q is disclosed, the eco-friendly and non-eco-friendly product firms set their own prices simultaneously. The optimal results are in Table 2 in Appendix A.

Under Model Q, the results of the sensitivity analysis of the optimal prices and profits can be found in Tables 1 and 2 for details. Also, we have results shown as follows.

Proposition 5.2: Under Model Q, both fewer eco-friendly consumers and an increased enhanced consumers' perceived belief for the product due to blockchain implementation increase the consumers' willingness to pay for quality.

Proposition 5.2 further identifies that the eco-friendly product should enhance its product quality if most consumers are unsustainable. The reason is that if the consumers are not environmentally friendly, then the green attribute of the product is not attractive to them. However, although the utility for unsustainable consumers does not change with green-level quality, the demand for the non-eco-friendly product also includes sustainable consumers. The eco-friendly product firm can produce a high-quality product to appeal to this group of consumers, which means that the eco-friendly product can recapture the demand cannibalized by the non-eco-friendly product by improving quality.

In addition, conventional wisdom suggests that if consumers' perceived belief in products is high, the firm lacks stimulus in improving product quality. Surprisingly, blockchain adoption enables the eco-friendly product firm to improve product quality while increasing consumers' perceived belief. This result implies that blockchain adoption can be a competitive method to increase market share.

VI. NUMERICAL ANALYSES

To ensure the numerical results are significant and in line with reality, we employ survey data from some authoritative reports in practice.

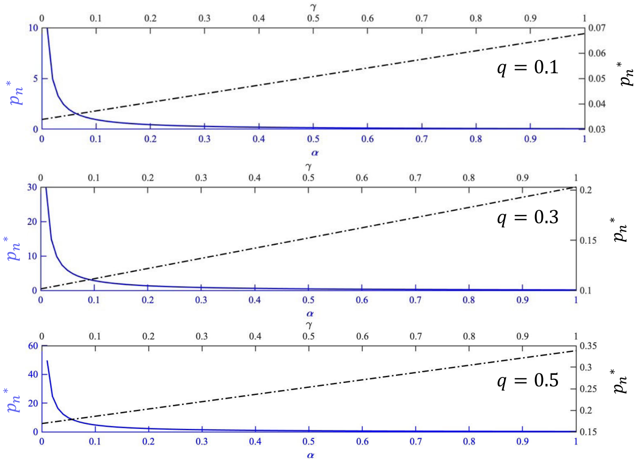

FIGURE 2. The impacts of α and γ on p_n^* under different green levels.

First, GreenPrint, an international business consulting firm, revealed in its Business of Sustainability Index that 66% of surveyed American consumers are willing to spend more for sustainable products compared to less sustainable competitors.[1] This allows us to choose $\alpha = 0.66$ in our numerical study.

Second, FMCG Gurus, a global market research company, polled 26,000 shoppers in 26 countries to gauge their opinions and acceptance of blockchain. Their findings indicate that 55% of respondents stated they would likely use blockchain to learn more about green products, beverages, and nutritional supplements.[2] Thus, we assume $\gamma = 0.55$ in this section.

It should be noted that, in order to verify the sensitivity of the numerical results, we consider different quality levels, where $q = 0.1$, 0.3, and 0.5, when discussing the influences of α and γ on p_i^* and π_i^*, respectively. We also consider the joint impacts of two parameter groups, which are the α and γ group and the α and q group when making comparisons.

The numerical results confirm all the theoretical results under the basic models. Specifically, the results are as follows.

Fig. 2 validates part of the findings shown in Proposition 3.1 (i) that the impact of α on p_n^* is monotonically decreasing, and the impact of γ on p_n^* is monotonically increasing. Fig. 2 also shows that the theoretical results are robust because the patterns are consistent under different quality levels. In addition, we find that a lower α has a more significant influence on the price, which reveals that the price is more sensitive when eco-friendly consumers dominate the market. With an increase in the number of sustainable consumers, the price of the non-eco-friendly product gradually becomes smoother. In contrast, the effect

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[1] [Access online] https://sustainablebrands.com/read/marketing-and-comms/majority-of-us-consumers-say-they-will-pay-more-for-sustainable-products Aug 29, 2023

[2] [Access online] https://www.newfoodmagazine.com/news/107917/survey-reveals-consumer-acceptance-and-willingness-to-use-blockchain/ Aug. 30, 2023

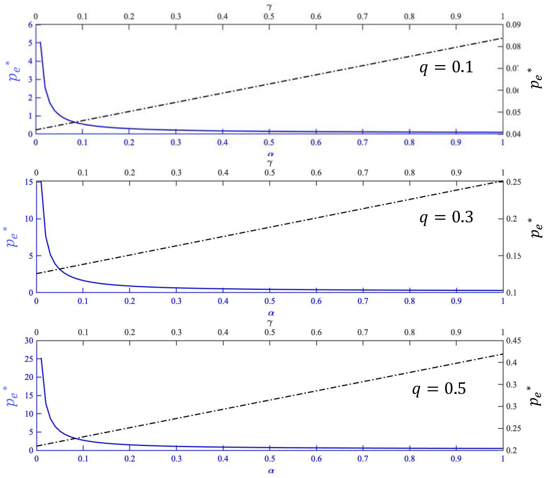

FIGURE 3. The impacts of α and γ on p_e^* under different green levels.

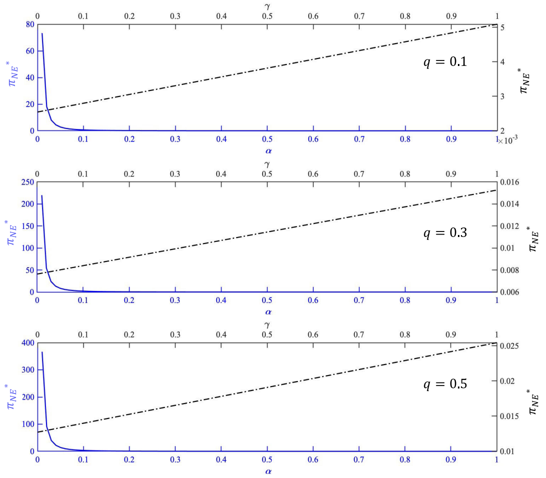

FIGURE 4. The impacts of α and γ on π_{NE}^* under different green levels.

of γ on price is always flat, meaning that any change in γ will not have an inconsistent effect on the price of the non-eco-friendly product.

Fig. 3 validates the remaining findings shown in Proposition 3.1 (i) that the impact of α on p_e^* is monotonically decreasing, and the impact of γ on p_e^* is monotonically increasing. Interestingly, the pattern shown in Fig. 2 is very similar to that in Fig. 3. We suggest that when the number of eco-friendly consumers is small, the price of the eco-friendly product changes drastically (decreases). This result highlights a managerial insight that the seller of the eco-friendly product cannot adjust the price when the number of eco-friendly consumers in the market reaches a certain level. In addition, it is easy to see the flat impact of γ on p_e^* because a higher γ means a higher value of blockchain, which makes the price of the eco-friendly product higher. Interestingly, comparing Figs. 2 and 3, we observe that the impact of γ is consistent (incremental) for both products, suggesting that blockchain may mitigate price competition.

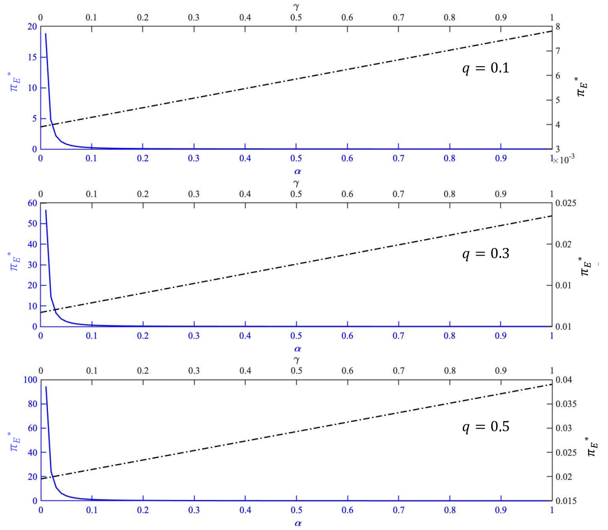

FIGURE 5. The impacts of α and γ on π_E^* under different green levels.

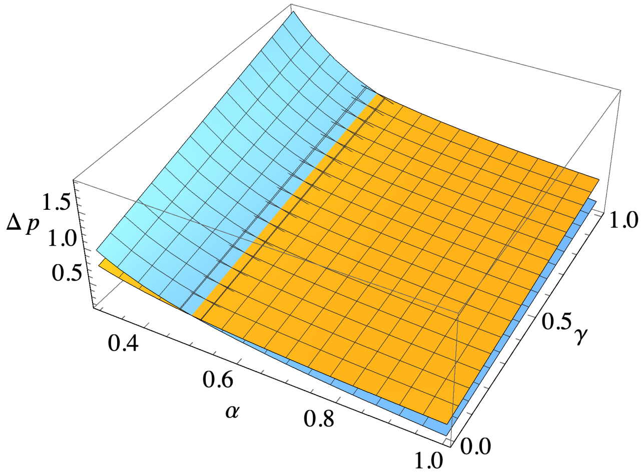

FIGURE 6. Comparison of p_n^* and p_e^* considering the joint impact of α and γ.

Fig. 4 visualizes some of the results in Proposition 3(ii) that the impact of α on π_{NE}^* is monotonically decreasing, and the impact of γ on π_{NE}^* is monotonically increasing. Although the pattern of profit changes is similar to the pattern of price changes, we uncover that the impact of α on profit is sharper than on price when α is relatively small. Surprisingly, under different quality levels, both α and γ have nearly the same impact on π_{NE}^*, but the higher quality will result in more profit for the non-eco-friendly product.

Fig. 5 visualizes the remaining results in Proposition 3(ii) that the impact of α on π_E^* is monotonically decreasing, and the impact of γ on π_E^* is monotonically increasing. Essentially, Fig. 5 reveals how the eco-friendly product can make more profit. Undoubtedly, a higher γ leads to increased profits, but more eco-friendly consumers are not always helpful.

Figs. 6 and 7 confirm the results shown in Proposition 4.1 (i). In both figures, the blue curved surface

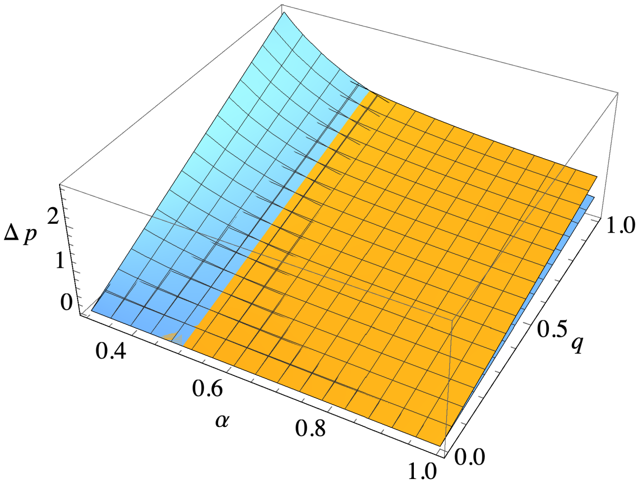

FIGURE 7. Comparison of p_n^* and p_e^* considering the joint impact of α and q.

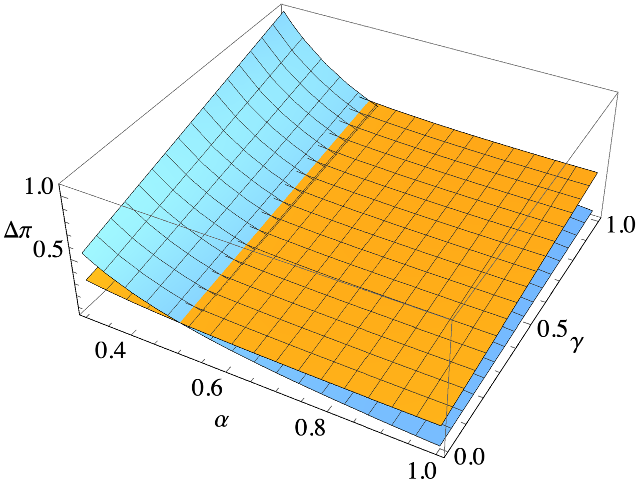

FIGURE 8. Comparison of π_{NE}^* and π_E^* considering the joint impact of α and γ.

represents the price of the non-eco-friendly product, and the yellow curved surface represents the price of the eco-friendly product. Note that in both Fig. 6 and Fig. 7, the value of α at the line of intersection of the two planes is 0.5. To further confirm the theoretical result, we consider the joint impacts of the α and γ group and the α and q group, respectively. Both intuitive results indicate that, regardless of any γ or q value, if α is greater than 0.5, then $p_e^* > p_n^*$. In addition, comparing Figs. 6 and 7, we find that q has a more significant impact on Δp than γ. This is because the difference between both products is apparent. Blockchain-enabled quality improvements help close the price gap.

Fig. 7 confirms the results shown in Proposition 4.1 (i). The blue curved surface represents the price of the non-eco-friendly product, and the yellow curved surface represents the price of the eco-friendly product. Regardless of any γ or q value, if α is greater than 0.5, then $p_e^* > p_n^*$.

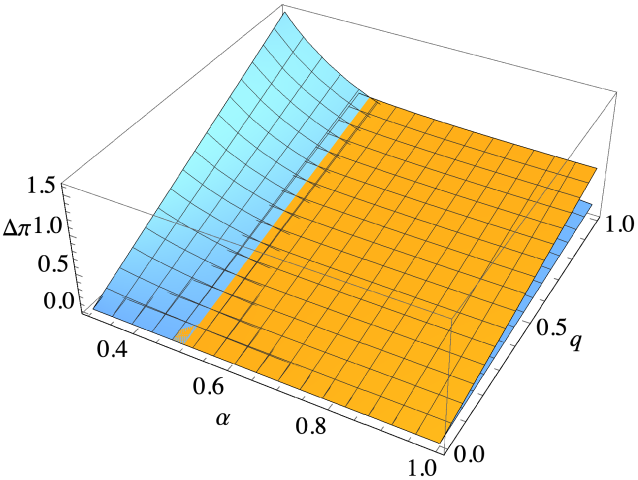

FIGURE 9. Comparison of π_{NE}^* and π_E^* considering the joint impact of α and q.

Figs. 8 and 9 confirm the results in Proposition 4.1 (ii). Similarly, the blue curve surface represents the profit for the non-eco-friendly product, and the yellow curve surface represents the profit for the eco-friendly product. The interaction between the blue and yellow curved surfaces represents the value where $\alpha = 0.5$. As shown in Figs. 8 and 9, the more substantial curvature of the blue plane indicates that the non-eco-friendly product is more influenced by the combination of α, γ, and q.

VII. CONCLUSION

A. CONCLUDING REMARKS

Following the real-world use of blockchain technology to verify product eco-friendliness, we are inspired to examine the landscape of competition for environmentally conscious and traditional product makers in the blockchain epoch. To address this inquiry, we segment consumers into two distinct categories based on their product preferences concerning environmental attributes. To delve further into this subject, we introduce two pricing models: one tailored for a firm producing blockchain-enabled eco-friendly products and another designed for a firm manufacturing non-eco-friendly product. These models serve as the foundation for our subsequent analysis. Our exploitation encompasses the derivation of optimal pricing strategies and profit assessments for both types of firms. We then undertake a comprehensive evaluation to discern how eco-friendly products can gain a competitive edge over their non-eco-friendly counterparts, a task accomplished through a comparative analysis of the optimal results from different models. We investigate extended models in three important factors, namely (i) blockchain cost, and (ii) exogenous quality decision.

B. MANAGERIAL IMPLICATIONS

We have the following main results: (i) Within the realm of competitive markets, it is essential to recognize that

TABLE 1. **Optimal results under the basic and extended models.**

Model	Optimal Solution	$i = n$	$i = g$
Basic Model	p_i^*	$\frac{q(2-\alpha)(1+\gamma)}{3\alpha}$	$\frac{q(1+\alpha)(1+\gamma)}{3\alpha}$
	π_i^*	$\frac{q(\alpha-2)^2(1+\gamma)}{9\alpha}$	$\frac{q(1+\alpha)^2(1+\gamma)}{9\alpha}$
Model C_exo	$p_i^{C_{exo}*}$	$\frac{q(2-\alpha)(1+\gamma)+\alpha c_b}{3\alpha}$	$\frac{q(1+\alpha)(1+\gamma)+2\alpha c_b}{3\alpha}$
	$\pi_i^{C_{exo}*}$	$\frac{(q(-2+\alpha)(1+\gamma)-\alpha c_b)^2}{9q\alpha(1+\gamma)}$	$\frac{(q(1+\alpha)(1+\gamma)-\alpha c_b)^2}{9q\alpha(1+\gamma)}$
Model C_end	$p_i^{C_{end}*}$	$\frac{q(4-\alpha)(1+\gamma)}{5\alpha}$	$\frac{3q(1+\alpha)(1+\gamma)}{5\alpha}$
	$\pi_i^{C_{end}*}$	$\frac{q(-4+\alpha)^2(1+\gamma)}{25\alpha}$	$\frac{q(1+\alpha)^2(1+\gamma)}{25\alpha}$
Model Q	p_i^{Q*}	$\frac{(2-\alpha)(1+\alpha)^2(1+\gamma)^2}{27c\alpha^2}$	$\frac{(1+\alpha)^3(1+\gamma)^2}{27c\alpha^2}$
	π_i^{Q*}	$\frac{(\alpha-2)^2(1+\alpha)^2(1+\gamma)^2}{81c\alpha^2}$	$\frac{(1+\alpha)^4(1+\gamma)^2}{162c\alpha^2}$

TABLE 2. **Results of sensitivity analysis under basic and extended models.**

Model	Optimal Solution	α	γ
Basic Model	p_i^*	$\downarrow$	$\uparrow$
	π_i^*	$\downarrow$	$\uparrow$
Model C_exo	$p_i^{C_{exo}*}$	$\downarrow$	$\uparrow$
	$\pi_i^{C_{exo}*}$	$\downarrow$ when $c_b < \tilde{c}_b$ (i=n) $\downarrow$ when $c_b < \bar{c}_b$ (i=e)	$\uparrow$ when $c_b < \tilde{c}_b$ (i=n) $\uparrow$ when $c_b < \bar{c}_b$ (i=e)
Model C_end	$p_i^{C_{end}*}$	$\downarrow$	$\uparrow$
	$\pi_i^{C_{end}*}$	$\downarrow$	$\uparrow$
Model Q	p_i^{Q*}	$\downarrow$	$\uparrow$
	π_i^{Q*}	$\downarrow$	$\uparrow$

blockchain's effectiveness and worth are not unconditionally assured. In the case of more eco-friendly consumers, the eco-friendly product outperforms the non-eco-friendly product, although more eco-friendly consumers reduce both firms' prices and profits. (ii) If the eco-friendly product firm employs blockchain, it must have the bargaining power to use blockchain. This is how the eco-friendly product would beat the non-eco-friendly product. In other words, the firm must be the game leader. (iii) Non-eco-friendly consumers have the potential to purchase green products, which implies that blockchain is valuable for environmental protection. (iv) Contrary to popular opinion, eco-friendly products can be lucrative without a large blockchain influence over consumers' beliefs, and environmental awareness promotes adopting blockchain for environmentally friendly product verification.

In addition, we are surprised to find that if non-eco-friendly consumers cannot be motivated by using blockchain to certify the sustainable degree of products, i.e., consumers stubbornly prefer non-green products, more eco-friendly consumers would reduce the profits of both products; otherwise, more eco-friendly consumers would drive both products to raise prices and make more profits. Thus, the eco-friendly product should take steps to increase consumers' utility of buying the eco-friendly product, such as adopting blockchain. Blockchain adoption helps reduce competition, and it will bring the Matthew effect to the sales of the eco-friendly product. However, if the eco-friendly product wants to outperform the non-eco-friendly product, enough eco-friendly consumers in the market may be helpful. Also, the eco-friendly product firm should be the game leader.

The theoretical results in the basic models are confirmed by the findings of the numerical analyses. In addition, according to the findings of the numerical studies, the profitability of the price for both eco-friendly and non-eco-friendly products is significantly impacted more by the presence of a lower total number of eco-friendly consumers. The increase in consumer's perceived belief in the eco-friendly product that blockchain promotes has a flat impact on the eco-friendly product's price and profit. The price and profit for the non-eco-friendly product are more influenced by the combination of consumers' quantity and quality (and the blockchain-based enhanced consumers' perceived belief for the eco-friendly product).

APPENDIX A THE OPTIMAL RESULTS AND SENSITIVITY ANALYSIS RESULTS

The optimal results, sensitivity analysis results under the basic and extended models, and the thresholds defined in this paper are given in Table 1 and Table 2, respectively.

APPENDIX B ALL PROOFS

Proof of Table 2:

We first demonstrate that π_{NE} is convex with respect to p_n as $\frac{\partial^2\pi_{NE}}{\partial p_n^2} = -\frac{2\alpha}{q(1+\gamma)}$. By examining the first-order condition, we obtain the sub-equilibrium $p_n(p_e)$. Simultaneously, π_E is convex with respect to p_e as $\frac{\partial^2\pi_E}{\partial p_e^2}$. By examining the first-order condition, we derive the sub-equilibrium $p_e(p_n)$. Since we are dealing with a duopoly market, solving $p_n(p_e)$ and $p_e(p_n)$ together, we can deduce the optimal solutions. The derivation of optimal results under the other models follows a similar pattern to that of the basic models, and we will not provide them here.

Proof of Proposition 3.1:

For the non-eco-friendly product, with the optimal results, we have:

1) $\frac{\partial p_n^*}{\partial \alpha} = -\frac{2q(1+\gamma)}{3\alpha^2} < 0$ and $\frac{\partial p_n^*}{\partial \gamma} = \frac{q(2-\alpha)}{3\alpha} > 0$.
2) $\frac{\partial \pi_{NE}^*}{\partial \alpha} = \frac{q(-2+\alpha)(2+\alpha)(1+\gamma)}{9\alpha^2} < 0$ and $\frac{\partial \pi_{NE}^*}{\partial \gamma} = \frac{q(-2+\alpha)^2}{9\alpha} > 0$.

For the eco-friendly product, with the optimal results, we have:

1) $\frac{\partial p_e^*}{\partial \alpha} = -\frac{q(1+\gamma)}{3\alpha^2} < 0$ and $\frac{\partial p_e^*}{\partial \gamma} = \frac{q(1+\alpha)}{3\alpha} > 0$.
2) $\frac{\partial \pi_e^*}{\partial \alpha} = \frac{q(-1+\alpha)(1+\alpha)(1+\gamma)}{9\alpha^2} < 0$ and $\frac{\partial \pi_e^*}{\partial \gamma} = \frac{q(1+\alpha)^2}{9\alpha} > 0$.

Proof of Proposition 4.1:

First, we have $\Delta\pi^* = \frac{q(2\alpha-1)(1+\gamma)}{3\alpha}$ and $\Delta p^* = \frac{q(2\alpha-1)(1+\gamma)}{3\alpha}$. Apparently, when $\alpha > \frac{1}{2}$, $\Delta\pi^* > 0$ and $\Delta p^* > 0$.

Proof of Proposition 5.1:

With endogenous blockchain cost, the difference between the profits of the non-eco-friendly product and the eco-friendly product is $\Delta\pi_{end} = \frac{q(-3+2\alpha)(1+\gamma)}{5\alpha}$. Since $\alpha \in [0, 1]$, we have $\Delta\pi_{end} < 0$. Thus, the non-eco-friendly product is more profitable than the eco-friendly product.

With exogenous blockchain cost, we have $\Delta\pi_{exo} = \frac{q(-1+2\alpha)(1+\gamma)-2\alpha c_b}{3\alpha}$. When $\Delta\pi_{exo} > 0$, we have $\alpha > \alpha_L$, $\gamma > \gamma_L$, where $\alpha_L = \frac{q\gamma(1+\gamma)}{2q\gamma(1+\gamma)-2c_b}$ and $\gamma_L = \frac{2\alpha c_b - q\gamma(2\alpha-1)}{q\gamma(2\alpha-1)}$.

Proof of Proposition 5.2:

For the eco-friendly product's quality decision, with the optimal results, we have $\frac{\partial q^*}{\partial \alpha} = \frac{(\alpha-1)(1+\alpha)(1+\gamma)}{9c\alpha^2} < 0$ and $\frac{\partial q^*}{\partial \gamma} = \frac{(1+\alpha)^2}{9c\alpha} > 0$.

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