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Applications of Blockchain Technology in Sustainable Fashion Supply Chains: Operational Transparency and Environmental Efforts

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Dear Prof. Choi and Prof. Chan,

Greetings!

I wish to resubmit to you my co-authored paper entitled "*Applications of Blockchain Technology in Sustainable Fashion Supply Chains: Operational Transparency and Environmental Efforts*" for its possible publication in Special Issue on "Impacts of Technology Management on the Apparel Retailing and Manufacturing Industry in the Data Analytics Era", *IEEE Transactions on ENGINEERING MANAGEMENT.*

We sincerely thank you and the three anonymous referees for their critical and constructive comments on our paper. In this revision, as advised, we have faithfully addressed the review concerns and improved the paper by making the needed amendments. The detailed responses to the review comments are listed in the individual responses to reviewers as attached. To facilitate review, the major changes in the paper are highlighted in yellow. Please check.

Thank you very much. I look forward to hearing from you.

Yours sincerely,
The authors

Applications of Blockchain Technology in Sustainable Fashion Supply Chains: Operational Transparency and Environmental Efforts

Abstract

Using environmentally friendly materials is a popular business practice in the fashion industry nowadays, which can affect both a fashion product's cost and its environmental impacts in the manufacturing process. Given the growing social consciousness of the public, the integration of environmentally friendly materials can also influence the market demand of fashion products. This paper studies the information disclosure games over the environmental efforts in fashion supply chains. We consider a fashion retailer, which is the Stackelberg leader, orders sustainable fashion products made from environmentally friendly materials from a manufacturer. The fashion retailer can choose either to affix the eco-label or to adopt the blockchain technology, to declare the environmental quality of the fashion product to consumers. Meanwhile, given that the environmental quality is unobservable to the fashion retailer and the consumers, the manufacturer with credibility concerns can have the actual environmental quality of the fashion product discounted. We discuss how the application of the blockchain technology influences the information disclosure games over the environmental efforts in the fashion industry. Findings in this paper advance the understanding on the application of the blockchain technology in sustainable practices in fashion supply chains.

***Keywords**:* Information Transparency, Environmental Efforts, Blockchain Technology, Fashion Supply Chain, Technology Management.

1. Introduction

1.1 Background and Motivation

The fashion industry has long been blamed by the public as a source of pollution. According to the statistics from the United Nations Environment Programme (UNEP) and the Ellen MacArthur Foundation [1], the fashion industry consumes 93 billion cubic meters of water each year. This is equivalent to the water needs of five million people. Besides, the fashion industry makes up 10% of the world's annual carbon emissions, even higher than that from all international flights and maritime transport. Among all the manufacturing processes, the textile treatment and dyeing process accounts for nearly 20% of water pollution of the fashion industry, as shown in the Waste and Resources Action Programme (WRAP) 2017 report. To meet the sustainability demand, more and more fashion companies are making their products from environmentally friendly materials [2]. For instance, the giant fashion brand H&M's innovative collection "Conscious Exclusive" is designed for sustainable fashion, in which all the products contain sustainable materials. Consumers can recognize this collection by the attached green tags, indicating that at least 50% sustainable raw materials or 20% recycled cotton are used[1]. C&A, another fashion brand, was named the world's largest buyer of organic cotton for the sixth time in 2018 and one of the world's largest buyers of more sustainable cotton.[2] In the meantime, overproduction and surplus stock are serious issues in the fashion industry. 87% of the aggregate fiber used in clothing ends up being incinerated or buried in a landfill. According to a Danish TV investigation report, for instance, H&M was blamed for burning 60 tons of usable garments since 2013. In 2018, it was revealed that Burberry had destroyed £28m of unsold stock. There are also reports showing that Nike and Urban Outfitters have demolished and ruined items, with the aim of maintaining brand uniqueness and avoiding discounted sales [3]. To address the large amount of product leftovers in the fashion industry, various recycled materials have been extensively adopted by fashion retailers like UNIQLO and VF Corporation in their new fashion products. For example, from the 2020 spring and summer seasons, UNIQLO began to sell its DRY-EX Polo shirts, which use recycled polyester made from post-consumer PET bottles by using the contaminant filtering technology[3]. The use of environmentally friendly materials helps fashion companies reduce the environmental pollutions resulting from the product development process, thus enhancing the environmental performance of their products.

[1] https://www.sohu.com/a/402949876_120113743?_trans_=000014_bdss_dkygcbz (Accessed on October, 2020).
[2] https://www.c-and-a.com/uk/en/corporate/company/newsroom/press-releases/2019/ca-reduces-carbon-and-water-footprints-significantly-by-sourcing-more-sustainable-raw-materials/ (Accessed on October, 2020).
[3] https://www.fastretailing.com/eng/sustainability/report/new.html(Accessed on October, 2020).

In the meantime, information asymmetry and visibility have been widely viewed as major concerns over the operations in multi-tier supply chains [4], [5]. Regarding the manufacturing process, the subsequent lack of supply chain traceability has also become an economic and social challenge, as companies may have limited information about the components or raw materials used to make their products [6]. Credibility concerns can then arise from the manufacturing of sustainable fashion products. A manufacturer lacking full credibility may produce the sustainable fashion products with a discounted environmental quality as stated. This can lead to environmental damage or pollutants with the actual chemicals being released. These concerns, however, can be addressed under the big data environment, in which data-based tracking systems are developed by utilizing advanced information technologies for information disclosure and sharing.

Among various advanced information technologies, blockchain represents a state-of-the-art technology for enabling traceability [7]. Blockchain is a digital ledger consisting of blocks of information [8], with all blocks interdependently linked to each other. In the blockchain-based traceability systems, each transaction and action are recorded visibly and can be tracked and retrieved by multiple parties at any time. Besides, given the complex cryptography of blockchain, all data are irreversibly and permanently recorded. Relevant parties involved therefore can share data with each other without trust and credibility concerns [9]. As a result, blockchain has been widely applied in practices. For instance, both Walmart and IBM are known for their blockchain programs for improving supply chain traceability. E-commerce firms like Alibaba and JD.com also have launched blockchain schemes for food and pharmaceuticals management [10]. In the fashion industry, a major blockchain application is to track materials and products throughout different manufacturing stages, ranging from initial raw materials management to finished products management. As an instance of the fashion product with the use of environmentally friendly materials, the promise of blockchain is it does not require the involvement of any additional inspections or certifications. Instead, once the information is recorded in the blockchain system, it is immutable and publicly visible [11]. This simplifies the information disclosure processes and ensures reliable environmental efforts claims.

The management of environmental efforts is challenging in fashion supply chains. In practice, the environmental quality of a fashion product is unobservable to both the fashion retailer and consumers. Consumers' preferences towards information disclosure games over the environmental efforts can also influence the environmental performance of sustainable fashion supply chains. Prior studies have explored how to improve the performance of sustainable fashion supply chains from various perspectives, like the influences of government intervention and cooperating contracts. However, the impacts of the application of advanced information technologies remain underexplored. Besides, the extant literature mainly focuses on studying the conditions under which information transparency can help improve supply chain efficiency. However, the associated advertisement strategies for the environmental quality of the products and the signaling roles played by the advertisement activities have not yet been investigated. In fact, advertisement plays an important role for fashion companies to announce the environmental quality of their products and thus is worth consideration. For example, on the official website of H&M, there is a special section called "Let's be transparent[4]", which guides customers to track the background details about the products they would like to purchase, such as the materials the product is made from, which countries it was produced in, and which suppliers and factories they partnered with to make it. C&A online displays all the sustainable fashion products with specific information about what types of the sustainable materials used, which are all certified by independent third parties to make customers feel confident that the products they purchase are made sustainably[5].

Motivated by the popularity of environmentally friendly fashion products nowadays, the importance of information transparency for environmental efforts, and the research gap in the literature, this paper therefore conducts a deep investigation on how the application of the blockchain technology influences the information disclosure games over the environmental efforts in the fashion industry.

1.2 Research Questions and Contribution Statements

Research questions: The industrial observations and literature motivate us to explore the application of the blockchain technology in the information disclosure games (over the environmental efforts) in the fashion supply chain by addressing the following research questions.

1) Under the considerations of information disclosure, what is the optimal environmental quality of the sustainable fashion product?

2) How does the blockchain technology influence the information disclosure games over the environmental efforts? Is an enhanced information transparency level brought by blockchain always beneficial to both the fashion retailer and the upstream manufacturer?

3) What are the impacts brought by the risk attitudes of the fashion retailer and the manufacturer towards the market uncertainty?

4 https://www2.hm.com/en_us/hm-sustainability/lets-change.html/transparent (Accessed on October, 2020).
5 https://www.c-and-a.com/eu/en/shop/women-topics-more-sustainable-fashion (Accessed on October, 2020).

The fashion retailer's environmental efforts in this paper is reflected by the environmental quality of the fashion product. To examine these questions, we present a fashion supply chain consists of a fashion retailer and an upstream manufacturer. The fashion retailer, which is the Stackelberg leader, orders the sustainable fashion product, which is made from environmentally friendly materials, from the manufacturer. The manufacturer, acting as the follower, then produces the product accordingly based on the requirements of the fashion retailer. To declare the environmental quality of the fashion product to the consumers, the fashion retailer can choose either to affix his own eco-label or to adopt the blockchain technology. Given that we follow Guo et al. [18] and Galbreth and Ghosh [42] and define the environmental quality of the fashion product as the amount of environmentally friendly material(s) adopted in the product development process, the environmental quality is unobservable to both the fashion retailer and the consumers. As a result, under the eco-label practice (i.e., in the traditional fashion supply chain without blockchain), the manufacturer with credibility concerns can have the actual environmental quality of the fashion product discounted. In the fashion supply chain with the support of blockchain, however, the manufacturer has to follow the requirements given the full information transparency. By comparing the information disclosure games between the traditional fashion supply chain without blockchain and the blockchain-based fashion supply chain, we discuss how the application of the blockchain technology influences the information disclosure games over the environmental efforts in the fashion industry. The environmental impacts are also examined.

Our research provides the following answers to the research questions.

1) Role of information disclosure. First, we find that under the traditional fashion supply chain, when the consumers hold a higher willingness to pay for the fashion retailer's internal inspection level, the optimal environmental quality of the fashion product will be higher. In the blockchain-based fashion supply chain, when the consumers hold a higher willingness to pay for the blockchain advertisement level, the optimal environmental quality of the fashion product will be higher. Both findings highlight the importance of information disclosure and transparency, which can help reduce the consumers' credibility concerns over the information provided by the affixed eco-label.

2) Role of the blockchain technology. We find that the consumer's willingness to pay for the fashion retailer's blockchain advertisement level impacts the value of blockchain in improving the optimal environmental quality of the sustainable fashion product. That is, as long as the consumer's willingness to pay for the blockchain advertisement level is sufficiently high, applying blockchain for information disclosure can always increase the optimal environmental quality of the fashion product. This accordingly increases the environmental performance of the fashion product. Whereas if the consumer's willingness to pay for the blockchain advertisement level is not that high, a higher optimal environmental quality of the product can be achieved in the blockchain-based fashion supply chain if and only if the basic manufacturing cost of the fashion product is sufficiently high. Besides, disclosing information via blockchain can always benefit both the fashion retailer and the manufacturer if the consumer's willingness to pay for the blockchain advertisement level is sufficiently high.

3) Impact of the risk attitudes. Our results show that, in the traditional fashion supply chain, the more risk averse the fashion retailer is, the lower the optimal environmental quality and internal inspection level can be. In addition, despite the risk attitudes of the fashion retailer and the manufacturer, applying blockchain for information disclosure is always beneficial to both the fashion retailer and the manufacturer as long as the consumer's willingness to pay for the blockchain advertisement level is sufficiently high. However, if the consumer's willingness to pay for the fashion retailer's blockchain advertisement level is not that high, blockchain can benefit both the fashion retailer and the manufacturer only when the risk aversion level of the fashion retailer or the market demand uncertainty is sufficiently high.

Contribution statements: We contribute to the literature by providing new insights beyond what is currently available in the literature on sustainable fashion supply chains, environmental efforts, information disclosure/transparency and technology investment in supply chains. Managerial implications on how the application of the blockchain technology influences the information disclosure games over the environmental efforts in the fashion industry can also serve as an important reference to business practices in the fashion industry nowadays.

The remainder of this paper is organized as follows. Section 2 presents the related literature, regarding the fields of sustainable fashion supply chains, environmental efforts, information disclosure/transparency, as well as technology investment in supply chains. Section 3 introduces the model formulation. Section 4 examines the games of information disclosure over environmental efforts. Section 5 conducts comparisons between the two information disclosure games and investigates the performance of the blockchain technology. Section 6 extends Section 4 with the risk considerations, and Section 7 finally concludes the paper with managerial insights and also provides future research opportunities. All proofs are placed in Online Supplementary Appendix A, and relevant tables are provided in Online Supplementary Appendix B.

2. Literature Review

The paper mainly relates to four research areas, which include: sustainable fashion supply chains, environmental efforts, information disclosure/transparency and technology investment in supply chains.

2.1 Sustainable Fashion Supply Chains

Sustainability issues in the fashion and apparel industry have been an important topic which attracts tremendous attentions from both practitioners and academia [12]. On one hand, governments play a critical role in enhancing sustainable operations for fashion supply chains. Government regulations will affect the procurement strategies taken by retailers. For example, Niu et al. [13] examine the impacts of two commonly used regulations on the improvement of supply chain sustainability. The results show that both subsidizing and punishing can help balance the conflicts between sustainability goal and social welfare maximization. Credibility plays a critical role for the government to take actions on stimulating sustainable operations. Murali et al. [14] examine the conditions under which the regulators should not intervene when competing firms can use self-labels or external certifications to show their sustainable performance.

On the other hand, the effective cooperating mechanisms among supply chain members are of great importance to realize full sustainability [15]. Fashion supply chain is evaluated as a well-qualified system of systems. Choi et al. [16] propose the critical principles for building a sustainable fashion supply chain. It is revealed analytically that sustainability coordination and technology employment are essential to achieve full sustainability. Bai et al. [17] propose different coordination mechanisms, such as cost sharing and two-part tariff contract, for a two-echelon sustainable supply chain under carbon cap-and-trade regulation. The results show that the cooperation between the manufacturer and the retailer may lead to both economic and environmental sustainability. Guo et al. [18] study a fashion supply chain in which one manufacturer and two retailers are involved. The effects of retail competition and consumer returns on the green development of the fashion products are investigated. The results help understand the underdevelopment of the green fashion products, as the features of fashion industry suppress the improvement of the greenness level for profit-oriented retailers. Joining a co-opetition game for the fashion companies are critical for both green product development and consumer returns management. Hong and Guo [19] study cooperation contracts for a green product supply chain in which the manufacturer is responsible for designing and producing a green product, and the retailer promotes the green product through green marketing. Different cooperation contracts are analyzed. The results show that cooperating contracts are valuable but may not always benefit all the parties. The social welfare increases with the supply chain's cooperation level.

The above research works have explored the ways to improve the performance of sustainable fashion supply chains from various aspects, like the influences of government intervention and cooperating contracts. The application of advanced information technologies, however, remains underexplored. This research contributes to the sustainable fashion supply chains literature by investigating the application of the blockchain technology in the information disclosure games over the environmental efforts in the fashion industry.

2.2 Environmental Efforts

With the enforcement of environmentally friendly regulations and policies and the increase in consumers' environmental awareness, firms put more efforts to address environmental issues by, for example, reducing emissions during the manufacturing and process stages [20]. The decision making and contracts adopted by supply chain members affect the performance of the environmental efforts as well as their profitability. Yang et al. [21] study a two-echelon supply chain where carbon emission charges and consumers' environmental awareness are both considered. Wholesale price contract and revenue sharing contract are examined for systems coordination. The numerical results show that different emission abatement strategies affect the profit of the supply chain systems and a first-mover will obtain a greater share of revenue. Zhu et al. [22] explore the coordination mechanism by cost-sharing contracts for green food manufacturing and marketing in a green food two echelon supply chain. Both food producer and supplier make green efforts for material processing and food manufacturing. The results show that a mutual cost-sharing contract induces more profits for both parties when consumers' sensitivity to the greenness level increases. Hosseini-Motlagh et al. [23] investigate a sustainable supply chain with one manufacturer investing to reduce carbon emissions and two retailers competing on investing in the green effort. The results show that a proposed coordination strategy called three-party compensation-based contract is effective to realize both economic and environmental sustainability. Kang et al. [24] analyze the effects of the environmentally friendly regulation on the manufacturer's efforts to reduce pollution in the supply chain. The numerical results indicate that, with the incentive scheme and consumers' environmental awareness, the manufacturer can create additional value by cooperating with its supplier for pollution reduction. Shi et al. [25] examine the value of the bargaining contract for a sustainable supply chain coordination and the effectiveness of different subsidies. The results show that the pareto improvement is achieved under bargaining contract when the manufacturer's bargaining power satisfies a certain condition. Both direct and indirect subsidies can increase the sustainability effort but total carbon emissions reduction may not be guaranteed.

The above discussion suggests that the effectiveness of additional charges (e.g., carbon emission charges) and subsidies have been extensively studied, but there is still limited literature examining the inherent challenges of environmental efforts management. In practice, the environmental quality of a fashion product is unobservable to both the fashion retailer and consumers. Consumers' preferences towards information disclosure games over the environmental efforts can also influence the environmental performance of sustainable fashion supply chains. This research therefore complements the literature on environmental efforts by exploring such impacts.

2.3 Information Disclosure/Transparency

Information transparency may help improve supply chain efficiency. However, it may not always benefit all parties in the supply chain. For example, Huang and Yang [26] study the retailer's contract design and supplier's information disclosure decisions in a supply chain where the retailer outsources the manufacturing to its supplier. The supplier can obtain the manufacturing cost information through costly forecasting effort. The results show that the supplier can benefit from transparency only under specific conditions. For the retailer, it is not always preferred to stimulate the supplier's forecasting, which in fact depends on the forecasting cost. Zhao et al. [27] study the quality disclosure strategies for small firms competing with heterogeneous product quality. The small firms disclose their quality information to their consumers through retailers first and decides the optimal selling price. The analytical results show that a high-quality firm should avoid disclosing quality information while a low-quality firm may choose to disclose. Disclosing quality information of the high-quality firm to the consumers may lower the selling price due to the competition and the mechanism of information disclosure.

Information disclosure helps improve social and environmental sustainability in supply chains. The deterrent such as punishing affects the optimal disclosure strategies as the disclosure affects the level of scrutiny by the third party. Chen et al. [28] study a model in which one buyer, one supplier and an NGO are involved. Both the buyer and supplier incur a penalty if the sustainability standard is violated by the supplier. It is verified that an increase in penalty stimulates the buyer to reveal its supplier. However only a modest increase in penalty and the buyer's effort to monitor its supplier benefit supply chain sustainability. Peng et al. [29] examine the value of the online information disclosure platform in solving the environmental data fraud problem of enterprises. An evolutionary game model is developed to analyze the optimal decisions for local governments and enterprises. The results verify that partial investment in the development of online information disclosure platform is better than the pure offline investigation mode. With the rapid development of platform economy, information disclosure of the products and services is critical for consumer surplus and social welfare. Choi et al. [30] study a Nash game between two rental service platforms with substitutable products-to-rent. The analytical results indicate that the level of consumers' information sensitivity helps decide whether each platform should disclosure products information or not. The information auditing cost as well as the profit margin of the product have positive impacts on the information disclosure. Blockchain technology plays an important role in such platform operations in realizing product information disclosure. Besides, radio frequency identification (RFID) as an AutoID technology is commonly used for achieving information transparency in fashion supply chains. For instance, a RFID embedded inventory system can help to reduce the inventory record inaccuracy through item-level visibility of the entire supply chain [68]. In fact, blockchain is implemented at the cyber layer, while RFID is implemented at the physical layer. The combination of blockchain and RFID forms a cyber-physical system to create a transparent supply chain [69], [70].

While the aforementioned literature has highlighted the conditions when information transparency can help improve supply chain efficiency, the associated advertisement strategies have been ignored. Innovatively, this paper addresses two information disclosure games with different advertisement activities and explores the signaling roles of the advertisement activities. Besides, different from above, we focus on the context of the fashion industry, by considering factors like the complex sourcing networks of the manufacturer and the unique cost structure of the fashion products made from environmentally friendly materials.

2.4 Technology Investment in Supply Chains

Nowadays, supply chain members pay more attention to the technology investment during manufacturing and service operations to improve supply chain efficiency as well as consumer surplus [31], [32]. For example, Sengupta [31] studies the impacts of environmental consciousness of consumers in the cleaner technology investment. The findings demonstrate that market competition has a positive impact on the technology investment while requiring mandatory disclosure of technology may discourage such investment. Ulloa et al. [33] analyze the effects of a fixed initial technology investment on preventive maintenance (PM) on the performance-based maintenance contracts. Additional coordination mechanism is proposed to achieve supply chain coordination in which the vender reduces the maintenance price in exchange for a reduction in the number of PM required by the client. With environmental sensitivity consideration, Saberi et al. [34] examine the effectiveness of green technology investment in the long run for a supply chain network model in which retailers, manufacturers and carriers collaborate. The study advocates that effective sustainable strategies are supposed to be analyzed with the consideration of the entire supply chain. Zhang et al. [35] study the optimal investment and pricing strategies for green products with the consideration of consumer environmental awareness and energy efficiency standard. The results show that a higher consumer environmental awareness attracts more technology investment; however, a moderate rather than a stringent standard of energy efficiency encourages the producer to enter the green market. There exists a tradeoff between satisfying the expectation induced by consumer environmental awareness and the cost for achieving energy efficiency. In recent years, blockchain technology, especially its cryptocurrency function, has been attracting increasingly attentions from both governments and companies [36]. It has been widely applied in different areas for addressing information and capital fraud issues such as supply chain finance [37], [38]. For example, ur Rehman et al. [37] propose a blockchain technology-based platform to solve the information asymmetry and non-trust issues in the traditional supply chain. The results show the effectiveness of the blockchain technology-based financial platform on the improvement of cost efficiency and service level of the supply chain. In addition, by having traceability, transparency, security and smart execution, blockchain helps to solve the information challenges in supply chain activities [62]. It is well known that the first use of blockchain in fashion related supply chains is on diamond trading. Choi [64] investigates the values of blockchain-technology-supported platform for diamond authentication and certification. For the use of blockchain technology, it is important to explore the threshold for the implementation cost to benefit all the parties in the supply chain. Choi [38] examines the all-win conditions to implement the blockchain technology for all the supply chain's members and consumers.

Due to the inherent high volatility of demand in the fashion industry and the risk created by emerging technologies [63], supply chain members may have different risk preferences towards demand uncertainty. To tackle with the volatile demand, different risk measures have been applied to reach effective operations decisions [65]. Choi and Chiu [66] propose mean-down-risk model and mean-variance model to analyze the profit risks arising from demand uncertainty. By analyzing different sustainable aspects, the results show that risk preference will affect the decision making of retailers such that risk-averse fashion retailers are more sustainable in terms of having fewer unsold products. A key factor to success in the fashion industry is the ability to satisfy customers' demands in a prompt manner. Choi et al. [67] investigate the impacts of stochastic risk preference of the retailer on the value of quick response. It is verified that being more risk-averse brings more benefits to the retailer but incurs a smaller profit loss for the manufacturer. However, ignoring the risk preference of the retailer induces negative impacts on the Pareto improvement in the supply chain.

Different from the extant literature on technology investment in supply chains, which basically focuses on analyzing the effectiveness of various technologies and the ways for further improvement, this paper discusses the value of blockchain by considering both the consumers' preferences towards different information disclosure games and studying the influences brought by the risk attitudes of supply chain members.

3. Model Formulation

The fashion retailer's environmental efforts in this paper is reflected by the environmental quality of the fashion product. Following Guo et al. [18] and Galbreth and Ghosh [42], we define the environmental quality of the fashion product as the amount of environmentally friendly material(s) adopted in the product development process. Given the lack of supply chain traceability in traditional fashion supply chains, the actual amount of environmentally friendly material(s) adopted in the product development process can be invisible to consumers. A manufacturer lacking full credibility thus can take advantage of information asymmetry and produce the sustainable fashion products with a discounted environmental quality as stated. Under the data analytics era, however, the blockchain-based tracking systems can be applied for information disclosure and the manufacturer has to produce sustainable fashion products consistently with the data recorded in blockchain for raw materials. This section therefore presents the information disclosure game for environmental efforts during the product development process. A fashion supply chain is established, which consists of one upstream manufacturer (she) and one downstream retailer (he). Both the traditional fashion supply chain without blockchain and the blockchain supported fashion supply chain are explored next, with modeling assumptions justified with industrial practices.

3.1 Traditional Fashion Supply Chain without Blockchain

Information disclosure: We first consider a traditional fashion supply chain without the support of blockchain. Without the support of blockchain, information regarding the fashion product's environmental quality $e^{\overline{B}}$ is disclosed by the affixed eco-label, which is a traditionally and widely used practice among retailers for their branded products [39]. Typical examples in the fashion industry include but not limit to the eco-labels provided under H&M's Conscious Collection, which provides composition details such as the percentage of sustainable materials integrated.

Market demand: Consistent with the extant literature (e.g., Huang et al. [40], and Wang et al. [41]), each consumer purchases at most one unit of the sustainable fashion product and holds his own valuation (i.e., the willingness to pay) as u. The valuation u follows a probability distribution function $g(u)$ and a cumulative distribution function $G(u)$. The heterogeneity of consumer valuations is determined by general factors like the product quality and brand image, and is captured by taking u to be uniformly distributed over $[0, a]$. The fashion product's environmental quality $e^{\overline{B}}$ is quantified by the amount of environmentally friendly material(s) adopted and reflects the environmental performance of product development process. As an example, using organic cotton can reduce the total water consumption to 182 liters/kg lint compared with the 2,120 liters/kg lint of conventional cotton[6]. Better environmental performance of the product development process thus can be achieved by blending a larger amount of organic cotton into the fashion product. Such sustainable practices are widely emphasized by various fashion retailers such as H&M, M&S, and Mango for enhancing the environmental quality levels of their products. It is also supported by prior sustainability research like Galbreth and Ghosh [42]. By providing information regarding the environmental quality level, the fashion retailer enhances the consumer's willingness to pay by $\alpha e^{\overline{B}}$. α is the consumer's marginal willingness to pay for the environmental quality of the fashion product. Such an environmental quality-induced consumer preference is supported both by the survey conducted by the Gallup International Institute (1992) [57] and by literature like Bei and Simpson [58], Chen [59], as well as Guo et al. [18].

Besides, given that it can be difficult for consumers to identify the environmental quality of a product [43], consumers can have credibility concerns over the fashion retailer's eco-label. In order to improve the credibility of the affixed eco-label, the fashion retailer simultaneously releases information regarding his internal inspection level $\xi_I^{\overline{B}}$ on the sustainable product to consumers. This helps increase the consumer willingness to pay for the sustainable fashion product by $\gamma\xi_I^{\overline{B}}$, with γ as the consumer's marginal willingness to pay for the fashion retailer's internal inspection level on the sustainable fashion product. Accordingly, given a retail price $p^{\overline{B}}$, a consumer gets the utility of $U_{\overline{B}} = u + \alpha e^{\overline{B}} - \beta p^{\overline{B}} + \gamma\xi_I^{\overline{B}}$ from purchasing the sustainable fashion

[6] http://textileexchange.org/wp-content/uploads/2017/06/TE-Material-Snapshot_Organic-Cotton.pdf (Accessed on August, 2020).

product without the integration of the blockchain technology. As a result, we have the demand of the sustainable fashion product as $d_{\overline{B}} = \int_{\beta p^{\overline{B}}-\alpha e^{\overline{B}}-\gamma\xi_I^{\overline{B}}}^{a} g(u)du = \frac{1}{a}(a + \alpha e^{\overline{B}} - \beta p^{\overline{B}} + \gamma\xi_I^{\overline{B}})$.

Cost and revenue parameters: The fashion retailer orders the sustainable fashion product from the upstream manufacturer with a per unit wholesale price $w^{\overline{B}}$ and charges the consumer a retail price $p^{\overline{B}}$ of each sustainable fashion product. In the meantime, similar to the prior literature like Savaskan and Van Wassenhove [44], the fashion retailer has an extra sustainable investment $\frac{k_E(e^{\overline{B}})^2}{2}$ for selling the product to the target market. The extra sustainable investment can result from advertising the environmental quality (i.e., $e^{\overline{B}}$) and other relevant costs. Here, k_E is the fashion retailer's cost coefficient related to the product's environmental quality. For example, to promote their sustainable collections (e.g., the H&M Conscious Exclusive Collection and the MANGO Committed), both H&M and Mango have devoted extra efforts in advertising the detailed information regarding the environmentally friendly material(s) that have been utilized. The public can easily get access to the details either from their official newsletters or from fashion magazines like Vogue.

In the meanwhile, given the lack of direct control, the fashion retailer also conducts internal inspection over the manufacturer's use of environmentally friendly material(s). Internal inspections, however, are always imperfect [45]. In particular, the complex sourcing networks of the manufacturer in the fashion industry, which may involve thousands of factories across various countries, makes the internal inspection even more challenging [46]. In this paper, we therefore assume the fashion retailer conducts costly but imperfect internal inspection at a level $\xi_I^{\overline{B}}$. The level $\xi_I^{\overline{B}}$ determines the probability that the fashion retailer can detect the manufacturer's underperformance over the environmentally friendly material(s) utilization during his internal inspections, if it exists. This accordingly induces an extra internal inspection cost $\frac{k_I(\xi_I^{\overline{B}})^2}{2}$, with k_I as the fashion retailer's cost coefficient related to the internal inspection. Besides, penalty schemes are widely adopted in addressing the lack of direct control [47]. Following the practices, a penalty scheme for managing the manufacturer's use of environmentally friendly material(s) is also considered. The manufacturer is charged by the fashion retailer with a per unit penalty of h for each fashion product with an underperformed environmental quality identified (i.e., lower than the required level). At the same time, the public also conducts external inspection at a level $\xi_E^{\overline{B}}$. Each underperformed sustainable fashion product that has passed internal inspection but identified by the public causes a goodwill loss g. With these cost and revenue parameters in mind, the fashion retailer makes optimal decisions of the environmental quality $e^{\overline{B}}$, the internal inspection level $\xi_I^{\overline{B}}$, as well as the retail price $p^{\overline{B}}$ of the sustainable fashion product to maximize his profit.

The upstream manufacturer bears the basic manufacturing cost c_m, covering the general energy, labor, and equipment costs of manufacturing. In addition, the manufacturer has an extra cost $\theta e^{\overline{B}}$ invested to produce the sustainable fashion product for the fashion retailer. θ reflects the manufacturer's cost coefficient of using environmentally friendly material(s) such as organic cotton. Consequently, the manufacturer faces a total cost of $c_m + \theta e^{\overline{B}}$ for each sustainable fashion product. Such a linear structure of the manufacturing cost is supported by both industrial practices and the literature (e.g., Porteus [48]; Galbreth and Ghosh [42]). In addition, given the imperfect internal inspection, the manufacturer may also produce the fashion product by only following a portion $(1-\delta)$ of the required environmental quality (i.e., $e^{\overline{B}}(1-\delta)$). By doing so, the manufacturer can have a reduced per unit manufacturing cost as $c_m + \theta e^{\overline{B}}(1-\delta)$. δ denotes the manufacturer's underperformance level over the use of environmentally friendly material(s) during product development process.

In addition, as mentioned above, the manufacturer pays the fashion retailer a penalty h for each underperformed product (i.e., lower than the required level) identified under internal inspection, the chance of which is $\xi_I^{\overline{B}}$. While if not identified, the manufacturer does not pay any additional cost for the underperformed product. We denote by ϕ the chance that the manufacturer chooses to produce the sustainable product at an underperformed environmental quality. Accordingly, the manufacturer produces the sustainable fashion product as required at the chance of $1-\phi$. We assume that both δ and ϕ are known to the fashion retailer. As in practice, retailers can find relevant information through public reputation systems for environmentally responsible sourcing practices of eco-labeled products provided by the manufacturers. As an example in the food industry, the Walmart buyer can use the Sustainability Index (the reputation system for Walmart's sustainably grown produce) to identify relevant business opportunities and risks, which provides details regarding supply security, costs, as well as the reputation risks[7]. As the follower, the manufacturer makes the optimal decision of the wholesale price $w^{\overline{B}}$ of each product offered to the retailer to maximize her profit.

To ensure a meaningful and non-trivial transaction, we have $\alpha > \beta\theta(1-\phi\delta)$ and $a > \beta g\phi\xi_E^{\overline{B}}$ for the traditional fashion supply chain without blockchain; as otherwise, a consumer will never purchase.

[7] Relevant information can be found in https://corporate.walmart.com/media-library/document/2019-environmental-social-governance-report/_proxyDocument?id=0000016c-20b5-d46a-afff-f5bdafd30000. (Accessed on August, 2020).

3.2 Blockchain-Based Fashion Supply Chain

Information disclosure: We next explore the fashion supply chain with the support of blockchain. With blockchain, the upstream manufacturer produces the sustainable fashion product consistently with the data recorded in blockchain for raw materials. A unique identity of each fashion product is created and tagged, e.g., via barcodes, serial numbers and digital tags like Radio Frequency Identification (RFID) or genetic tags, which will be updated into the blockchain interface. Both the fashion retailer and consumers in the target market can then easily access and trace the complete history of each sustainable product by using the tag attached to the fashion product. The tag acts as an interface for the authentication and information traceability, and no characteristics of the fashion product are changed.

Market demand: Similar to the traditional fashion supply chain, the consumer's marginal willingness to pay for the environmental quality e^B and the retail price p^B are α and β, respectively. While differently, with the application of blockchain, all information regarding the environmental quality becomes transparent. No internal and external inspections therefore will be conducted. Consumers' credibility concerns over the fashion product's eco-label (induced by the fashion retailer's imperfect internal inspection) can also be addressed. In the meantime, given that the blockchain technology is still relatively new to the market, the fashion retailer devotes extra advertisement at a level of η^B. This enhances the consumer's willingness to pay by $\tau\eta^B$ and leads to the final utility as $U_B = u + \alpha e^B - \beta p^B + \tau\eta^B$ from purchasing the sustainable fashion product. Accordingly, we have the demand of the sustainable fashion product in the blockchain-based fashion supply chain as $d_B = \int_{\beta p^B - \alpha e^B - \tau\eta^B}^{a} g(u)du = \frac{1}{a}(a + \alpha e^B - \beta p^B + \tau\eta^B)$.

Cost and revenue parameters: Given the enhanced information transparency under the blockchain technology, the upstream manufacturer produces each fashion product by following the environmental quality e^B as required. No investment for internal inspection thus is needed at the fashion retailer's level. Instead, the fashion retailer launches new e-marketing (advertisement) activities regarding the application of blockchain (in disclosing the product's environmental quality) and has an extra blockchain advertisement cost as $\frac{k_B(\eta^B)^2}{2}$.[8] k_B is the fashion retailer's cost coefficient related to the blockchain advertisement level.[9] With the support of

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[8] As a remark, in this paper we assume the advertisement on the fashion product's environmental quality and the advertisement on information transparency are two independent e-marketing activities. The fashion retailer's cost coefficient for the product environmental quality k_E therefore is assumed to be the same under both fashion supply chains.

[9] Notice that although both the fashion retailer and the manufacturer can have extra fixed installation investments of blockchain (e.g., new facilities, unique identity creation of the products, and additional labor training), the fixed investments do not influence the equilibrium results in this paper. We therefore exclude the impacts of the fixed investment costs of blockchain at both the fashion retailer level and the manufacturer level. This helps us to better present the influences brought by the market preferences (i.e., consumers' willingness to pay) and the risk attitudes of supply chain members, regarding the application of blockchain in enhancing information transparency.

blockchain, the fashion retailer then makes optimal decisions of the environmental quality e^B, the blockchain advertisement level η^B, as well as the retail price p^B of the sustainable fashion product. As the follower, the manufacturer makes the optimal decision of the wholesale price $w^{\overline{B}}$ of each sustainable fashion product.

To ensure a meaningful and non-trivial transaction, we have $\alpha > \beta\theta$ and $\alpha > \beta c_m$ for the fashion supply chain with blockchain. For convenience, a list of all notations is shown in Table 1. Besides, different features of the traditional fashion supply chain without blockchain and the blockchain supported fashion supply chain are elaborated in Table 2.

Table 1. Notation.

u	The consumer's valuation (i.e., the willingness to pay) for the sustainable fashion product
$e^{\overline{B}}(e^B)$	The fashion product's environmental quality (with $\overline{B}$ representing for the traditional fashion supply chain without blockchain, and B denoting for the fashion supply chain with blockchain)
α	The consumer's marginal willingness to pay for the environmental quality of the fashion product
$\xi_I^{\overline{B}}$	The fashion retailer's internal inspection level on the sustainable product provided by the manufacturer
$p^{\overline{B}}(p^B)$	The retail price of the fashion sustainable product
β	The consumer's sensitivity to the retail price of the sustainable fashion product
γ	The consumer's marginal willingness to pay for the fashion retailer's internal inspection level
$d_{\overline{B}}(d_B)$	The market demand of the sustainable fashion product
$w^{\overline{B}}(w^B)$	The wholesale price of the sustainable fashion product
k_E	The fashion retailer's cost coefficient related to the product environmental quality
k_I	The fashion retailer's cost coefficient related to the internal inspection
h	The penalty charged by the fashion retailer on the manufacturer, for each fashion product identified with an underperformed environmental quality
$\xi_E^{\overline{B}}$	The external inspection level done by the public
g	The goodwill loss for each underperformed sustainable fashion product that has passed internal inspection but identified by the public
c_m	The manufacturer's basic manufacturing cost
θ	The cost coefficient of using environmentally friendly material(s) during product development process
δ	The manufacturer's underperformance level over the use of environmentally friendly material(s)
ϕ	The chance that the manufacturer chooses to produce the sustainable product at an underperformed environmental quality
η^B	The fashion retailer's the blockchain advertisement level
τ	The consumer's marginal willingness to pay for the fashion retailer's the blockchain advertisement level
k_B	The fashion retailer's cost coefficient related to the blockchain advertisement level
$\pi_R(\pi_M)$	The profit of the fashion retailer (the manufacturer)
$\lambda_R(\lambda_M)$	The risk attitude of the fashion retailer (the manufacturer)
$\Phi_R(\Phi_M)$	The mean-risk benefit of the fashion retailer (the manufacturer)

Table 2. Features of the traditional fashion supply chain without blockchain and the blockchain supported fashion supply chain.

	Information disclosure		Market demand	
Traditional fashion supply chain without blockchain	Operational feature(s)	1) Information regarding the fashion product's environmental quality is disclosed by the affixed eco-label. 2) The fashion retailer conducts internal inspection and the public has external inspection. 3) The manufacturer can either produce the product at the required environmental quality or only follow a portion of the required environmental quality.	Operational feature(s)	In addition to the retail price and the environmental quality level, consumers are also sensitive to the fashion retailer's internal inspection level.
	Relevant costs	1) The fashion retailer has the advertisement investment for the environmental quality. 2) The fashion retailer suffers from internal inspection cost. 3) The fashion retailer launches a penalty scheme for managing the manufacturer's underperformance.	Relevant costs	Each underperformed sustainable fashion product that has passed internal inspection but identified by the public causes a goodwill loss.
Blockchain supported fashion supply chain	Operational feature(s)	1) Both the fashion retailer and consumers can trace the complete history of each sustainable product by using the blockchain interface. 2) The upstream manufacturer produces the sustainable fashion product consistently with the raw materials data recorded in blockchain. 3) No internal and external inspections will be conducted.	Operational feature(s)	In addition to the retail price and the environmental quality level, consumers are also sensitive to the fashion retailer's advertisement level on the blockchain technology (for disclosing the product's environmental quality).
	Relevant costs	The fashion retailer launches new e-marketing (advertisement) activities regarding the application of blockchain and has an extra blockchain advertisement cost.	Relevant costs	The manufacturer produces each fashion product by following the environmental quality as required. Therefore, there will be no goodwill loss.

4. Games of Information Disclosure over Environmental Efforts

In this section, we explore the information disclosure games over the environmental efforts under the traditional fashion supply chain (i.e., without the support of the blockchain technology) and the blockchain-based fashion supply chain, respectively. Detailed comparisons are conducted and the value of the blockchain technology is discussed.

4.1 Traditional Fashion Supply Chain without Blockchain

In this paper, we argue that the fashion retailer, which can be giant retailers like Nike, and M&S, H&M and Mango, is the Stackelberg leader and has the power to determine the environmental quality of his sustainable fashion product. In practice, for example, both Nike and M&S have strict requirements regarding the percentage of sustainable materials (e.g., organic cotton) contained in their products and H&M also has a specific chemical restrictions list for the product development process [18]. The sequence of events under the traditional fashion supply chain is as follows.

1) The fashion retailer first determines the environmental quality $e^{\overline{B}}$ and the internal inspection level $\xi_I^{\overline{B}}$, simultaneously.

2) Given the environmental quality required by the retailer, the manufacturing activities are conducted and the manufacturer decides the wholesale price $w^{\overline{B}}$ of each product offered to the retailer.

3) The retailer accordingly decides the retail price $p^{\overline{B}}$ of the sustainable fashion product.

We can then have the respective objective functions of the fashion retailer and the manufacturer as:

$$\max_{e^{\overline{B}}\geq 0,\xi_I^{\overline{B}}\geq 0,p^{\overline{B}}\geq 0} \pi_R^{\overline{B}} = \left\{(1-\phi)\left(p^{\overline{B}}-w^{\overline{B}}\right)+\phi\left[p^{\overline{B}}-w^{\overline{B}}+h\xi_I^{\overline{B}}-g\xi_E^{\overline{B}}\left(1-\xi_I^{\overline{B}}\right)\right]\right\}d_{\overline{B}}-\frac{k_E(e^{\overline{B}})^2}{2}-\frac{k_I(\xi_I^{\overline{B}})^2}{2} \quad . \tag{1}$$

$$\max_{w^{\overline{B}}\geq 0} \pi_M^{\overline{B}} = (1-\phi)\left[w^{\overline{B}}-\left(c_m+\theta e^{\overline{B}}\right)\right]d_{\overline{B}}+\phi\{\left\{w^{\overline{B}}-\left[c_m+\theta e^{\overline{B}}(1-\delta)\right]\right\}\left(1-\xi_I^{\overline{B}}\right)+\left\{w^{\overline{B}}-\left[c_m+\theta e^{\overline{B}}(1-\delta)\right]-h\right\}\xi_I^{\overline{B}}\}d_{\overline{B}}. \tag{2}$$

The fashion retailer and the manufacturer make their respective optimal decision(s) by following the sequence of events elaborated above. Accordingly, under the conditions of $k_E > \frac{A^2}{8\alpha\beta}$ and $k_I > \frac{k_E B^2}{8\alpha\beta k_E - A^2}$,[10] we have the equilibrium decisions as follows:

$e^{\overline{B}*} = \frac{k_I A(a-\beta c_m-\beta g\phi\xi_E^{\overline{B}})}{k_I(8\alpha\beta k_E-A^2)-k_E B^2}$, $\xi_I^{\overline{B}*} = \frac{k_E B(a-\beta c_m-\beta g\phi\xi_E^{\overline{B}})}{k_I(8\alpha\beta k_E-A^2)-k_E B^2}$,

$w^{\overline{B}*} = \frac{\left(a-\beta g\phi\xi_E^{\overline{B}}\right)(4\alpha k_I k_E+C)+c_m(4\alpha\beta k_I k_E-D)}{k_I(8\alpha\beta k_E-A^2)-k_E B^2}$, and $p^{\overline{B}*} = \frac{a(6\alpha k_I k_E+E)+(c_m+g\phi\xi_E^{\overline{B}})(2\alpha\beta k_I k_E-F)}{k_I(8\alpha\beta k_E-A^2)-k_E B^2}$.

The list of all abbreviations is available in Table B2 in Online Supplementary Appendix B.

The conditions of $k_E > \frac{A^2}{8\alpha\beta}$ and $k_I > \frac{k_E B^2}{8\alpha\beta k_E - A^2}$ imply that both the internal inspection and advertising

[10] With the sequence of events in mind, we follow the backward induction to solve the objective functions of the fashion retailer and the manufacturer. By taking the first and second order derivations of $\pi_R^{\overline{B}}$ and $\pi_M^{\overline{B}}$ respectively, we find that $\pi_R^{\overline{B}}$ and $\pi_M^{\overline{B}}$ are concave under the conditions of $k_E > \frac{A^2}{8\alpha\beta}$ and $k_I > \frac{k_E B^2}{8\alpha\beta k_E - A^2}$. The equilibrium decisions are hence derived.

the environmental quality of the fashion product are expensive. This result is consistent with the practices in the fashion industry.

Proposition 1. In the traditional fashion supply chain without the support of the blockchain technology for information transparency: a) *a)* $\frac{\partial e^{\overline{B}*}}{\partial \gamma} > 0$, $\frac{\partial d^{\overline{B}*}}{\partial \gamma} > 0$, $\frac{\partial \pi_R^{\overline{B}*}}{\partial \gamma} > 0$, $\frac{\partial \pi_M^{\overline{B}*}}{\partial \gamma} > 0$; *b)* $\frac{\partial \xi_I^{\overline{B}*}}{\partial \theta} < 0$, $\frac{\partial d^{\overline{B}*}}{\partial \theta} < 0$, $\frac{\partial \pi_R^{\overline{B}*}}{\partial \theta} < 0$, $\frac{\partial \pi_M^{\overline{B}*}}{\partial \theta} < 0$; *c)* $\frac{\partial e^{\overline{B}*}}{\partial c_m} < 0$, $\frac{\partial \xi_I^{\overline{B}*}}{\partial c_m} < 0$, $\frac{\partial d^{\overline{B}*}}{\partial c_m} < 0$, $\frac{\partial \pi_R^{\overline{B}*}}{\partial c_m} < 0$, $\frac{\partial \pi_M^{\overline{B}*}}{\partial c_m} < 0$.

Proposition 1a) indicates that when the consumers hold a higher willingness to pay for the fashion retailer's internal inspection level, the optimal environmental quality of the fashion product will be higher. This can then enhance the profit levels of both the fashion retailer and the manufacturer. While according to Proposition 1b) and 1c), a higher production cost of the sustainable fashion product (either with a higher cost coefficient θ of using environmentally friendly materials or with a higher basic manufacturing cost c_m) can lead to a lower optimal internal inspection level, although this can lead to the lower profit levels of both the fashion retailer and the manufacturer.

Proposition 1 therefore provides important managerial insights regarding the impacts of the consumers' willingness to pay for the internal inspection level of the sustainable fashion product as well as the influences of the sustainable fashion product's production cost. Given the complex sourcing networks of the manufacturer in the fashion industry [47] and the subsequently limited information traceability, consumers in the fashion industry can hold credibility concerns over the fashion product's eco-label. The fashion retailer's internal inspection then becomes critical for enhancing the consumers' overall willingness to pay for the sustainable fashion product. This result therefore highlights the importance of information disclosure and transparency, which can help reduce the consumers' credibility concerns over the information provided by the fashion product's eco-label. As can be seen from Proposition 1, to achieve a higher optimal internal inspection level, the fashion retailer and the manufacturer should pay close attention to the production cost. For instance, if with a relatively high basic manufacturing cost (e.g., brands like Nike and Timberland, compared with fast fashion brands like M&S, H&M), the manufacturer can use economies of scale and advanced production technologies to reduce the per unit basic production cost. For the case with a relatively high cost coefficient of using environmentally friendly materials (e.g., M&S and H&M), different fashion companies can sometimes join an alliance for sustainable production of fashion products, like Textile Exchange[11]. These companies can then establish a co-opetition relationship to lessen the huge burden of environmentally friendly materials sourcing.

4.2 Blockchain-Based Fashion Supply Chain

Different from the information disclosure game (over the environmental efforts) under the traditional fashion supply chain, the sequence of events under the blockchain-based fashion supply chain is as below.

1) The fashion retailer first determines the environmental quality e^B and simultaneously launch the blockchain technology for sharing and releasing the information regarding the environmental quality of the sustainable fashion product. At the same, advertisements on the application of the blockchain technology for information transparency are also executed at the level of η^B.

2) Given the environmental quality required by the retailer, the manufacturing activities are conducted and the manufacturer decides the wholesale price w^B of each product offered to the retailer.

3) The retailer accordingly decides the retail price p^B of the sustainable fashion product.

We can then have the respective objective functions of the fashion retailer and the manufacturer as:

$$\max_{e^B \geq 0, \eta^B \geq 0, p^B \geq 0} \pi_R^B = (p^B - w^B)d_B - \frac{k_E(e^B)^2}{2} - \frac{k_B(\eta^B)^2}{2}. \quad (3)$$

$$\max_{w^B \geq 0} \pi_M^B = [w^B - (c_m + \theta e^B)]d_B. \quad (4)$$

Similarly, the fashion retailer and the manufacturer make their respective optimal decision(s) by following the sequence of events. Under the conditions of $k_E > \frac{G^2}{8\alpha\beta}$ and $k_B > \frac{k_E\tau^2}{8\alpha\beta k_E - G^2}$, we then have the equilibrium decisions as follows:

$$e^{B*} = \frac{k_B G(a-\beta c_m)}{k_B(8\alpha\beta k_E - G^2) - k_E\tau^2}, \ \eta^{B*} = \frac{k_E\tau(a-\beta c_m)}{k_B(8\alpha\beta k_E - G^2) - k_E\tau^2},$$

$$w^{B*} = \frac{a(4\alpha k_B k_E + \theta k_B G) + c_m[4\alpha\beta k_B k_E - \alpha k_B G - k_E\tau^2]}{k_B(8\alpha\beta k_E - G^2) - k_E\tau^2}, \text{ and } p^{B*} = \frac{a(6\alpha k_B k_E + \theta k_B G) + c_m(2\alpha\beta k_B k_E - \alpha k_B G - k_E\tau^2)}{k_B(8\alpha\beta k_E - G^2) - k_E\tau^2}.$$

The conditions of $k_E > \frac{G^2}{8\alpha\beta}$ and $k_B > \frac{k_E\tau^2}{8\alpha\beta k_E - G^2}$ imply that advertising the environmental quality and the blockchain technology are both expensive. In practice, for example, compared to the existing technologies, the high setup cost and transaction cost of the blockchain technology are known as inevitable due to technology immaturity and duplicated storage for supply chain management [52].

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[11] https://textileexchange.org/members/. (Accessed on August, 2020).

Proposition 2. In the fashion supply chain with the support of the blockchain technology for information transparency: a) $a)\ \frac{\partial e^{B*}}{\partial \tau} > 0,\ \frac{\partial d^{B*}}{\partial \tau} > 0,\ \frac{\partial \pi_R^{B*}}{\partial \tau} > 0,\ \frac{\partial \pi_M^{B*}}{\partial \tau} > 0;$ b) $\frac{\partial \eta^{B*}}{\partial \theta} < 0,\ \frac{\partial d^{B*}}{\partial \theta} < 0,\ \frac{\partial \pi_R^{B*}}{\partial \theta} < 0,\ \frac{\partial \pi_M^{B*}}{\partial \theta} < 0;$ c) $\frac{\partial e^{B*}}{\partial c_m} < 0,\ \frac{\partial \eta^{B*}}{\partial c_m} < 0, \frac{\partial d^{B*}}{\partial c_m} < 0,\ \frac{\partial \pi_R^{B*}}{\partial c_m} < 0,\ \frac{\partial \pi_M^{B*}}{\partial c_m} < 0.$

Similarly, Proposition 2 reveals managerial insights on the impacts of the consumers' willingness to pay for information disclosure and transparency of the sustainable fashion product as well as the influences of the sustainable fashion product's production cost. Given that blockchain can effectively reduce the consumers' credibility concerns over the information on the environmental quality of the fashion product, a higher consumer willingness to pay for the blockchain advertisement level can then contribute to a higher optimal environmental quality of the fashion product. This consequently increases the profits of both the fashion retailer and the manufacturer. In the meantime, Proposition 2b) and Proposition 2c) proves the robustness of the findings in Proposition 1, regarding the influences of the production cost of the sustainable fashion product. That is, despite the approach for information disclosure, minimizing the production cost of the sustainable fashion product is always of great importance, so that more efforts can be devoted into enhancing the environmental performance (i.e., through the utilization of environmentally friendly materials).

5. Comparisons and Implications

In this section, we compare the equilibrium solutions of the two information disclosure games and investigate how the performance of the blockchain technology in enhancing information transparency over the environmental efforts. Define: $\Delta e = e^{B*} - e^{\overline{B}*},\ \Delta\pi_R = \pi_R^{B*} - \pi_R^{\overline{B}*},\ \Delta\pi_M = \pi_M^{B*} - \pi_M^{\overline{B}*}.$

Proposition 3. a) If $\tau^2 > \frac{8\alpha\beta\phi\delta k_I k_E k_B + k_B GH}{k_I k_E A}$: i) $e^{B*} > e^{\overline{B}*}$, ii) $\frac{\partial \Delta e}{\partial c_m} < 0;$ b) If $\tau^2 < \frac{8\alpha\beta\phi\delta k_I k_E k_B + k_B GH}{k_I k_E A}$: i) $e^{B*} > e^{\overline{B}*}$ if and only if $c_m > \frac{\alpha}{\beta} - \frac{g\phi\xi_E^{\overline{B}}[k_B(8\alpha\beta k_E - G^2) - k_E\tau^2]}{(8\alpha\beta k_E + AG)k_I k_B\phi\delta + (k_B GB^2 - k_I A\tau^2)k_E}$, $e^{B*} < e^{\overline{B}*}$ if and only if $c_m < \frac{\alpha}{\beta} - \frac{g\phi\xi_E^{\overline{B}}[k_B(8\alpha\beta k_E - G^2) - k_E\tau^2]}{(8\alpha\beta k_E + AG)k_I k_B\phi\delta + (k_B GB^2 - k_I A\tau^2)k_E}$; ii) $\frac{\partial \Delta e}{\partial c_m} > 0.$[12]

Proposition 3 characterizes how the consumer's willingness to pay for the fashion retailer's blockchain advertisement level impacts the value of blockchain in improving the optimal environmental quality of the sustainable fashion product. As can be observed above, as long as the consumer's willingness to pay for the

[12] Notice that replacing the condition of τ^2 by the condition of τ would not influence our findings. For ease of presentation, we therefore use the condition of τ^2 to show our key findings throughout the whole paper.

fashion retailer's blockchain advertisement level is sufficiently high (i.e., $\tau^2 > \frac{8a\beta\phi\delta k_I k_E k_B + k_B GH}{k_I k_E A}$), applying blockchain for information disclosure can always increase the optimal environmental quality of the fashion product. Whereas if the consumer's willingness to pay for the fashion retailer's blockchain advertisement level is not that high (i.e., $\tau^2 < \frac{8a\beta\phi\delta k_I k_E k_B + k_B GH}{k_I k_E A}$), a higher optimal environmental quality of the fashion product can be achieved if and only if the basic manufacturing cost of the fashion product is sufficiently high. This is because when the consumers are less sensitive to the advertisement over information disclosure and transparency, the fashion retailer can stimulate the market demand and make more profits only by a higher environmental quality, which is of great importance when the basic production cost is high.

Proposition 3 shows managerial insights about the impacts of the consumers' willingness to pay for information disclosure and transparency from the perspective of their preference towards the fashion retailer's blockchain advertisement level. In the marketing and economics literature, it has been widely acknowledged that advertising is a signal of product quality [53], [54]. The advertising spending is believed to be positively correlated to product quality. A high consumers' willingness to pay here signifies the signaling role of the fashion retailer's blockchain advertisement level over the environmental quality of the fashion product. A higher consumer willingness to pay for the blockchain advertisement level thus can raise the value of blockchain in improving the optimal environmental quality of the sustainable fashion product.

Proposition 4. a) If $\tau^2 > \frac{k_I k_B I + k_E k_B (a-\beta c_m)^2 B^2}{k_I k_E (a-\beta c_m - \beta g\phi\xi_E^{\overline{B}})^2}$, $\pi_R^{B*} > \pi_R^{\overline{B}*}$; b) If $\tau^2 < \frac{k_I k_B I + k_E k_B (a-\beta c_m)^2 B^2}{k_I k_E (a-\beta c_m - \beta g\phi\xi_E^{\overline{B}})^2}$, $\pi_R^{B*} < \pi_R^{\overline{B}*}$; c) $\frac{\partial \Delta\pi_R}{\partial \tau^2} > 0$.

Proposition 5. a) If $\tau^2 > \frac{k_I k_B J + k_E k_B (a-\beta c_m) B^2 - 8a\beta^2 k_I k_E k_B g\phi\xi_E^{\overline{B}}}{k_I k_E (a-\beta c_m - \beta g\phi\xi_E^{\overline{B}})}$, $\pi_M^{B*} > \pi_M^{\overline{B}*}$; b) If $\tau^2 < \frac{k_I k_B J + k_E k_B (a-\beta c_m) B^2 - 8a\beta^2 k_I k_E k_B g\phi\xi_E^{\overline{B}}}{k_I k_E (a-\beta c_m - \beta g\phi\xi_E^{\overline{B}})}$, $\pi_M^{B*} < \pi_M^{\overline{B}*}$; c) $\frac{\partial \Delta\pi_M}{\partial \tau^2} > 0$.

Proposition 4 and Proposition 5 further support the critical signaling role of the blockchain advertisement level over the environmental quality of the fashion product from the profits of both the fashion retailer and the manufacturer. Together with Proposition 3, we can see that a higher consumer willingness to pay for the blockchain advertisement level can bring a higher value of blockchain for information disclosure in the fashion industry.

Define the environmental performance of the sustainable fashion product under the traditional fashion supply chain and the blockchain-based fashion supply chain as $EP^{\overline{B}} = e^{\overline{B}} d_{\overline{B}}$, and $EP^B = e^B d_B$, respectively.

Accordingly, we have $\Delta EP = EP^{B*} - EP^{\overline{B}*}$.

Proposition 6. a) If $\tau^2 > \frac{k_I k_B J + k_E k_B (a-\beta c_m) B^2 - 8a\beta^2 k_I k_E k_B g \phi \xi_E^{\overline{B}}}{k_I k_E (a-\beta c_m - \beta g \phi \xi_E^{\overline{B}})}$, $EP^{B*} > EP^{\overline{B}*}$; b) If $\tau^2 < \frac{k_I k_B J + k_E k_B (a-\beta c_m) B^2 - 8a\beta^2 k_I k_E k_B g \phi \xi_E^{\overline{B}}}{k_I k_E (a-\beta c_m - \beta g \phi \xi_E^{\overline{B}})}$, $EP^{B*} > EP^{\overline{B}*}$ if and only if $\delta > \frac{G\{k_I(a-\beta c_m - \beta g \phi \xi_E^{\overline{B}})[k_B(8a\beta k_E - G^2) - k_E\tau^2]\}^2 - \{k_B(a-\beta c_m)[k_I(8a\beta k_E - A^2) - k_E B^2]\}^2\}}{\beta\theta\phi\{(a-\beta c_m - \beta g \phi \xi_E^{\overline{B}})[k_B(8a\beta k_E - G^2) - k_E\tau^2]\}^2}$, $EP^{B*} < EP^{\overline{B}*}$ if and only if $\delta < \frac{G\{k_I(a-\beta c_m - \beta g \phi \xi_E^{\overline{B}})[k_B(8a\beta k_E - G^2) - k_E\tau^2]\}^2 - \{k_B(a-\beta c_m)[k_I(8a\beta k_E - A^2) - k_E B^2]\}^2\}}{\beta\theta\phi\{(a-\beta c_m - \beta g \phi \xi_E^{\overline{B}})[k_B(8a\beta k_E - G^2) - k_E\tau^2]\}^2}$.

Proposition 6 highlights the value of blockchain for the environmental performance of the sustainable fashion product. As we can observe from Proposition 6a), given the enhanced information transparency and eliminated credibility concerns, a high consumer willingness to pay for the fashion retailer's blockchain advertisement level (i.e., $\tau^2 > \frac{k_I k_B J + k_E k_B (a-\beta c_m) B^2 - 8a\beta^2 k_I k_E k_B g \phi \xi_E^{\overline{B}}}{k_I k_E (a-\beta c_m - \beta g \phi \xi_E^{\overline{B}})}$) can always bring a better environmental performance of the fashion product. This is a result of the strong signaling role of the fashion retailer's blockchain advertisement activities, which can induce a high optimal environmental quality level of the fashion product. When the consumer willingness to pay for the blockchain advertisement level is relatively low (i.e., $\tau^2 < \frac{k_I k_B J + k_E k_B (a-\beta c_m) B^2 - 8a\beta^2 k_I k_E k_B g \phi \xi_E^{\overline{B}}}{k_I k_E (a-\beta c_m - \beta g \phi \xi_E^{\overline{B}})}$), however, blockchain can bring more value in the environmental performance only when the manufacturer's underperformance level over the use of environmentally friendly material(s) is high (i.e., $\delta > \frac{G\{k_I(a-\beta c_m - \beta g \phi \xi_E^{\overline{B}})[k_B(8a\beta k_E - G^2) - k_E\tau^2]\}^2 - \{k_B(a-\beta c_m)[k_I(8a\beta k_E - A^2) - k_E B^2]\}^2\}}{\beta\theta\phi\{(a-\beta c_m - \beta g \phi \xi_E^{\overline{B}})[k_B(8a\beta k_E - G^2) - k_E\tau^2]\}^2}$). It is therefore, important for the fashion retailer to search and know the credibility level of the contracted manufacturer, so as to decide whether to launch blockchain or not. Proposition 6 accordingly complements the managerial insights on the aforementioned impacts of the signaling role of the blockchain advertisement level, from the perspective of the contracted manufacturer's credibility level.

6. Extended Model: Risk considerations

In the above discussions, we exclude the risk attitudes of the fashion retailer and the upstream manufacturer. In reality, however, the everchanging fashion market is always with uncertainties and risks. Given that decision makers can have different risk attitudes towards uncertainties and risks [49], [50], we next explore the influences brought by the risk attitudes of the fashion retailer and the upstream manufacturer (towards the market uncertainty). We define the operational risks that the fashion retailer and the upstream manufacturer may face as the market uncertainty of the sustainable fashion product. Besides, since the application of the blockchain technology does not influence the product composition and quality, we do not consider product uncertainty in this paper.

Model *R* (*R* denotes for risk considerations) is discussed in the following, under which both the fashion retailer and the contracted manufacturer can be risk averse, risk neutral, or even risk seeking towards the market uncertainty. The decision makers' risk attitudes have been operationally known as a characteristic of the choice alternatives regarding the variance of outcomes [60]. Specifically, risk aversion means that the decision makers are averse to the variance of outcomes (i.e., the profit in this paper), and the variance of the outcomes decrease the objective function. In contrast, the risk seeking attitude means that the variance of outcomes can increase the objective function and thus motivate the decision makers to take the risks. By integrating the risk considerations, we therefore perform the optimization problem in the format of the decision makers' tradeoff between the profit and the associated risk. Such a tradeoff reflects the true metric when it comes to making a decision [61]. Regarding different risk attitudes here, it is traditionally true that many firms facing operational risks tend to be risk-averse. In practice, however, market participants may also exhibit risk-seeking behaviors. A typical example is the shipping firms who are known for their risk-taking preferences [56]. To ensure the reliability and robustness of our findings, we therefore consider all kinds of risk attitudes as listed above. Without loss of generality, we assume the market includes *N* consumers who are interested in the sustainable fashion product. *N* is a random variable following a symmetric distribution with mean μ_d and variance σ_d.

6.1 Traditional Fashion Supply Chain without Blockchain

Under the traditional fashion supply chain, the number of consumers who will buy the sustainable fashion product is $d_{\overline{B}}^{R} = N\int_{\beta p^{\overline{B}}-\alpha e^{\overline{B}}-\gamma\xi_I^{\overline{B}}}^{a} g(u)du$. Taking expectation with respect to *N*, the expected market demand for the traditional fashion supply chain is: $E\left[d_{\overline{B}}^{R}\right] = E(\int_{\beta p^{\overline{B}}-\alpha e^{\overline{B}}-\gamma\xi_I^{\overline{B}}}^{a} g(u)du) = \frac{\mu_d}{a}(a+\alpha e^{\overline{B}}-\beta p^{\overline{B}}+\gamma\xi_I^{\overline{B}})$. We then have the fashion retailer's profit as: $\pi_R^{R\overline{B}} = \left\{(1-\phi)\left(p^{\overline{B}}-w^{\overline{B}}\right)+\phi\left[p^{\overline{B}}-w^{\overline{B}}+h\xi_I^{\overline{B}}-g\xi_E^{\overline{B}}\left(1-\xi_I^{\overline{B}}\right)\right]\right\}N\int_{\beta p^{\overline{B}}-\alpha e^{\overline{B}}-\gamma\xi_I^{\overline{B}}}^{a} g(u)du-\frac{k_E(e^{\overline{B}})^2}{2}-\frac{k_I(\xi_I^{\overline{B}})^2}{2}$. The operational risk is quantified by the standard deviation of the profit, i.e., $SD\left(\pi_R^{R\overline{B}}\right)=\sqrt{V\left(\pi_R^{R\overline{B}}\right)}$ from the perspective of the fashion retailer. We denote the fashion retailer's risk attitude parameter as λ_R, with $\lambda_R > 0$ for the attitude of risk averse, $\lambda_R = 0$ for risk neutral, and $\lambda_R < 0$ for risk seeking. Besides, consistent with the practices, the fashion retailer's risk attitude parameter λ_R is bounded by $\lambda_R < \frac{\mu_d}{\sigma_d}$, which means the fashion retailer will not be "extremely risk averse". Similarly, we have λ_M $(\lambda_M < \frac{\mu_d}{\sigma_d})$ for the risk attitude of the manufacturer. Following Choi et al. [51], we define the mean-risk (MR) objective function of the fashion retailer under the traditional fashion supply chain as $\Phi_R^{R\overline{B}}$, which shows the fashion retailer's trade-off between the "expected profit" and the risks induced by the "standard deviation of profit". We use the term "MR benefit" (MRB) to denote the MR objective function value for discussions below.

$$\Phi_R^{R\overline{B}} = E\left[\pi_R^{R\overline{B}}\right] - \lambda_R SD\left(\pi_R^{R\overline{B}}\right) = (\mu_d - \sigma_d\lambda_R)\left[p^{\overline{B}} - w^{\overline{B}} + h\xi_I^{\overline{B}}\phi - g\xi_E^{\overline{B}}\left(1 - \xi_I^{\overline{B}}\right)\phi\right]\int_{\beta p^{\overline{B}} - \alpha e^{\overline{B}} - \gamma\xi_I^{\overline{B}}}^{a} g(u)du - \frac{k_E(e^{\overline{B}})^2}{2} - \frac{k_I(\xi_I^{\overline{B}})^2}{2}. \quad (5)$$

Following the same logic, the MR objective function of the manufacturer is:

$$\Phi_M^{R\overline{B}} = E\left[\pi_M^{R\overline{B}}\right] - \lambda_M SD\left(\pi_M^{R\overline{B}}\right) = (\mu_d - \sigma_d\lambda_M)[w^{\overline{B}} - c_m - \theta(1-\delta)e^{\overline{B}} - \phi h\xi_I^{\overline{B}}]\int_{\beta p^{\overline{B}} - \alpha e^{\overline{B}} - \gamma\xi_I^{\overline{B}}}^{a} g(u)du. \quad (6)$$

Under the conditions of $k_E > \frac{(\mu_d - \sigma_d\lambda_R)A^2}{8a\beta}$ and $k_I > \frac{(\mu_d - \sigma_d\lambda_R)k_E B^2}{8a\beta k_E - (\mu_d - \sigma_d\lambda_R)A^2}$, we have the equilibrium decisions as:

$e^{R\overline{B}*} = \frac{(\mu_d - \sigma_d\lambda_R)k_I A(a - \beta c_m - \beta g\phi\xi_E^{\overline{B}})}{k_I[8a\beta k_E - (\mu_d - \sigma_d\lambda_R)A^2] - (\mu_d - \sigma_d\lambda_R)k_E B^2}$, $\xi_I^{R\overline{B}*} = \frac{(\mu_d - \sigma_d\lambda_R)k_E B(a - \beta c_m - \beta g\phi\xi_E^{\overline{B}})}{k_I[8a\beta k_E - (\mu_d - \sigma_d\lambda_R)A^2] - (\mu_d - \sigma_d\lambda_R)k_E B^2}$,

$w^{R\overline{B}*} = \frac{\left(a - \beta g\phi\xi_E^{\overline{B}}\right)[4ak_I k_E + (\mu_d - \sigma_d\lambda_R)C] + c_m[4a\beta k_I k_E - (\mu_d - \sigma_d\lambda_R)D]}{k_I[8a\beta k_E - (\mu_d - \sigma_d\lambda_R)A^2] - (\mu_d - \sigma_d\lambda_R)k_E B^2}$, and

$p^{R\overline{B}*} = \frac{a[6ak_I k_E + (\mu_d - \sigma_d\lambda_R)E] + (c_m + g\phi\xi_E^{\overline{B}})[2a\beta k_I k_E - (\mu_d - \sigma_d\lambda_R)F]}{k_I[8a\beta k_E - (\mu_d - \sigma_d\lambda_R)A^2] - (\mu_d - \sigma_d\lambda_R)k_E B^2}$.

Proposition 7. In the traditional fashion supply chain without the support of the blockchain technology for information transparency: a) *a)* $\frac{\partial e^{R\overline{B}*}}{\partial\gamma} > 0$, $\frac{\partial d^{R\overline{B}*}}{\partial\gamma} > 0$, $\frac{\partial\Phi_R^{\overline{B}*}}{\partial\gamma} > 0$, $\frac{\partial\Phi_M^{\overline{B}*}}{\partial\gamma} > 0$; *b)* $\frac{\partial\xi_I^{R\overline{B}*}}{\partial\theta} < 0$, $\frac{\partial d^{R\overline{B}*}}{\partial\theta} < 0$, $\frac{\partial\Phi_R^{\overline{B}*}}{\partial\theta} < 0$, $\frac{\partial\Phi_M^{\overline{B}*}}{\partial\theta} < 0$; *c)* $\frac{\partial e^{R\overline{B}*}}{\partial c_m} < 0$, $\frac{\partial\xi_I^{R\overline{B}*}}{\partial c_m} < 0$, $\frac{\partial d^{R\overline{B}*}}{\partial c_m} < 0$, $\frac{\partial\Phi_R^{\overline{B}*}}{\partial c_m} < 0$, $\frac{\partial\Phi_M^{\overline{B}*}}{\partial c_m} < 0$; *d)* $\frac{\partial e^{R\overline{B}*}}{\partial\lambda_R} < 0$, $\frac{\partial\xi_I^{R\overline{B}*}}{\partial\lambda_R} < 0$, $\frac{\partial d^{R\overline{B}*}}{\partial\lambda_R} < 0$, $\frac{\partial\Phi_R^{\overline{B}*}}{\partial\lambda_R} < 0$, $\frac{\partial\Phi_M^{\overline{B}*}}{\partial\lambda_R} < 0$; *e)* $\frac{\partial e^{R\overline{B}*}}{\partial\mu_d} > 0$, $\frac{\partial\xi_I^{R\overline{B}*}}{\partial\mu_d} > 0$, $\frac{\partial d^{R\overline{B}*}}{\partial\mu_d} > 0$, $\frac{\partial\Phi_R^{\overline{B}*}}{\partial\mu_d} > 0$, $\frac{\partial\Phi_M^{\overline{B}*}}{\partial\mu_d} > 0$.[13]

Proposition 7 firstly proves the robustness of our previous findings in Proposition 1. Besides, Proposition 7e) shows that when the expected market demand is large, it can be optimal to provide a higher environmental quality together with a higher internal inspection level. While in the meantime, Proposition 7d) demonstrates the important roles of the fashion retailer's risk attitude. As can be seen above, the more risk averse the fashion

[13] As can be observed from the equilibrium decisions, the market demand variance σ_d holds the same influences as the fashion retailer's risk attitude λ_R. We therefore focus on the impacts of the fashion retailer's risk attitude in the following discussions.

retailer is, the lower the optimal environmental quality and internal inspection level can be. The reason behind is that although a higher environmental quality and a higher internal inspection level can both contribute to an increased consumer willingness to pay for the sustainable fashion product, it also brings more operational risks when the market is with uncertainties. In particular, given the imperfect internal inspection, the manufacturer with a relatively low credibility level can produce the sustainable fashion product with an underperformed environmental quality. This, however, can subsequently induce extra goodwill loss to the fashion retailer. Proposition 7 therefore indicates another limitation of using the affixed eco-label together with internal inspection to disclose information on the environmental efforts. That is, in addition to the inherently imperfectness, the internal inspection level can be influenced by many operational factors like the risk attitude of the fashion retailer. This can lead to a higher level of the consumers' credibility concerns over the fashion retailer's eco-label in the traditional fashion supply chain.

6.2 Blockchain-Based Fashion Supply Chain

Under the blockchain-based fashion supply chain, the number of consumers who will buy the sustainable fashion product is $d_B^R = N\int_{\beta p^B-\alpha e^B-\tau\eta^B}^{a} g(u)du$. Following the same logic as in the traditional fashion supply chain, we then have the respective MR objective functions for the fashion retailer and the manufacturer as follows.

$$\Phi_R^{RB} = (\mu_d - \sigma_d\lambda_R)(p^B - w^B)\int_{\beta p^B-\alpha e^B-\tau\eta^B}^{a} g(u)du - \frac{k_E(e^B)^2}{2} - \frac{k_B(\eta^B)^2}{2} - F_R^B. \quad (7)$$

$$\Phi_M^{RB} = (\mu_d - \sigma_d\lambda_M)[w^B - (c_m + \theta e^B)]\int_{\beta p^B-\alpha e^B-\tau\eta^B}^{a} g(u)du - F_M^B. \quad (8)$$

Under the conditions of $k_E > \frac{(\mu_d-\sigma_d\lambda_R)G^2}{8a\beta}$ and $k_B > \frac{(\mu_d-\sigma_d\lambda_R)k_E\tau^2}{8a\beta k_E-(\mu_d-\sigma_d\lambda_R)G^2}$, we have the equilibrium decisions as follows:

$e^{RB*} = \frac{(\mu_d-\sigma_d\lambda_R)k_B G(a-\beta c_m)}{k_B[8a\beta k_E-(\mu_d-\sigma_d\lambda_R)G^2]-(\mu_d-\sigma_d\lambda_R)k_E\tau^2}$, $\eta^{RB*} = \frac{(\mu_d-\sigma_d\lambda_R)k_E\tau(a-\beta c_m)}{k_B[8a\beta k_E-(\mu_d-\sigma_d\lambda_R)G^2]-(\mu_d-\sigma_d\lambda_R)k_E\tau^2}$,

$w^{RB*} = \frac{a[4ak_Bk_E+(\mu_d-\sigma_d\lambda_R)\theta k_B G]+c_m[4a\beta k_Bk_E-(\mu_d-\sigma_d\lambda_R)K]}{k_B[8a\beta k_E-(\mu_d-\sigma_d\lambda_R)G^2]-(\mu_d-\sigma_d\lambda_R)k_E\tau^2}$, and

$p^{RB*} = \frac{a[6ak_Bk_E+(\mu_d-\sigma_d\lambda_R)\theta k_B G]+c_m[2a\beta k_Bk_E-(\mu_d-\sigma_d\lambda_R)K]}{k_B[8a\beta k_E-(\mu_d-\sigma_d\lambda_R)G^2]-(\mu_d-\sigma_d\lambda_R)k_E\tau^2}$.

Proposition 8. In the fashion supply chain with the support of the blockchain technology for information transparency: a) *a)* $\frac{\partial e^{RB*}}{\partial\tau} > 0$, $\frac{\partial d^{RB*}}{\partial\tau} > 0$, $\frac{\partial\Phi_R^{RB*}}{\partial\tau} > 0$, $\frac{\partial\Phi_M^{RB*}}{\partial\tau} > 0$; *b)* $\frac{\partial\eta^{RB*}}{\partial\theta} < 0$, $\frac{\partial d^{RB*}}{\partial\theta} < 0$, $\frac{\partial\Phi_R^{RB*}}{\partial\theta} < 0$, $\frac{\partial\Phi_M^{RB*}}{\partial\theta} <$

0; *c)* $\frac{\partial e^{RB*}}{\partial c_m} < 0, \frac{\partial \eta^{RB*}}{\partial c_m} < 0, \frac{\partial d^{RB*}}{\partial c_m} < 0, \frac{\partial \Phi_R^{RB*}}{\partial c_m} < 0, \frac{\partial \Phi_M^{RB*}}{\partial c_m} < 0$; *d)* $\frac{\partial e^{RB*}}{\partial \lambda_R} < 0, \frac{\partial \eta^{RB*}}{\partial \lambda_R} < 0, \frac{\partial d^{RB*}}{\partial \lambda_R} < 0, \frac{\partial \Phi_R^{RB*}}{\partial \lambda_R} < 0, \frac{\partial \Phi_M^{RB*}}{\partial \lambda_R} < 0$; *e)* $\frac{\partial e^{RB*}}{\partial \mu_d} > 0, \frac{\partial \eta^{RB*}}{\partial \mu_d} > 0, \frac{\partial d^{RB*}}{\partial \mu_d} > 0, \frac{\partial \Phi_R^{RB*}}{\partial \mu_d} > 0, \frac{\partial \Phi_M^{RB*}}{\partial \mu_d} > 0$.

Similar to Proposition 7, Proposition 8 also shows the reliability of our previous findings in Proposition 2, as well as highlights the influences brought by the fashion retailer's risk attitude as mentioned above.

6.3 Discussions

We next examine the impacts brought by the risk attitudes of the fashion retailer and the upstream manufacturer towards the uncertainties in the market of the sustainable fashion product.

Proposition 9. a) If $\tau^2 > \frac{8\alpha\beta\phi\delta k_I k_E k_B + (\mu_d - \sigma_d\lambda_R)k_B GH}{(\mu_d - \sigma_d\lambda_R)k_I k_E A}$: i) $e^{RB*} > e^{R\overline{B}*}$, ii) $\frac{\partial \Delta e}{\partial c_m} < 0$; b) If $\tau^2 < \frac{8\alpha\beta\phi\delta k_I k_E k_B + (\mu_d - \sigma_d\lambda_R)k_B GH}{(\mu_d - \sigma_d\lambda_R)k_I k_E A}$: i) $e^{RB*} > e^{R\overline{B}*}$ if and only if $c_m > \frac{a}{\beta} - \frac{g\phi\xi_E^{\overline{B}}\{k_B[8\alpha\beta k_E - (\mu_d - \sigma_d\lambda_R)G^2] - (\mu_d - \sigma_d\lambda_R)k_E\tau^2\}}{(\mu_d - \sigma_d\lambda_R)[8\alpha\beta k_E k_I k_B\phi\delta + (\mu_d - \sigma_d\lambda_R)(k_B GH - k_I k_E A\tau^2)]}$, $e^{RB*} < e^{R\overline{B}*}$ if and only if $c_m < \frac{a}{\beta} - \frac{g\phi\xi_E^{\overline{B}}\{k_B[8\alpha\beta k_E - (\mu_d - \sigma_d\lambda_R)G^2] - (\mu_d - \sigma_d\lambda_R)k_E\tau^2\}}{(\mu_d - \sigma_d\lambda_R)[8\alpha\beta k_E k_I k_B\phi\delta + (\mu_d - \sigma_d\lambda_R)(k_B GH - k_I k_E A\tau^2)]}$; ii) $\frac{\partial \Delta e^R}{\partial c_m} > 0$.

Findings in Proposition 9 proves that our previous findings on the impacts of the consumers' willingness to pay for the fashion retailer's blockchain advertisement level still hold even under the risk considerations. To ensure the success of launching the blockchain program for information disclosure, therefore, the fashion retailer should always pay close attention to the signaling role of the blockchain advertisement level over the environmental quality of the fashion product.

Proposition 10. a) If $\tau^2 > \frac{k_I k_B I + k_E k_B (a - \beta c_m)^2 B^2}{k_I k_E (a - \beta c_m - \beta g\phi\xi_E^{\overline{B}})^2}$, $\Phi_R^{B*} > \Phi_R^{\overline{B}*}$; b) If $\tau^2 < \frac{k_I k_B I + k_E k_B (a - \beta c_m)^2 B^2}{k_I k_E (a - \beta c_m - \beta g\phi\xi_E^{\overline{B}})^2}$, $\Phi_R^{B*} > \Phi_R^{\overline{B}*}$ if and only if $(\mu_d - \sigma_d\lambda_R) < \frac{8\alpha\beta k_E k_I k_B\left[(a - \beta c_m)^2 - \left(a - \beta c_m - \beta g\phi\xi_E^{\overline{B}}\right)^2\right]}{k_I k_B I + k_E k_B (a - \beta c_m)^2 B^2 - k_I k_E (a - \beta c_m - \beta g\phi\xi_E^{\overline{B}})^2\tau^2}$, $\Phi_R^{B*} < \Phi_R^{\overline{B}*}$ if and only if $(\mu_d - \sigma_d\lambda_R) > \frac{8\alpha\beta k_E k_I k_B\left[(a - \beta c_m)^2 - \left(a - \beta c_m - \beta g\phi\xi_E^{\overline{B}}\right)^2\right]}{k_I k_B I + k_E k_B (a - \beta c_m)^2 B^2 - k_I k_E (a - \beta c_m - \beta g\phi\xi_E^{\overline{B}})^2\tau^2}$; c) $\frac{\partial \Delta\Phi_R}{\partial \tau^2} > 0$.

Proposition 11. a) If $\tau^2 > \frac{k_I k_B J + k_E k_B (a - \beta c_m) B^2}{k_I k_E (a - \beta c_m - \beta g\phi\xi_E^{\overline{B}})}$, $\Phi_M^{B*} > \Phi_M^{\overline{B}*}$; b) If $\tau^2 < \frac{k_I k_B J + k_E k_B (a - \beta c_m) B^2}{k_I k_E (a - \beta c_m - \beta g\phi\xi_E^{\overline{B}})}$, $\Phi_M^{B*} > \Phi_M^{\overline{B}*}$ if and only if $(\mu_d - \sigma_d\lambda_R) < \frac{8\alpha\beta k_E k_I k_B \beta g\phi\xi_E^{\overline{B}}}{k_I k_B J + k_E k_B (a - \beta c_m) B^2 - k_I k_E (a - \beta c_m - \beta g\phi\xi_E^{\overline{B}})\tau^2}$, $\Phi_M^{B*} < \Phi_M^{\overline{B}*}$ if and only if $(\mu_d - \sigma_d\lambda_R) > \frac{8\alpha\beta k_E k_I k_B \beta g\phi\xi_E^{\overline{B}}}{k_I k_B J + k_E k_B (a - \beta c_m) B^2 - k_I k_E (a - \beta c_m - \beta g\phi\xi_E^{\overline{B}})\tau^2}$; c) $\frac{\partial \Delta\Phi_M}{\partial \lambda_M} > 0$; d) $\frac{\partial \Delta\Phi_M}{\partial \tau^2} > 0$

Proposition 10 and Proposition 11 together complement the findings on the impacts of the signaling role of the blockchain advertisement level, from the perspective of the fashion retailer's risk attitude and the market demand. Firstly, similar to Proposition 4 and Proposition 5, we can see that despite the risk attitudes, applying blockchain for information disclosure is always beneficial to both the fashion retailer and the manufacturer as long as the consumer's willingness to pay for the fashion retailer's blockchain advertisement level is sufficiently high (i.e., $\tau^2 > \max\left(\frac{k_I k_B I + k_E k_B (a-\beta c_m)^2 B^2}{k_I k_E \left(a-\beta c_m-\beta g \phi \xi_E^{\overline{B}}\right)^2}, \frac{k_I k_B J + k_E k_B (a-\beta c_m) B^2}{k_I k_E \left(a-\beta c_m-\beta g \phi \xi_E^{\overline{B}}\right)}\right)$). Besides, a stronger signaling role of the blockchain advertisement can always contribute a larger value of blockchain in the information disclosure game. However, if the consumer's willingness to pay for the fashion retailer's blockchain advertisement level is not that high, blockchain can benefit both the fashion retailer and the manufacturer if and only if the risk aversion level of the fashion retailer or the market demand uncertainty is sufficiently high.[14] This indicates the market condition when blockchain can bring more value. Specifically, applying blockchain for information disclosure and transparency can be a better alternative when the fashion retailer and the manufacturer are more risk averse or the market demand is with more uncertainties, while it can only have limited contributions when the fashion retailer is more risk seeking or the market demand is more stable. Given the inherently high-demand uncertainty of innovative products [55], Proposition 10 and Proposition 11 therefore provide important guidelines to the fashion supply chains' sustainability practices, such as the adoption of new and innovative environmentally friendly materials.

Proposition 12. a) If $\tau^2 > \frac{k_I k_B J + k_E k_B (a-\beta c_m) B^2}{k_I k_E (a-\beta c_m-\beta g \phi \xi_E^{\overline{B}})}$, $EP^{RB*} > EP^{R\overline{B}*}$; b) If $\tau^2 < \frac{k_I k_B J + k_E k_B (a-\beta c_m) B^2}{k_I k_E (a-\beta c_m-\beta g \phi \xi_E^{\overline{B}})}$, $EP^{RB*} > EP^{R\overline{B}*}$ if and only if $\delta > \frac{G(L^2-M^2)}{\beta\theta\phi\{\left(a-\beta c_m-\beta g \phi \xi_E^{\overline{B}}\right)[8a\beta k_E k_B-(\mu_d-\sigma_d\lambda_R)(k_B G^2+k_E\tau^2)]\}^2}$, $EP^{RB*} < EP^{R\overline{B}*}$ if and only if $\delta < \frac{G(L^2-M^2)}{\beta\theta\phi\{\left(a-\beta c_m-\beta g \phi \xi_E^{\overline{B}}\right)[8a\beta k_E-(\mu_d-\sigma_d\lambda_R)(k_B G^2+k_E\tau^2)]\}^2}$.

According to Proposition 12, we can see that the impacts of contracted manufacturer's credibility level, which is mentioned in Proposition 6, are also reliable under the risk considerations. Consequently, to successfully enhance the environmental performance of the sustainable fashion product via blockchain, the fashion retailer should fully utilize the available public reputation systems for launching environmentally responsible sourcing practices, which helps to better understand the reliability of the eco-labeled products provided by the manufacturers together with the associated operational risks (e.g., the reputation risks).

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[14] It means $\sigma_d\lambda_R > \max\left(\mu_d - \frac{8a\beta k_E k_I k_B \beta g \phi \xi_E^{\overline{B}}}{\sigma_d\left\{k_I k_B J + k_E k_B (a-\beta c_m) B^2 - k_I k_E \left(a-\beta c_m-\beta g \phi \xi_E^{\overline{B}}\right)\tau^2\right\}}, \mu_d - \frac{8a\beta k_E k_I k_B\left[(a-\beta c_m)^2-\left(a-\beta c_m-\beta g \phi \xi_E^{\overline{B}}\right)^2\right]}{k_I k_B I + k_E k_B (a-\beta c_m)^2 B^2 - k_I k_E (a-\beta c_m-\beta g \phi \xi_E^{\overline{B}})^2\tau^2}\right)$.

7. Conclusion

Motivated by the popularity of environmentally friendly fashion products nowadays, the importance of information transparency for environmental efforts, and the research gap in the literature, we present analyses of a fashion supply chain consisting of a fashion retailer and an upstream manufacturer. This paper is the first to conduct a deep investigation on how the application of the blockchain technology influences the information disclosure games over the environmental efforts in the fashion industry. Specific managerial implications are discussed in the following which provides new insights into the underexplored area of information disclosure games over the environmental efforts in the fashion industry. These novel findings can serve as references for both industrial practices and future studies of the information disclosure game in the fashion industry and other retail contexts.

7.1 Key Findings and Managerial Implications

a) ***Role of information disclosure:*** Given the complex sourcing networks of the manufacturer in the fashion industry and the subsequently limited information traceability, consumers in the fashion industry can hold credibility concerns over the fashion product's eco-label. Our analyses highlight the importance of information disclosure and transparency, which can help reduce the consumers credibility concerns over the limited information provided by the affixed eco-label. We find that the fashion retailer's internal inspection and the blockchain technology can both help enhance the consumers' overall willingness to pay for the sustainable fashion product. However, to achieve a higher optimal internal inspection level or a higher blockchain advertisement level, the fashion retailer and the manufacturer should pay close attention to the production cost of the sustainable fashion product.

b) ***Role of the blockchain technology:*** In light of the value of the blockchain technology, we find that it is closely related to the consumer's willingness to pay for the fashion retailer's blockchain advertisement level. A high consumer's willingness to pay for the blockchain advertisement level, which signifies the signaling role of the fashion retailer's blockchain advertisement activities over the environmental quality of the fashion product, can always raise the value of blockchain in improving the optimal environmental quality of the sustainable fashion product as well as in increasing the profits of both the fashion retailer and the manufacturer. Regarding the value of blockchain in improving the environmental performance of the sustainable fashion product, close attention should be paid to the contracted manufacturer's credibility level when the consumer's willingness to pay for the blockchain advertisement level is relatively low.

b) ***Impact of the risk attitudes:*** As for the impact of the risk attitudes, our results show that, in addition to the inherently imperfectness, internal inspection also shows its limitations under the influences of operational factors like the risk attitude of the fashion retailer. This can lead to a higher level of the consumers' credibility concerns over the fashion retailer's eco-label in the traditional fashion supply chain. Besides, applying blockchain for information disclosure and transparency can be a better alternative when the fashion retailer and the manufacturer are more risk averse or the market demand is with more uncertainties (e.g., fashion products made from innovative sustainable materials), while can have limited contributions when the fashion retailer is more risk seeking or the market demand is more stable (e.g., fashion products made from general sustainable materials).

7.2 Limitations and Future Research

While our model captures the essential elements of different information disclosure games in the fashion industry, other aspects should be considered in the future. First, we restrict our attention to the utilization of environmentally friendly materials in the manufacturing stage. In the future, we may consider information disclosure games for other sustainability practices such as the use of child labor in the fashion industry. Second, we exclude market competition. However, in practice, competition can happen at both the retailer and the manufacturer levels. Therefore, it will be interesting to explore the influences of market competition on the information disclosure games. Third, this paper focuses on the value of blockchain. Given the availability of other advanced technologies in the market, the values of other technologies for information disclosure games deserve further investigation.

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Online Supplementary Appendix A – Technical Proofs

Proof of Proposition 1. Based on the equilibrium decisions of $e^{\overline{B}*}$, $\xi_I^{\overline{B}*}$, $w^{\overline{B}*}$ and $p^{\overline{B}*}$ shown in Section 4.1, we accordingly have the optimal market demand as well as the optimal profits of the fashion retailer and the manufacturer as: $d^{\overline{B}*}=\frac{2\beta k_I k_E(a-\beta c_m-\beta g\phi\xi_E^{\overline{B}})}{k_I(8a\beta k_E-A^2)-k_E B^2}$, $\pi_R^{\overline{B}*}=\frac{k_I k_E(a-\beta c_m-\beta g\phi\xi_E^{\overline{B}})^2}{2[k_I(8a\beta k_E-A^2)-k_E B^2]}$, and $\pi_M^{\overline{B}*}=\frac{8a\beta k_I^2 k_E^2(a-\beta c_m-\beta g\phi\xi_E^{\overline{B}})^2}{[k_I(8a\beta k_E-A^2)-k_E B^2]^2}$. Proposition 1 can then be proved by taking the first order derivatives of above optimal results with respect to γ, θ, and c_m, respectively. (Q.E.D.)

Proof of Proposition 2. Based on the equilibrium decisions of e^{B*}, ξ_I^{B*}, w^{B*} and p^{B*} shown in Section 4.2, we have the optimal market demand as well as the optimal profits of the fashion retailer and the manufacturer as: $d^{B*}=\frac{2\beta k_B k_E(a-\beta c_m)}{k_B(8a\beta k_E-G^2)-k_E\tau^2}$, $\pi_R^{B*}=\frac{k_B k_E(a-\beta c_m)^2}{2[k_B(8a\beta k_E-G^2)-k_E\tau^2]}$, and $\pi_M^{B*}=\frac{8a\beta k_B^2 k_E^2(a-\beta c_m)^2}{[k_B(8a\beta k_E-G^2)-k_E\tau^2]^2}$. Proposition 2 can then be proved by taking the first order derivatives of above optimal results with respect to τ, θ, and c_m, respectively. (Q.E.D.)

Proof of Proposition 3. Based on equilibrium results found in Section 4.1 and Section 4.2, we have $\Delta e = e^{B*}-e^{\overline{B}*}=\frac{(a-\beta c_m)\{k_B G[k_I(8a\beta k_E-A^2)-k_E B^2]-k_I A[k_B(8a\beta k_E-G^2)-k_E\tau^2]\}+\beta g\phi\xi_E^{\overline{B}}[k_B(8a\beta k_E-G^2)-k_E\tau^2]}{[k_I(8a\beta k_E-A^2)-k_E B^2][k_B(8a\beta k_E-G^2)-k_E\tau^2]}$. It can then be proved that: a) if $\tau^2>\frac{8a\beta\phi\delta k_I k_E k_B+k_B GH}{k_I k_E A}$: i) $e^{B*}>e^{\overline{B}*}$, ii) $\frac{\partial\Delta e}{\partial c_m}=\frac{(-\beta c_m)\{k_B G[k_I(8a\beta k_E-A^2)-k_E B^2]-k_I A[k_B(8a\beta k_E-G^2)-k_E\tau^2]\}}{[k_I(8a\beta k_E-A^2)-k_E B^2][k_B(8a\beta k_E-G^2)-k_E\tau^2]}<0$; b) If $\tau^2<\frac{8a\beta\phi\delta k_I k_E k_B+k_B GH}{k_I k_E A}$: i) $e^{B*}>e^{\overline{B}*}$ if and only if $c_m>\frac{a}{\beta}-\frac{g\phi\xi_E^{\overline{B}}[k_B(8a\beta k_E-G^2)-k_E\tau^2]}{(8a\beta k_E+AG)k_I k_B\phi\delta+(k_B GB^2-k_I A\tau^2)k_E}$, $e^{B*}<e^{\overline{B}*}$ if and only if $c_m<\frac{a}{\beta}-\frac{g\phi\xi_E^{\overline{B}}[k_B(8a\beta k_E-G^2)-k_E\tau^2]}{(8a\beta k_E+AG)k_I k_B\phi\delta+(k_B GB^2-k_I A\tau^2)k_E}$; ii) $\frac{\partial\Delta e}{\partial c_m}>0$. (Q.E.D.)

Proof of Proposition 4. Based on equilibrium results listed in Section 4.1 and Section 4.2, we have $\Delta\pi_R=\pi_R^{B*}-\pi_R^{\overline{B}*}=\frac{k_E\{8a\beta k_I k_E k_B\left[(a-\beta c_m)^2-\left(a-\beta c_m-\beta g\phi\xi_E^{\overline{B}}\right)^2\right]-[k_I k_B I+k_E k_B(a-\beta c_m)^2 B^2-k_I k_E\left(a-\beta c_m-\beta g\phi\xi_E^{\overline{B}}\right)^2\tau^2]}{2[k_I(8a\beta k_E-A^2)-k_E B^2][k_B(8a\beta k_E-G^2)-k_E\tau^2]}$. It can then be proved that: a) If $\tau^2>\frac{k_I k_B I+k_E k_B(a-\beta c_m)^2 B^2}{k_I k_E(a-\beta c_m-\beta g\phi\xi_E^{\overline{B}})^2}$, $\pi_R^{B*}>\pi_R^{\overline{B}*}$; b) If $\tau^2<\frac{k_I k_B I+k_E k_B(a-\beta c_m)^2 B^2}{k_I k_E(a-\beta c_m-\beta g\phi\xi_E^{\overline{B}})^2}$, $\pi_R^{B*}<\pi_R^{\overline{B}*}$; c) $\frac{\partial\Delta\pi_R}{\partial\tau^2}>0$. (Q.E.D.)

Proof of Proposition 5. Based on equilibrium results listed in Section 4.1 and Section 4.2, we have $\Delta\pi_M=\pi_M^{B*}-\pi_M^{\overline{B}*}=\frac{8a\beta k_E^2\left[\{k_B(a-\beta c_m)[k_I(8a\beta k_E-A^2)-k_E B^2]\}^2-\{k_I\left(a-\beta c_m-\beta g\phi\xi_E^{\overline{B}}\right)[k_B(8a\beta k_E-G^2)-k_E\tau^2]\}^2\right]}{[k_I(8a\beta k_E-A^2)-k_E B^2]^2[k_B(8a\beta k_E-G^2)-k_E\tau^2]^2}$. It can then be proved that: If $\tau^2>\frac{k_I k_B J+k_E k_B(a-\beta c_m)B^2-8a\beta^2 k_I k_E k_B g\phi\xi_E^{\overline{B}}}{k_I k_E(a-\beta c_m-\beta g\phi\xi_E^{\overline{B}})}$, $\pi_M^{B*}>\pi_M^{\overline{B}*}$; b) If $\tau^2<\frac{k_I k_B J+k_E k_B(a-\beta c_m)B^2-8a\beta^2 k_I k_E k_B g\phi\xi_E^{\overline{B}}}{k_I k_E(a-\beta c_m-\beta g\phi\xi_E^{\overline{B}})}$, $\pi_M^{B*}<\pi_M^{\overline{B}*}$; c) $\frac{\partial\Delta\pi_M}{\partial\tau^2}>0$. (Q.E.D.)

Proof of Proposition 6. According to the definition, we have $EP^{\overline{B}*} = \frac{2\beta k_I^2 k_E A(a-\beta c_m-\beta g\phi\xi_E^{\overline{B}})^2}{[k_I(8a\beta k_E-A^2)-k_E B^2]^2}$ and $EP^{B*} = \frac{2\beta k_B^2 k_E G(a-\beta c_m)^2}{[k_B(8a\beta k_E-G^2)-k_E \tau^2]^2}$. Proposition 6 can then be proved by following the same logic as Proposition 4 and Proposition 5. (Q.E.D.)

Proof of Proposition 7. Based on the equilibrium decisions of $e^{R\overline{B}*}$, $\xi_I^{R\overline{B}*}$, $w^{R\overline{B}*}$ and $p^{R\overline{B}*}$ shown in Section 6.1, we have the optimal market demand as well as the optimal profits of the fashion retailer and the manufacturer as: $d^{R\overline{B}*} = \frac{2\beta k_I k_E(a-\beta c_m-\beta g\phi\xi_E^{\overline{B}})}{k_I[8a\beta k_E-(\mu_d-\sigma_d\lambda_R)A^2]-(\mu_d-\sigma_d\lambda_R)k_E B^2}$, $\Phi_R^{R\overline{B}*} = \frac{k_I k_E(\mu_d-\sigma_d\lambda_R)(a-\beta c_m-\beta g\phi\xi_E^{\overline{B}})^2}{2\{k_I[8a\beta k_E-(\mu_d-\sigma_d\lambda_R)A^2]-(\mu_d-\sigma_d\lambda_R)k_E B^2\}}$, and $\Phi_M^{R\overline{B}*} = \frac{8a\beta k_I^2 k_E^2(\mu_d-\sigma_d\lambda_M)(a-\beta c_m-\beta g\phi\xi_E^{\overline{B}})^2}{\{k_I[8a\beta k_E-(\mu_d-\sigma_d\lambda_R)A^2]-(\mu_d-\sigma_d\lambda_R)k_E B^2\}^2}$. Proposition 7 can then be proved by taking the first order derivatives of above optimal results with respect to γ, θ, c_m, λ_R, and μ_d, respectively. (Q.E.D.)

Proof of Proposition 8. Based on the equilibrium decisions of e^{RB*}, ξ_I^{RB*}, w^{RB*} and p^{RB*} shown in Section 6.2, we have the optimal market demand as well as the optimal profits of the fashion retailer and the manufacturer as: $d^{B*} = \frac{2\beta k_B k_E(a-\beta c_m)}{k_B[8a\beta k_E-(\mu_d-\sigma_d\lambda_R)G^2]-(\mu_d-\sigma_d\lambda_R)k_E\tau^2}$, $\Phi_R^{B*} = \frac{k_B k_E(\mu_d-\sigma_d\lambda_R)(a-\beta c_m)^2}{2\{k_B[8a\beta k_E-(\mu_d-\sigma_d\lambda_R)G^2]-(\mu_d-\sigma_d\lambda_R)k_E\tau^2\}}$, and $\Phi_M^{B*} = \frac{8a\beta k_B^2 k_E^2(\mu_d-\sigma_d\lambda_M)(a-\beta c_m)^2}{\{k_B[8a\beta k_E-(\mu_d-\sigma_d\lambda_R)G^2]-(\mu_d-\sigma_d\lambda_R)k_E\tau^2\}^2}$. Proposition 8 can then be proved by taking the first order derivatives of above optimal results with respect to τ, θ, and c_m, respectively. (Q.E.D.)

Proof of Proposition 9. Based on equilibrium results found in Section 6.1 and Section 6.2, Proposition 9 can be proved by following the same logic as Proposition 3. (Q.E.D.)

Proof of Proposition 10. Based on equilibrium results found in Section 6.1 and Section 6.2, Proposition 10 can be proved by following the same logic as Proposition 4. (Q.E.D.)

Proof of Proposition 11. Based on equilibrium results found in Section 6.1 and Section 6.2, Proposition 10 can be proved by following the same logic as Proposition 5. (Q.E.D.)

Proof of Proposition 12. According to the definition, we have $EP^{\overline{B}*} = \frac{2\beta k_I^2 k_E A\mu_d(\mu_d-\sigma_d\lambda_R)(a-\beta c_m-\beta g\phi\xi_E^{\overline{B}})^2}{\{k_I[8a\beta k_E-(\mu_d-\sigma_d\lambda_R)A^2]-(\mu_d-\sigma_d\lambda_R)k_E B^2\}^2}$ and $EP^{B*} = \frac{2\beta k_B^2 k_E G\mu_d(\mu_d-\sigma_d\lambda_R)(a-\beta c_m)^2}{\{k_B[8a\beta k_E-(\mu_d-\sigma_d\lambda_R)G^2]-(\mu_d-\sigma_d\lambda_R)k_E\tau^2\}^2}$. Proposition 12 can then be proved by following the same logic as Proposition 6. (Q.E.D.)

Online Supplementary Appendix B - Supplementary Tables

Table B1. Summary of recent research (✓: covered; ×: not covered).

Literature	Sustainable fashion supply chain	Environmental efforts	Information disclosure/transparency	Technology investment
Bai et al. (2017)	✓	×	×	×
Chan et al. (2016)	×	✓	×	×
Chan et al. (2018)	×	×	×	✓
Chen et al. (2019)	✓	×	✓	×
Chiu et al. (2016)	✓	×	×	×
Choi et al. (2019)	✓	×	×	×
Choi et al. (2020)	×	×	✓	✓
Choi (2020)	×	×	×	✓
Du et al. (2020)	×	×	×	✓
Guo et al. (2020)	✓	✓	×	×
Hong and Guo (2019)	✓	✓	×	×
Hosseini-Motlagh et al. (2019)	✓	✓	×	×
Huang and Yang (2016)	×	×	✓	×
Kang et al. (2020)	×	✓	×	×
Murali et al. (2019)	✓	×	✓	×
Niu et al. (2017)	✓	×	×	×
Niu et al. (2018)	✓	×	×	×
Peng et al. (2019)	×	×	✓	✓
Saberi et al. (2018)	✓	×	×	✓
Sengupta (2015)	×	×	×	✓
Shi et al. (2020)	✓	✓	×	×
Ulloa et al. (2018)	×	×	×	✓
ur Rehman et al. (2018)	×	×	✓	✓
Yang et al. (2017)	×	✓	×	×
Zhang et al. (2018)	×	×	×	✓
Zhao et al. (2018)	×	×	✓	×
This paper	✓	✓	✓	✓

Table B2. All abbreviations.

$A = \alpha - \beta\theta(1 - \phi\delta)$	$B = \gamma + \beta g\phi\xi_E^{\overline{B}}$
$C = \theta k_I(1 - \phi\delta)A + \phi h k_E B$	$D = \alpha k_I A - k_E B(B + \beta h\phi)$
$E = \theta k_I(1 - \phi\delta)A - g\phi\xi_E^{\overline{B}} k_E B$	$F = \alpha k_I A + \gamma k_E B$
$G = \alpha - \beta\theta$	$H = \phi\delta k_I A + k_E B^2$
$I = A^2(a - \beta c_m)^2 - G^2\left(a - \beta c_m - \beta g\phi\xi_E^{\overline{B}}\right)^2$	$J = k_B A^2(a - \beta c_m) - k_I G^2\left(a - \beta c_m - \beta g\phi\xi_E^{\overline{B}}\right)$
$K = \alpha k_B G + k_E\tau^2$	