# Green Product Development under Competition: A Study of the Fashion Apparel Industry

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## Abstract

Motivated by the observed industrial issues, we analytically develop a fashion supply chain consisting of one manufacturer and two competing retailers and investigate how retail competition and consumer returns affect green product development in fashion apparel. In the basic model, that is, the pure "product greenness level" game, we find that the optimal greenness level of the fashion product decreases along with the level of market competition. This finding implies that a more competitive market leads to a lower optimal greenness level. We also identify that when the consumer return rate increases, the optimal product greenness level is substantially reduced. In the extended model with joint decisions on greenness and pricing, we find that the optimal product greenness level for the whole channel is always higher in the scenario when both retailers charge a higher retail price than in the case with a lower retail price. As such, the underdevelopment of green fashion products is a result of fashion industry features, such as an extremely competitive environment for green product development, relatively low retail prices for fashion products, and high consumer return rates. Therefore, fashion companies should join a co-opetition game for the green product market and simultaneously enhance their efficiency in managing consumer returns. To support our analytical findings, we conduct extensive industrial interviews with various representative companies. Based on this multi-methodological approach (MMA), this paper generates practice-relevant managerial insights that not only contribute to the literature, but also act as valuable references for industrialists.

***Keywords*:** Game Theory, Green Product Development, Retail Competition, Product Greenness Level, Consumer Returns, Multi-Methodological Research

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# 1. Introduction

## 1.1 Background and Motivation

***Industrial observation:*** The public is concerned that the fashion industry is a source of pollution. In 2017, the Waste and Resources Action Programme (WRAP) report showed that nearly 20% of water pollution from the fashion industry came from the textile treatment and dyeing processes. The situation is even more serious in China, where the yearly polluted wastewater from fashion product development processes is around 2.5 billion tons. It is therefore urgent for the fashion industry to develop green products with cleaner processes.

To meet the needs for sustainability, fashion companies are competing with product greenness by using green materials and producing in a sustainable manner (Liu et al., 2012). *Product greenness* is an ecological performance and social acceptance concept when a company pursues its own economic benefit (Lee and Tang, 2017). In the fashion business world, product greenness competition is prevailing. For example, organic cotton was first introduced into product development processes by environmentally motivated pioneers in the United States and Turkey in the early 1990s. After that, many fashion retailers, such as M&S, H&M, Nike, and Timberland, have participated in the competition game on the usage of organic cotton in products (see Table 1). Clearly, product greenness (e.g., the use of organic cotton) has been competed in the fashion industry for more than a decade and continues to play an important role in product development processes. Surprisingly, green product development performance remains poor in the fashion industry (e.g., the overall adoption of green materials and green products in the fashion market is still relatively limited). This paper therefore conducts a deep investigation of green product development and attempts to explain this phenomenon.

**Table 1. Instances of the organic cotton game among various fashion companies.**

| Fashion Companies | Specific Practice in Organic Cotton |
|---|---|
| Nike | - has produced products with organic cotton since 1996;<br>- has been a global leader in organic cotton usage since 2005 (around 4.3 million pounds in total). |
| Timberland | - has adopted organic cotton programs for a range of clothing and footwear products since 2003;<br>- used around 227,000 pounds of total cotton in 2005. |
| Marks & Spencer | - has participated in the organic cotton game since the early 1990s, and has launched blending programs since 2000, with at least 5% of its products using organic cotton;<br>- is one of the founders of the organic cotton business network known as Organic Exchange. |
| H&M | - has sold organic cotton blended fashion products since 2004;<br>- is increasing its usage of organic cotton (e.g., 12.1% in 2017 compared with 8.9% in 2012, for all sustainable cotton). |

Consumer returns have become a top managerial challenge to fashion retailers due to the high return rate and magnitude of handling costs (Phadnis and Fine, 2017). In 2015, for example, U.S. retailers received an estimated US$260.5 billion in consumer returns, a distinct increase (i.e., roughly 50%) from 2007 (Shang et al., 2017). According to the 2018 Consumer Returns Report released by Appriss Retail[2], consumer returns reached US$369 billion in the U.S. retail industry in 2018, comprising around 10% of the total sales. Consumer returns

[2] See https://appriss.com/retail/wp-content/uploads/sites/4/2018/12/AR3018_2018-Customer-Returns-in-the-Retail-Industry_Digital.pdf, which is based on the National Retail Federation (NRF) 2018 Organized Retail Crime Survey (Accessed on December 31, 2018).

are a serious issue for fashion companies seeking to be green. To enhance green performance through better management of the salvage value of returned products, various schemes have recently been launched. For instance, VF Corporation launched the "Clothes the Loop" project, under which yarn is recycled from used fashion products for remanufacturing. Similarly, green product development, which can substantially decrease the environmental pollutions of salvaged products, is also helpful for fashion companies to enhance the salvage value of their products. Therefore, given the chemical-intensive characteristic of fashion products, it is imperative to explore the impacts of consumer returns and product greenness in the retail competition game.

***Literature background:*** A search of the literature reveals no prior research exploring the green product development game in the fashion industry with consumer returns. This paper significantly differs from works on service competition (e.g., Allon and Federgruen (2009)), as in this paper the greenness level of fashion products is specifically quantified by the used material(s) and is directly related to the salvage value of consumer returns (while the retail service level cannot directly influence the salvage value).

Motivated by both the importance of product greenness in the fashion industry and the research gap in the literature, this paper investigates the potential reasons of why overall green product development performance remains unsatisfying in the competitive fashion market by jointly exploring different retail competition games and the strategic impacts of consumer returns.

## 1.2 Research Questions and Contribution Statements

***Research questions:*** The industrial observations and literature motivate us to explore why overall green product development performance remains unsatisfactory in the competitive fashion market by addressing the following research questions.

1) How does retail competition affect the green product development game among various fashion companies?

2) How do consumer returns influence green product development?

3) Is the current underdevelopment of green fashion products a result of the fashion industry features? If yes, what can fashion companies do to change the situation?

To examine these questions, we present a fashion supply chain consisting of one manufacturer and two retailers that compete in the same market, with a focus on the greenness level of their similar fashion products over a short selling season. The two competing fashion retailers could be any fashion brands (e.g., H&M and Mango) that have adopted green materials (e.g., organic cotton). As H&M's official website states[3], green sourced cotton (e.g., organic, recycled, and better cotton[4]) currently accounts for about 43% of the entire cotton used by the company. H&M has even set a target of achieving 100% sustainable cotton usage by 2020. Organic products can also be found at Mango[5]. In our supply chain model, there is a common manufacturer for the two competing retailers. In real world, both H&M and Mango source from a common manufacturer called "the Crystal Group" (one of the largest apparel manufacturers in Asia). So, our supply chain model can be visualized as the one in which the manufacturer is the Crystal Group, and the retailers are H&M and Mango.

[3] Refer to the official website of H&M http://about.hm.com/en/sustainability/sustainable-fashion/materials/cotton.html for more details (Accessed on March 18, 2018).

[4] Refers to the cotton grown with the consideration of reducing stress on the local environment and improving the social welfare of the communities, such as cotton produced with less water and chemical usage (see https://bettercotton.org/about-better-cotton/) (Accessed on March 18, 2018).

[5]https://shop.mango.com/us/search?kw=organic+cotton (Accessed on March 18, 2018).

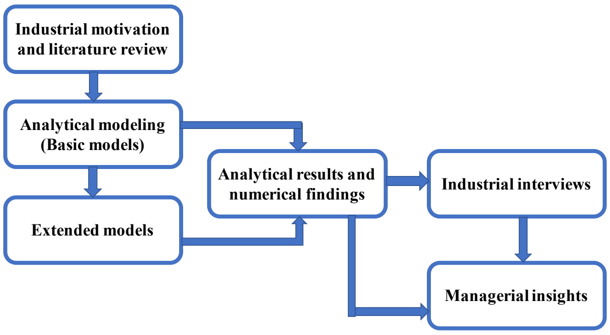


**Figure 1. The multi-methodological approach (MMA) adopted in this paper.**

**Table 2. Interviewee Details.**

| Interviewees (shown as notations) | Position | Date of interview |
|---|---|---|
| | **Firm Type: A global supply chain manager** | |
| **SC1** | Design manager at Li & Fung Limited | May 19, 2018 |
| | **Firm Type: Manufacturer** | |
| **M1** | Deputy general manager at a big reputable manufacturer in Asia producing for Nike | May 29, 2018 |
| **M2** | Manager at a big manufacturer in Asia producing for various international fashion brands like Calvin Klein and Tommy Hilfiger who has also worked as a manager of the production control team at Uniqlo | June 5, 2018 |
| | **Firm Type: Retailer** | |
| **R1** | Product manager at a European international fast fashion brand | May 30, 2018 |

As highlighted in Joglekar et al. (2016), emphasis on the link between observed industrial practice and analytical models has increased in recent years. Following Iyer and Bergen (1997), Phadnis and Fine (2017), and Chiu et al. (2019), in this paper, we adopt the multi-methodological approach (MMA) (see Figure 1), by including both analytical studies and industrial interviews (refer to Table 2 for more details)[6]. The MMA is defined as an innovative operations management (OM) research approach, which emphasizes on enhancing research rigor and connecting research with real world practices by simultaneously employing different OM research methodologies (Sodhi and Tang, 2014). By adopting the MMA, we address the real world practices (based on specific industrial cases and deep industrial interviews) with stylized analytical model formulations and analyses (based on the prior literature)[7]. Our research approach enables us to provide the following answers to our research questions.

*1) Role of retail competition.* First, the product greenness competition level decreases the optimal product greenness level, no matter whether pricing is a strategic decision. Second, when the target market is sensitive to both the product greenness level and retail price, the optimal product greenness level for the whole channel is always higher in the case where both retailers charge a high retail price than in the case with a low retail price.

*2) Role of consumer returns.* When the consumer return rate increases, the optimal product greenness level

[6] The criteria for selecting these four managers, and other specific information, are available in Online Supplementary Appendix B.
[7] We do admit that since the number of conducted interviews is limited and the practitioners' post hoc critiques can be subjective.

decreases. The optimal product greenness level increases when the salvage value of consumer returns increases. *3) Impact of the fashion industry features*. In our theoretical study, we find that the underdevelopment of green fashion products is a result of fashion industry features, such as the extremely competitive environment surrounding green product development, the relatively low retail price of the fashion product, and the high consumer return rate in the fashion market. Fashion companies, therefore, are advised to establish a co-opetition relationship for the green product market and enhance their efficiency in managing consumer returns.

These findings provide new managerial insights beyond what is currently available in the literature and explain why overall green product development performance remains low in the fashion industry. This paper also shows the importance of consumer returns management. For example, fashion retailers should explore ways to reduce the consumer return rate or to enhance the salvage value of consumer returns when engaged in a green-sensitive market. The findings serve as a reference for industrialists and lay a foundation for future studies.

In addition, the discussion in this paper is mainly based mainly on the decentralized setting because most fashion supply chains are operated in a decentralized manner, and the new product development game is becoming increasingly decentralized (Anderson and Joglekar, 2005). In addition, similar to most existing literature, we assume that all supply chain members have access to the same market information.

***Contribution statements:*** We contribute to the competition literature by examining the product greenness competition game under a quantified product greenness level. Impacts of different retail competition scenarios on green product development performance are deeply examined and compared. Furthermore, in contrast to the literature on consumer returns, which mainly focuses on the design of consumer return policies and consumer behaviors, our paper extensively investigates the influence of consumer returns on green product development in the competitive fashion market. Last but not least, in addition to justifying specific industry practices for each modeling assumption based on official websites of fashion companies, industry publications, and other public information, we conduct industrial interviews and present industry executives' critiques of the findings and observations (see Online Supplementary Appendix B for more details). Consequently, the novel and substantive insights derived in this paper are not only theoretically proved but also verified by real-world practice.

The remainder of this paper is organized as follows. Section 2 presents the related literature. Section 3 introduces the model formulation. Section 4 examines the basic greenness competition game, and Section 5 conducts comparisons and numerical analyses. Section 6 extends Section 4 with retail price competition, and Section 7 reports comparisons between two new greenness competition games. Section 8 concludes the paper with managerial insights and provides future research opportunities. All details for the industrial interviews are placed in Online Supplementary Appendix B.

# 2. Literature Review

This paper relates to the literature on competition games, consumer returns, and product greenness competition, the details of which are provided as follows.

## 2.1 Competition Game

Given the popularity of various competing markets in practice, a group of papers in operations management explore competition game. For instance, Savaskan and Van Wassenhove (2006) discuss the interaction between manufacturers' collection effort for postconsumer goods in the reverse channel and retailers' pricing competition game in the forward channel. Allon and Federgruen (2009) analyze retail competition on the retail price, waiting time, and capacity levels, under which consumers can freely select the market segment they wish to belong to. Buell et al. (2016) examine customers' responses to increased service quality under the competition game and the tradeoff between service quality and price. Kogan and Chernonog (2019) investigate the industry-stock-driven competition and analyze the industry output and pollution under different conditions (e.g., with the number of competing firms, market uncertainty and pollution taxation). These papers have important implications in the competitive context, such as ways to design price frames or services. In contrast, in this paper, we focus on the competition games of product greenness levels, which are modeled following observed practices in the fashion apparel industry.

## 2.2 Consumer Returns

Motivated by the challenges of managing consumer returns, an increased research interest in consumer returns can be observed among a large number of supply chain management studies, such as Su (2009), Shulman et al. (2011), Phadnis and Fine (2017), Shang et al. (2017), and Rao et al. (2018). For instance, Su (2009) focuses on consumers' valuation of the product, and explores the strategic influences of consumer returns policies on supply chain contracting. Shulman et al. (2011) argue that heterogeneous target consumers purchase a product only after a trial and investigate the influence of consumer return policies on pricing and restocking fee decisions. Shang et al. (2017) assume that strategic consumers decide whether or not to use the trial period for opportunistic short-term consumption, and analyze the influence of consumer return policies on the wardrobing service design. Phadnis and Fine (2017) consider two different consumer return rates for two sales channels. The authors explore both the product return rate and the online returns penalty when discussing sourcing and sales strategies. Most recently, Rao et al. (2018) study cases with a longer return time leniency and a shorter return time leniency. The authors uncover the influence of the window of time for accepting consumer returns. Similar to Phadnis and Fine (2017), this paper emphasizes the strategic influence of the consumer return rate. However, no studies have investigated the salvage perspective of consumer returns, which is crucial for managing consumer-returned items after collection. This paper therefore supplements the consumer returns literature by analyzing the consumer returns management under consideration of the salvage value.

## 2.3 Product Greenness Competition Game

Developing green products is an industrial trend in fashion apparel (Choi, 2018), and companies take "product greenness" as an area to develop a competitive edge. As such, several studies explore "product greenness competition". For instance, Galbreth and Ghosh (2012) establish a greenness competition model consisting of two asymmetric firms. They show that if the degree of greenness concern varies in different consumers, the increases in consumer awareness benefit both firms only if the consumers' greenness awareness is sufficiently high. Liu et al. (2012) discuss the influence of consumer environmental awareness on the greenness competition game at both the retailer and manufacturer levels. The authors find that when the greenness competition level is low, the profit of the firm that offers inferior green products decreases if the greenness competition is keen. Murali et al. (2018) explore the green product design competition game under the considerations of voluntary ecolabels and mandatory environmental regulation. The authors reveal that with an external certifier (for the firm's environmental quality), the regulator should intervene if consumers do not value the green product highly. The insights these papers provide are interesting and inspiring for this paper because they prove that consumers can be very influential in the greenness competition game. Similar to these two papers, this paper explores the product greenness competition game in a supply chain with risk-neutral members. Innovatively, however, this paper explores the product greenness competition between two fashion retailers in a retailer-manufacturer network with consumer returns, and supposes that the product greenness level is dependent on the raw materials used in the green product development processes. It is an underexplored research domain in the current fashion literature. For example, fashion-related studies such as Donohue (2000), and Cachon and Swinney (2011) have failed to fill this research gap when investigating the improvement measures for the product development processes of fashion products. In addition, green product design studies such as Chen (2001) provide no specific criterion for quantifying the greenness performance of fashion products. Consequently, this study contributes to the current greenness knowledge by proposing a quantified greenness level for green product development, which can affect the market demand and the salvage value of consumer-returned items.

Against this backdrop, the main contribution of this study to the literature is its in-depth exploration of the greenness competition in a retail market in the presence of consumer returns via the integration of important factors in a real business environment (e.g., level of competition, consumer return rate and salvage value of consumer-returned items) into a unified framework. Similar to Galbreth and Ghosh (2012), this paper assumes that greenness performance can influence consumer behavior in a competitive environment and emphasizes the usage of green materials such as organic cotton for enhancing the greenness level of fashion products. However, different from Galbreth and Ghosh (2012), who are devoted to examining the heterogeneity level of consumer attitudes toward greenness, the major focus of this paper is the greenness competition game under different retail competition scenarios. Consumer returns, which Galbreth and Ghosh (2012) do not consider, are emphasized in this paper. In the meantime, the term *greenness* is specifically quantified in this paper by the materials used for green product development, instead of serving as a subjective term as in Galbreth and Ghosh (2012). In fact, as "greenness" is a rather multidimensional construct that mainly refers to the ecological dimension of sustainable development, the greenness investment devoted to different dimensions can have totally different impacts on the greenness competition game in the target market. For instance, while one green-oriented firm may invest heavily in waste elimination in the production process, the other may focus more on the usage of organic materials. Consequently, findings in this paper, which are based on a quantified greenness level, can effectively avert such nuances and present a higher pertinence level in the greenness competition game than those in Galbreth and Ghosh (2012). In addition, based on a deep search of the literature, no research has explored consumer returns together with product greenness competition. Furthermore, we establish a connection between product greenness competition and consumer returns via a greenness-dependent salvage value. Therefore, this paper complements the current research (interested readers can refer to Table B1 in Appendix B for more details) and present insights distinct from those already derived.

# 3. Model

This section presents the model of a fashion supply chain consisting of one common manufacturer and two competing retailers (denoted by $i$=1,2). Two competing retailers, both of which have devoted plenty of efforts to green product development, are assumed to have the identical dominant power in the collaborations with the manufacturer and play as the Stackelberg leaders (e.g., H&M and Mango). The common manufacturer is the follower (e.g., the Crystal Group). Modeling assumptions are justified with industrial practice.

## 3.1 Retailers

***Market demand:*** Consistent with prior competition literature (Savaskan and Van Wassenhove, 2006; Chen et al., 2010; Karray and Martín-Herrán, 2019), we assume market demand follows a linear function of the product greenness level. An increase in the product greenness level $b_i$ of fashion product *i* decreases the demand for product *3-i*, and vice versa. The greenness-dependent demand of product *i* thus takes the following form:

$$q_i(b_i, b_{3-i}) = \alpha_i + b_i - \gamma b_{3-i}, \text{ s.t. } 0 < \gamma < 1, i=1, 2, \tag{3.1}$$

where $\alpha_i$ represents the primary market scale of the product offered by retailer *i* (i.e., when $b_i = b_{3-i} = 0$), which is determined by general factors such as the retail price, product quality, and brand image.

Following Banker et al. (1998), we assume that the two competing retailers' primary market sizes are equal, that is, $\alpha_i = \alpha_{3-i} = \alpha > 0$,[8] and can be observed from the historical data and the reaction to the products in public media. The positive sensitivity of the market demand with respect to the greenness level of the product provided by retailer *i* is scaled to be 1. That is, as $b_i$ increases, the demand for product *i* increases from its base value at the rate of 1. In addition, $\gamma$ is the negative sensitivity of the market demand with respect to the greenness level of its competitor's product, that is, retailer *3-i*, and it describes the reduction rate of demand from the base value as the greenness level of the product provided by the opponent retailer *3-i* increase. This greenness-dependent demand function models consumers' environmental awareness, and is supported by global survey results such as the one mentioned in Hong et al. (2018), which has proved that plenty of consumers nowadays pay attention to the greenness of products when making their purchasing decisions. In addition, *product greenness level* $b_i$ is quantified by the amount of material(s) adopted in the product development processes such as the amount of organic cotton, which is widely emphasized by various fashion companies such as H&M and Mango. Greenness performance of a fashion product relates to the material(s) used in the manufacturing process (Galbreth and Ghosh, 2012). For example, the total water consumption of organic cotton (i.e., 182 liters/kg lint) is usually much less than that of conventional cotton (i.e., 2,120 liters/kg lint)[9]; the crop cultivation and fiber production processes create only 2.35 kg of $CO_2$ emissions per ton of spun fiber[10]. In fact, if the material is nylon, the greenhouse gas emissions are even worse because it results in emissions of $N_2O$ instead of $CO_2$. ($N_2O$ is estimated to be 300 times more damaging than $CO_2$.) In addition, the rationality of our greenness indicator is supported by our interview with SC1, a design manager at Li & Fung Limited (more details can be found in Table 1) who claimed that in practice the "greenness level" of a fashion product is measured by either the integrated materials (e.g., the percentage of some specific materials) or the finishing approaches. (However, the finishing approaches are much more difficult to measure.) M2, a manager at a big manufacturer in Asia producing for various international fashion brands such as Calvin Klein and Tommy

[8] As the results in the case of $\alpha_i \neq \alpha_{3-i}$ (i.e., when the two competing retailers have different dominant powers) are similar to those in the case of $\alpha_i = \alpha_{3-i}$, we simply discuss the case of $\alpha_i = \alpha_{3-i}$ to clearly present the influences of market competition in the product greenness game. In addition, this is also consistent with the real world observations since most dominant fashion retailers from the same market segments usually have similar market powers like the brands of H&M, Mango, and M&S under the fast fashion segment.

[9] http://textileexchange.org/wp-content/uploads/2017/06/TE-Material-Snapshot_Organic-Cotton.pdf (Accessed on April 1, 2018).

[10] Refer to https://oecotextiles.wordpress.com/2011/01/19/estimating-the-carbon-footprint-of-a-fabric/ (Accessed on April 1, 2018).

Hilfiger, and R1, a product manager at a European international fast fashion brand, also noted similar information. Therefore, it is reasonable to assume that the greenness level of a fashion product can be quantified by the material(s) used to develop the product. The increased adoption of green clothing in the fashion industry can also be observed from the 2017 WRAP report. Greenness-oriented fashion retailers such as H&M, M&S, and Mango can enhance the greenness levels of their products by increasing the percentage of organic cotton blended into the products.[11]

In the basic model, we focus on the product greenness game by excluding the retail price. First, regular product pricing in fashion relates to the brand and its positioning. Product pricing is a strategic decision, rather than a decision for supply-demand matching and operational revenue (Chiu et al., 2018). Second, as learned from M1, the deputy general manager at a big reputable manufacturer in Asia producing for Nike, consumers in the market prefer green products to "brown" (i.e., non-green) products if the selling prices are almost equal.

***Cost and revenue parameters:*** The fashion retailer *i* charges the consumer a retail price $p$ and trades with the manufacturer via a wholesale pricing contract (i.e., with a unit wholesale price $w_i$), which is one of the most popular supply chain contracts in the literature. In practice, R1, the product manager at a European multinational fast fashion brand, and SC1, the design manager at Li & Fung Limited, agreed on the popularity of the wholesale pricing contract in the fashion industry. Moreover, similar to the work of Savaskan and Van Wassenhove (2006), retailer $i$ has an extra investment $\frac{\xi b_i^2}{2}$ for selling green products to the target market (i.e., retailer $i$'s green product development investment cost), which can result from advertising, supervision, evaluation, and other non-price promotional activities. $\xi$ is the retail cost coefficient related to the product greenness level and plays a crucial role when retailer *i* determines his or her investment on the product greenness level. Product greenness competition relies heavily on advertising and other retail efforts in emerging markets such as China (based on the information from M2). Similar to Mostard and Teunter (2006), consumers are allowed to return a product without any conditions, and the consumer return rate is $\lambda$ $(0 < \lambda < 1)$. Consumer return policies are widely observable in green product retailing in various fashion companies such as H&M, Mango, and M&S[12]. We consider the consumer return rate as exogenous and a result of the product quality (which is one of the key elements in the brand system) because M2 mentioned that consumer return rate is related to product quality, rather than a decision controlled by one supply chain member. Such an exogenous consumer return rate is also supported by the literature like Li and Rajagopalan (1998), which argues that the consumer return rate should be a function of product quality. Besides, prior literature like Pinçe et al. (2016) shows that the consumer return rates are consistent and similar in real world practices across all brands (i.e., consistently in the range of 8–12%).

The selling season of the fashion products is short, and there is no chance to resell the returned products in the same market. Thus, all consumer-returned items are salvaged by retailers (*i*=1, 2) with a value $v_i$ at the end of the selling season to the salvage market, which is for recycling or other reverse logistics activities. As noted by R1, big retailers such as H&M emphasize "fair business"; this is a common practice and beneficial to establishing a long-term cooperative relationship with manufacturers. R1 mentioned that the retailer does not

[11]For instance, a 98% organic cotton with a 2% elastane denim organic cotton skirt can be found at Mango (https://shop.mango.com/us/women/skirts-midi/denim-organic-cotton-skirt_23060451.html?c=TS&n=1&s=search), and a similar organic cotton skirt with 100% organic cotton is also available in H&M (https://shop.mango.com/us/women/skirts-short/denim-organic-cotton-skirt_23075624.html?c=01&n=1&s=search) (Accessed on April 1, 2018).

[12] The specific terms of the consumer returns policy at H&M can be found at http://www2.hm.com/en_ca/customer-service/returns.html. Details on the consumer returns policy provided by Mango are available at https://shop.mango.com/gb/dam/help/6943.html, and those for M&S are available at http://help.marksandspencer.com/support/returns-and-refunds/returns-international-orders (Accessed on March 18, 2018)

return consumer returns or unsold leftovers back to the manufacturer unless serious quality problems occur, and M2 informed us that in most cases consumer returns are under the responsibility of retailers if the returns are not induced by quality-related problems. The products offered by two competing retailers are homogenous if there is no greenness investment, while the greenness level $b_i$ of product $i$ increases the salvage value of product $i$. The green product $i$*'s* salvage value $v_i$ is given as follows:

$$v_i = t + kb_i, \tag{3.2}$$

where *t* is the basic salvage value (i.e., when no green effort has been invested into product *i*) and *k* is the gain in the final salvage value with respect to the increase (or decrease) in the product greenness level $b_i$. This assumption is well supported by the real world practices. For instance, the preference for green products can be seen in various salvage markets, like the Secondary Materials and Recycled Textiles Association. Therefore, it is reasonable to assume that, when retailer *i* sells the product with a higher organic cotton usage, the final salvage value of the consumer return increases. While if the investment into the product greenness level is small (i.e., a small organic cotton proportion), the final salvage value is much lower.

## 3.2 Manufacturer

***Cost and revenue parameters:*** The manufacturer bears the manufacturing costs, covering the material, energy, labor, and equipment costs of production (i.e., the goods without any investment in the product greenness performance), which are presented by $c_m$. Apart from this, as the follower, the manufacturer has to follow the greenness level requirements from the dominant retailers. Accordingly, an extra unit cost is invested to achieve a required greenness level $\theta b_i$ (i.e., the manufacturer's development cost of green product), where $b_i$ is the product's greenness level and $\theta$ is the cost coefficient of green product development[13]. This additional cost is induced by the adoption of green materials such as organic cotton (Galbreth and Ghosh, 2012). R1 confirmed this cost structure and claimed that responsible fashion firms purchased green products from qualified green manufacturers (e.g., with a green product development line and related certifications from the authority). The manufacturer's development cost of green product thus comprises the material costs only. Consequently, for each green fashion product, the manufacturer faces a total cost of $c_m + \theta b_i$. Therefore, such a linear cost function is supported by both industrial interviews and the literature (e.g., Porteus, 1985). In addition, since the greenness level of a fashion product in this paper is determined by the materials used in the product development process, the potential spillover effects which may be induced by a free-rider manufacturer are not considered.

To ensure a meaningful and non-trivial transaction, we consider $c_m > t > 0$, $\theta > k > 0$. Note that $c_m > t > 0$ and $\theta > k > 0$ ensure that the salvage value of consumer returns is smaller than the production cost. For convenience, a list of notations is shown in Table 3.

**Table 3. Notation.**

| | |
|---|---|
| $p_i$ | Retail price of product *i* |
| $w_i$ | Unit basic wholesale price charged by the manufacturer for product *i* |
| $b_i$ | Greenness level of product *i* |
| $q_i$ | Market demand of the product offered by retailer *i* |

[13] The substantial efforts the Crystal Group have devoted to the green issue can be found in its latest sustainability report (https://www.crystalgroup.com/static/media/1505203666074_gOy4pIJQl2.pdf) (Accessed on March 18, 2018).

| | |
|---|---|
| $c_m$ | Base production cost for each general product (i.e., without consideration of product greenness) |
| $v_i$ | Salvage value of the consumer returned products of retailer *i* |
| $\lambda_i$ | Consumer return rate of the product *i* |
| $t$ | Fixed salvage value when there is no effort invested into the greenness level of the product |
| $k$ | Gain in the final salvage value with respect to the greenness level $b_i$ |
| $\theta$ | Manufacturer's cost coefficient related to green product development |
| $\xi$ | Retailer's cost coefficient related to green product development |
| $\alpha_i$ | Primary market scale of the product *i* |
| $\gamma$ | Negative sensitivity of the demand with respect to the greenness level of the product from its competitor |
| $y$ | Positive sensitivity of the market demand of product *i* with respect to the retail price of the product offered by retailer *3-i* |
| $\pi_{r(i)}$ | Profit function of retailer *i* |
| $\pi_m$ | Profit function of the manufacturer |
| $\pi_{SC}$ | Profit function of the whole supply chain |

# 4. Product Greenness Games

In this section, we first explore the product greenness games without the considerations on the influences of the retail price on the market demand and present the problem formulations of three product greenness competition scenarios. This is a reasonable structure since the retail price of a fashion product, which is one of the key elements of a specific fashion brand, is usually very stable from the long term. Besides, it is also well known that in practice, some of the fashion companies develop and sell green products under the pressure of public emphases on product greenness, especially for brands from the fast fashion segment, which are accused for the heavy pollutions in the past years (Turker and Altuntas, 2014). These companies will never charge a higher retail price because of the additional product greenness investment. The sequence of events thus is as follows[14].

1) The fashion retailers first determine the greenness levels (i.e., $b_1$ and $b_2$) of their own products, respectively.

2) Given the product greenness levels required by the retailers, the production activities are conducted and the manufacturer decides the wholesale prices $w_1$ and $w_2$.

3) The retailers accordingly decide the ordering quantities of their own products (i.e., $q_1$ and $q_2$).

4) The selling season begins. At the end of the selling season, the unsatisfying products are returned by the consumers and salvaged by the retailers.

In this paper, we argue that fashion retailers like H&M and Mango are powerful Stackelberg leaders and can determine the greenness levels of their fashion products. For example, H&M Group manages the chemicals used in its product development process by setting a chemical restrictions list for all of its contracted suppliers[15]. Moreover, Nike, and M&S have specific requirements for the percentage of organic cotton in their products for their manufacturers. M2 agreed that many fashion retailers have implemented such practices. M1 and R1 confirmed the feasibility of this assumption and claimed that fashion retailers (e.g., Nike) promoted their green products by emphasizing the usage of organic cotton in those products. Many giant fashion retailers adopt global

[14] Only the case with two competing retailers is specifically elaborated here, as the sequence of events in the case with one single retailer is similar.
[15] http://sustainability.hm.com/en/sustainability/commitments/use-natural-resources-responsibly/chemicals/chemical-restrictions.html (Accessed on March 18, 2018).

sourcing. Their manufacturers are responsible only for production, rather than reselling the returned products.

## 4.1 Case 1: One Single Retailer

We start with Case 1 (G1) when there is only one retailer and no product greenness competition in the retail market (see Figure 2). This case is designed as a benchmark for later comparisons with the competition case.

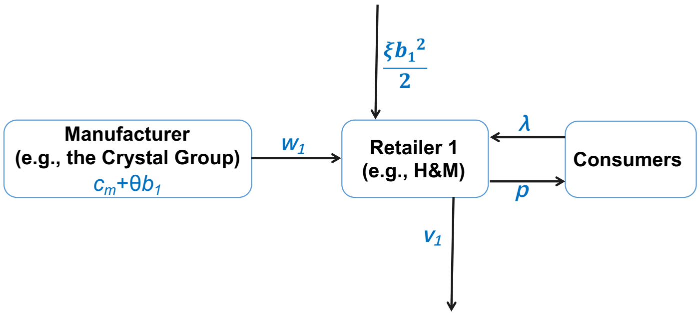


**Figure 2. Supply Chain Structure in Case 1.**

The retailer's and manufacturer's profit functions are given as follows.

$\max_{b_1} \pi_{r1}^{G1} = [p - w_1 - \lambda p + (t + kb_1)\lambda] \cdot (\alpha + b_1) - \frac{\xi b_1^2}{2}$, and $\max_{w_1} \pi_m^{G1} = (w_1 - c_m - \theta b_1) \cdot (\alpha + b_1)$.

Under the condition $\xi > 2k\lambda$, the optimal product greenness level $b_1^{G1*}$ decided by fashion retailer 1 and the optimal wholesale price $w_1^{G1*}$ chosen by the manufacturer are as follows:

$b_1^{G1*} = \frac{A - c_m - (\xi - 2k\lambda + \theta)\alpha}{2(\xi - 2k\lambda + \theta)}$, and $w_1^{G1*} = \frac{(\xi - 2k\lambda + \theta)(\xi - 2k\lambda)\alpha + (\xi - 2k\lambda + 2\theta)A + (\xi - 2k\lambda)c_m}{2(\xi - 2k\lambda + \theta)}$,

where $A = (1 - \lambda)p + t\lambda + k\lambda\alpha$.

The optimal solutions can be found when $\xi > 2k\lambda$, i.e., retailer 1's green product development investment is sufficiently expensive, which can result from relevant activities like advertising, supervision, and evaluation. Similar constraint structures for optimal solutions are widely adopted in extant literature like Pazoki and Zaccour (2019), which ensures the explored cases are meaningful and captures the real practices. As a remark, the constraint of $\xi > 2k\lambda$ in this paper is consistent with the real practice of a fashion business. To be specific, based on H&M's sustainability report, training cotton farmers is one kind of their greenness investment, but is surprisingly expensive[16]. Besides, H&M has also invested in training its suppliers to minimise the usage of hazardous chemicals in product development process. Furthermore, fashion retailers may have testing and evaluation investment for green product development. For example, H&M has conducted 48,700 chemical tests in 2018 with its suppliers to ensure the chemical usage in their products is all fine (H&M Group Sustainability Report, 2018[17]). Thus, following the fashion industry's real practices, we have made this assumption in this paper.

## 4.2 Case 2: Two Homogenous Retailers

For Case 2, as shown in Figure 3, retailers 1 and 2 enjoy the same market share of their homogenous fashion products and the same consumer return rate, that is, $\alpha_1 = \alpha_2 = \alpha$ and $\lambda_1 = \lambda_2 = \lambda$. The market demand of

[16] http://about.hm.com/en/media/news/financial-reports/2014/8/1664374.html (Accessed on March 18, 2018).
[17] https://about.hm.com/content/dam/hmgroup/groupsite/documents/masterlanguage/CSR/reports/2018_Sustainability_report/HM_Group_Sustainability Report_2018_%20FullReport.pdf (Accessed on July 5, 2019).

retailer $i$ is $q_i(b_i, b_{3-i}) = \alpha + b_i - \gamma b_{3-i}$, s.t. $0 < \gamma < 1$, $i$=1, 2.

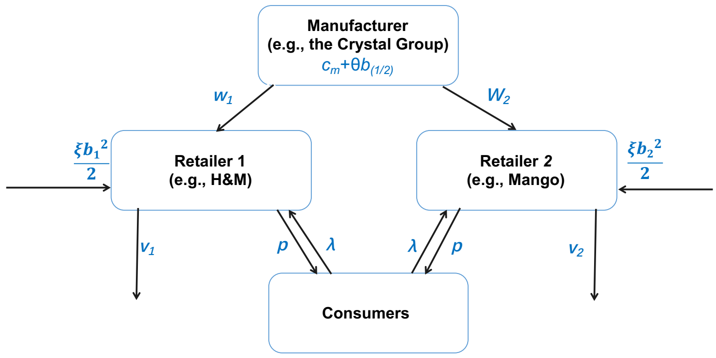


**Figure 3. Supply Chain Structure in Case 2.**

The profit functions for two homogenous retailers and one common manufacturer are given as follows:

$$\max_{b_1} \pi_{r1}^{G2} = [p - w_1 - \lambda p + (t + kb_1)\lambda] \cdot (\alpha + b_1 - \gamma b_2) - \frac{\xi {b_1}^2}{2},$$

$$\max_{b_2} \pi_{r2}^{G2} = [p - w_2 - \lambda p + (t + kb_2)\lambda] \cdot (\alpha + b_2 - \gamma b_1) - \frac{\xi {b_2}^2}{2}, \text{ and}$$

$$\max_{w_1, w_2} \pi_m^{G2} = (w_1 - c_m - \theta b_1) \cdot (\alpha + b_1 - \gamma b_2) + (w_2 - c_m - \theta b_2) \cdot (\alpha + b_2 - \gamma b_1).$$

Similar to Case 1, when the retailers' green product development investment is sufficient enough (i.e., $\xi > (2+\gamma)k\lambda$), the optimal responses of these homogenous retailers and their manufacturer are:

$${b_1}^{G2*} = {b_2}^{G2*} = \frac{(1-\gamma)(A-c_m)-(C+\theta)\alpha}{2(1-\gamma)(C+\theta)}, \text{ and } {w_1}^{G2*} = {w_2}^{G2*} = \frac{(C+\theta)C\alpha+(1-\gamma)[C \cdot c_m+(C+2\theta)A]}{2(1-\gamma)(C+\theta)},$$

where $B = \xi - (2+\gamma)k\lambda$, and $C = \xi - (2-\gamma)k\lambda$.

## 4.3 Case 3: Two Heterogeneous Retailers

The profit functions of the two heterogeneous retailers and one upstream manufacturer are given as follows:

$$\max_{b_1} \pi_{r1}^{G3} = [p - w_1 - \lambda_1 p + (t + kb_1)\lambda_1] \cdot (\alpha + b_1 - \gamma b_2) - \frac{\xi {b_1}^2}{2},$$

$$\max_{b_2} \pi_{r2}^{G3} = [p - w_2 - \lambda_2 p + (t + kb_2)\lambda_2] \cdot (\alpha + b_2 - \gamma b_1) - \frac{\xi {b_2}^2}{2}, \text{ and}$$

$$\max_{w_1, w_2} \pi_m^{G3} = (w_1 - c_m - \theta b_1) \cdot (\alpha + b_1 - \gamma b_2) + (w_2 - c_m - \theta b_2) \cdot (\alpha + b_2 - \gamma b_1).$$

Under the condition of $\xi > 2k\lambda_1$ and $\xi > 2k\lambda_2$, in addition to $X_1 > 0$ and $X_2 > 0$, the two heterogeneous retailers and the manufacturer have the following optimal solutions:

$${b_1}^{G3*} = \frac{\eta_1 p-(1-\gamma)Z(\gamma B_1\varrho_2+B_2\varpi_1)c_m+H_1(t+k\alpha)-ZI_1\alpha}{Z(4X_1X_2-\gamma^2U^2)}, \quad {b_2}^{G3*} = \frac{\eta_2 p-(1-\gamma)Z(\gamma B_2\varrho_1+B_1\varpi_2)c_m+H_2(t+k\alpha)-ZI_2\alpha}{Z(4X_1X_2-\gamma^2U^2)},$$

$${w_1}^{G3*} = \frac{Y_1 p+(1-\gamma)Z(2B_2X_1+\gamma B_1U)c_m+J_1(t+k\alpha)+ZK_1\alpha}{4X_1X_2-\gamma^2U^2}, \text{ and } {w_2}^{G3*} = \frac{Y_2 p+(1-\gamma)Z(2B_1X_2+\gamma B_2U)c_m+J_2(t+k\alpha)+ZK_2\alpha}{4X_1X_2-\gamma^2U^2}.$$

$X_{1/2} = (Z + \theta D_{1/2})E_{1/2} + \theta\gamma^2 k\lambda_{1/2}(\xi - k\lambda_{1/2})$, $E_{1/2} = \xi - (2-\gamma^2)k\lambda_{1/2}$ and $Z = D_1D_2 - \gamma^2k^2\lambda_1\lambda_2$. The list of abbreviations and notations is available in Table B2 in Appendix B. Besides, notice that the retail cost coefficient of the product greenness level (i.e., $\xi$) is assumed to be the same for these two heterogeneous retailers in Case 3. This is because the retailer $i$'s green product development investment cost is defined as the result of advertising, supervision, and other non-price promotional activities in this paper. Given that the same market segment usually share the same market characteristics and consumer preferences as well as sensitivity, this green product development investment cost coefficient should be the same for these two competing retailers. In fact, we also have relaxed this assumption to the case when these two heterogeneous retailers face two different retail cost coefficients of the product greenness level and our results demonstrate that this does not change the main findings. This shows the robustness of our findings. In later discussions, therefore, we stick to the assumption of an identical retail cost coefficient of the product greenness level so as to simplify the exposition of our model and results. Interested readers can refer to Online Supplementary Appendix C for more details.

# 5. Comparisons and Implications

In this section, we compare the equilibrium solutions of three competition scenarios and investigate how retail competition and consumer returns affect the equilibrium decisions (see Table 4 for the meanings of each case). Sensitivity analyses of Cases 1 and 2 are shown in Table 5. Note that numerical examples confirm the robustness of our analytical findings and highlight some crucial insights that cannot be analytically demonstrated. Referring to Bernstein and Federgruen (2007), the default values of numerical examples in this section are set as $\alpha$=13, $\gamma$=0.235, $\lambda_1$=0.34, $\lambda_2$=0.35, $k$ =0.3, $t$ =0.2, $\theta$=0.7, $\xi$=1.25, $c_m$=2.5, $p$=50, respectively. All of the selected values satisfy the constraints mentioned in the basic model.

**Table 4. Notations for each case.**

| Case | Specific Meaning | Monopoly Game or Duopoly Game |
|---|---|---|
| Case 1 | Case with one single retailer. | Monopoly game |
| Case 2 | Case with two homogenous retailers. | Duopoly game |
| Case 3 | The case with two heterogeneous retailers. | Duopoly game |

**Table 5. Comparisons of the optimal solutions under Cases 1 and 2.**

| Cases | Case 1: One Single Retailer | Case 2: Two homogenous retailers |
|---|---|---|
| ${w_1}^*$ | $\lambda \uparrow, {w_1}^{G1*} \uparrow$, if and only if $t > t_w^{G1}$; $\lambda \uparrow, {w_1}^{G1*} \downarrow$, if and only if $t < t_w^{G1}$. | $\lambda \uparrow, {w_1}^{G2*} \uparrow$, if and only if $t < t_w^{G2}$; $\lambda \uparrow, {w_1}^{G2*} \downarrow$, if and only if $t > t_w^{G2}$. |
| | $\theta \uparrow, {w_1}^{G1*} \uparrow$. | $\theta \uparrow, {w_1}^{G2*} \uparrow$. |
| ${b_1}^*$ | $\lambda \uparrow, {b_1}^{G1*} \uparrow$, if and only if $t > t_b^{G1}$; $\lambda \uparrow, {b_1}^{G1*} \downarrow$, if and only if $t < t_b^{G1}$. | $\lambda \uparrow, {b_1}^{G2*} \uparrow$, if and only if $t > t_b^{G2}$; $\lambda \uparrow, {b_1}^{G2*} \downarrow$, if and only if $t < t_b^{G2}$. |
| | $t \uparrow, {b_1}^{G1*} \uparrow$. | $t \uparrow, {b_1}^{G2*} \uparrow$. |
| | $k \uparrow, {b_1}^{G1*} \uparrow$. | $k \uparrow, {b_1}^{G2*} \uparrow$. |
| | $\xi \uparrow, {b_1}^{G1*} \downarrow$. | $\xi \uparrow, {b_1}^{G2*} \downarrow$. |
| | Nil | $\gamma \uparrow, {b_1}^{G2*} \downarrow$. |

## 5.1 Influences of retail competition

We explore the impacts of retail competition on green product development in the duopoly game. Following the approach of Phadnis and Fine (2017), we provide practitioners' post hoc critiques to support the robustness of our findings. We make Proposition 5.1 (mathematically proven) and Observation 5.1 (based on the numerical analysis in Online Supplementary Appendix A.1) as follows.

**PROPOSITION 5.1.** *For the case with two homogenous retailers (i.e., Case 2): the optimal greenness level of product 1 (i.e.,* $b_1{}^*$*) is decreasing in the product greenness competition level* $\gamma$.

**OBSERVATION 5.1.** *For the impact of the product greenness competition level* $\gamma$ *on the optimal product greenness level* $b_1{}^*$*, the result in the case with two heterogeneous retailers (i.e., Case 3) is the same as that in the case with two homogenous retailers.*

Proposition 5.1 and Observation 5.1 characterize the optimal product greenness level of Cases 2 and 3 from the impacts of retail competition (i.e., $\gamma$). Interestingly, we find that retail competition can reduce the optimal product greenness level of retailer 1 in both Cases 2 and 3. When the competition on product greenness is high, the fashion retailer with superior green products is more profitable only when his greenness gap with the inferior green retailer is relatively high. The additional investment to help achieve this distinct greenness gap, however, can be very expensive at the "fashion retailers' level" (i.e., $\xi > (2+\gamma)k\lambda$ in Case 2, and $\xi > 2k\lambda_1$ and $\xi > 2k\lambda_2$ in Case 3). The costs of lessening this negative effect brought on by the product greenness competition can therefore be extremely high. Consequently, given the high green product development investment cost, two competing fashion retailers such as H&M and Mango are cost-conscious and prefer a low product greenness level so as to lower the product greenness competition. Proposition 5.1 and Observation 5.1 are also supported by Klastorin et al. (2016), which indicates that an increased product differentiation can better segment duopoly consumers and further increase the profits of both competing firms.

**Practitioners' post hoc critique of Proposition 5.1 and Observation 5.1:** *SC1, M2, and R1 confirm our findings and explanations in Proposition 5.1 and Observation 5.1. SC1 claimed, "For each fashion product, its retail price comprises both a cost (e.g., 30%) and a profit margin (e.g., 70%)". Therefore, all profit-maximizing retailers reasonably minimize their green product development investment costs if the competition costs on the product greenness level are too high. These high competition costs, for instance, can be the investment to achieve a higher degree of product differentiation. This is vital in a competitive market environment, as addressed by R1. In addition, the costs may be the time and capital investment spent on other competition-related issues, which can be extremely costly for all competitors, as explained by M2.*

## 5.2 Influences of consumer returns

We now examine the influences of consumer returns. Similarly, the findings in this section are supported by the literature and industrial practice. Proposition 5.2 and Observation 5.2 summarize the results.

**PROPOSITION 5.2.** *In both Cases 1 and 2: (i) when the consumer returns' basic salvage value* $t$ *is small*[18]*, an increase in the consumer return rate* $\lambda$ *correspondingly leads to a decrease in the optimal greenness level of the fashion product (i.e.,* $b_1{}^*$*); (ii) when the salvage value of consumer-returned items (i.e., both* $t$ *and* $k$*) becomes higher, the optimal product greenness level* $b_1{}^*$ *increases; and (iii) when the green product development investment coefficient* $\xi$ *increases, the optimal product greenness level* $b_1{}^*$ *decreases.*

[18] $t < t_b^{G1} = \frac{(\xi+\theta)(p-k\alpha)-2k(p-c_m)}{\xi+\theta}$ in Case 1 and $t < t_b^{G2} = \frac{(\xi+\theta)(p-k\alpha)-k(2-\gamma)(p-c_m)}{\xi+\theta}$ in Case 2.

**OBSERVATION 5.2.** *For the influences of consumer returns and the green product development investment coefficient* $\xi$ *on the optimal product greenness level* $b_1^*$*, the results in Case 3 are similar to those in Case 2.*

Proposition 5.2 captures the impacts of consumer returns, referring to the consumer return rate $\lambda$ and the salvage value of consumer returns (i.e., both $t$ and $k$), in addition to the influence of the green product development investment coefficient $\xi$ on the optimal product greenness level of retailer 1. As the results of $b_2^*$ are similar to those of $b_1^*$, only the analyses of $b_1^*$ in Proposition 5.2 and Observation 5.2 are shown.

From Proposition 5.2 and Observation 5.2, we see that when the consumer returns' basic salvage value $t$ is small, an increase in the consumer return rate $\lambda$ can lead to a decrease in the optimal greenness level of fashion product 1. When the salvage value of the consumer returns is relatively low, any additional increase in the consumer return rate substantially hurts the profit of the fashion retailer 1. Consequently, the green product development investment at the retail level decreases, as does the product greenness level. In the meantime, as the unit increase in the salvage value of consumer returns is lower than the unit increase in the wholesale price, fashion retailer 1's interests in increasing the product greenness level are also depressed by a raised consumer return rate. As evidenced by Letizia et al. (2018), when the salvage value of consumer returns is low, the firm tends to reduce the consumer return rate (e.g., increase return penalties). Similarly, it is intuitive that the optimal product greenness level $b_1^*$ is positively correlated with the salvage value of consumer returns (i.e., both $t$ and $k$), regardless of whether greenness competition exists. A high salvage value is efficient at alleviating the inventory burden of consumer returns. In practice, e.g., for organic cotton T-shirts priced at US$19.99 for three in H&M, the heterogeneity level and salvage value are low once they have been partially used and returned. Based on the preceding discussion, it can be concluded that the low level of effort devoted to green product development is inevitable in the fashion industry, which is dominated by the fast fashion trend.

Moreover, based on Proposition 5.2 (iii) and Observation 5.2, when the green product development investment coefficient $\xi$ increases, the optimal product greenness level is lower in all of the aforementioned cases. This finding is reasonable, as when the retailer's green product development coefficient $\xi$ is sufficiently large, the extra investment in the greenness performance of the fashion products can lead to many additional costs to the fashion retailer. This can hinder the pursuit of a higher product greenness level at the retailer level. For example, at both H&M and Mango, the extra investment can be either the additional investment in advertising or the promotion of the launch of green collections (e.g., the H&M Conscious Exclusive Collection and the MANGO Committed), or the additional training service provided to the farmers responsible for organic cotton production. As a result, considering the expensive product greenness investment, the overall green product development performance in the fashion industry is also reasonably low.

**Practitioners' post hoc critique of Proposition 5.2 and Observation 5.2:** *SC1 and M2 confirmed the findings and explanations in Proposition 5.2 and Observation 5.2. As explained by SC1, any capital and efforts invested into producing a greener fashion product means additional operational risks for the retailer. Consequently, if the loss induced by the consumer returns is too high, due to either a high consumer return rate or a low salvage value for consumer returns, the retailer holds little profitability. This substantially lowers fashion retailers' interests in achieving a higher greenness level.*

Proposition 5.3 and Observation 5.3 show the findings for the optimal wholesale prices.

**PROPOSITION 5.3.** *For the optimal wholesale price offered to retailer 1 (i.e.,* $w_1^*$*): (i) when the consumer* *returns' basic salvage value $t$ belongs to Interval I (i.e., $t_w^{G2} < t < t_w^{G1}$), if the consumer return rate $\lambda$ increases, the optimal wholesale price decreases in both Cases 1 and 2; and (ii) the optimal wholesale prices in both Cases 1 and 2 increase in the manufacturer's green product development coefficient $\theta$.*

**OBSERVATION 5.3.** *Similar to Cases 1 and 2, the optimal wholesale price in Case 3 increases in the manufacturer's green product development coefficient $\theta$.*

Proposition 5.3 (i) states that when the basic salvage value $t$ of the consumer returns is small (i.e., $t < t_w^{G1}$), the optimal wholesale price charged to retailer 1 decreases due to a reduced optimal greenness level of the fashion product. However, if the consumer returns' basic salvage value $t$ is too small (i.e., $t < t_w^{G2}$), the fashion retailer must invest more in the product greenness level when the consumer return rate $\lambda$ continues to increase. Thus, this additional green investment can enhance the overall salvage value of consumer-returned items and help the retailer to survive in a competitive market with high uncertainty.

Proposition 5.3 (ii) and Observation 5.3 uncover that a higher green product development cost coefficient $\theta$ increases the optimal wholesale price $w_1{}^*$ regardless of the competition structure in the retail environment. A higher manufacturer's green product development cost coefficient can be induced by a higher supply cost of organic cotton provided by organic cotton processors such as Cotonea due to the raised quality standards or increased monitoring costs of the production process. This leads to a higher wholesale price. In the meantime, the higher manufacturer's greenness cost coefficient reduces the optimal profits of all related fashion supply chain members, as the greenness costs are higher.

**Practitioners' post hoc critique of Proposition 5.3 and Observation 5.3:** *Both SC1 and R1 agreed with the findings in Proposition 5.3 and Observation 5.3 and the claim that the wholesale price could be indirectly affected by consumer returns through the ordering quantity passed by the retailer.*

**PROPOSITION 5.4.** *The supply chain can be coordinated by either adopting a two-part tariff contract, which follows the form of ($c_m + \theta b_i$,$\phi_i$) or establishing a vertical integration agreement.*

Considering the existence of double marginalization in the foregoing decentralized supply chains (Li et al. 2013), Proposition 5.4 advocates that a fixed credit transfer (i.e., a two-part tariff contract) or a vertical integration arrangement (e.g., VMI) is desirable to achieve an optimal supply chain. Results from Anderson et al. (2006), De Giovanni et al. (2019) and Hong and Guo (2019) all support this finding. Coordination and vertical integration are important tools for improving operational efficiency in supply chains. To be specific, with the help of the two-part tariff contract, the fashion retailers and the manufacturer can achieve channel coordination by changing the wholesale price and ensure a win-win outcome by carefully designing the fixed lump-sum fee in the contract. While for vertical integration, which is a common practice in the fashion industry, the conflicted interests among different supply chain members can also be solved since all supply chain members are controlled by one central decision maker.

# 6. Extended Model: Joint Competition on Product Greenness and Retail Prices

To ensure the robustness, we further extend our findings to the case of joint competition on product greenness and retail prices (see Figure 4). The market demand in (3.1) is extended as follows:

$q_i(b_i, b_{3-i}, p_i, p_{3-i}) = \alpha + b_i - \gamma b_{3-i} - p_i + y p_{3-i}$, s.t. $0 < \gamma < 1$, $0 < y < 1$, $i$=1, 2,

where $y$ is the positive sensitivity of product $i$'s market demand with respect to the retail price of the product offered by retailer *3-i*. This implies that when the rate of demand from the base value is higher, the retail price of the product provided by the opponent retailer *3-i* is higher. In addition, different pairs of $(\gamma, y)$ capture the different acceptance levels of consumers to substitute the retail price with the product greenness level.

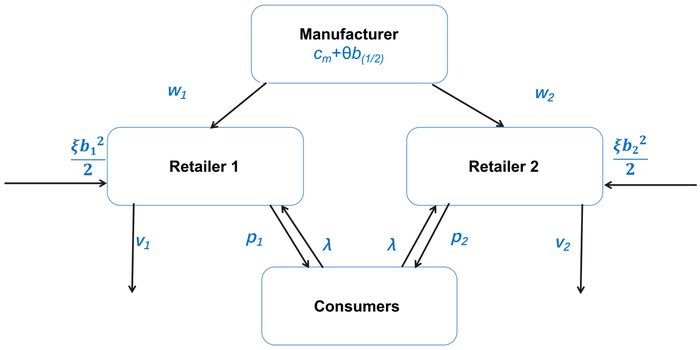


**Figure 4. Fashion Supply Chain with Joint Competition on Product Greenness and Price.**

Following operations research literature like Janssen and Non (2009), and Osadchiy and Vulcano (2010), we highlight the impact of retail price competition by assuming a binary retail pricing scenario (i.e., either $p_H$ or $p_L$) in this section. Both retailers 1 and 2 choose either a high retail price $p_H$ or a low retail price $p_L$ and maximize their own profits by making the optimal greenness level of their products under different retail price competition scenarios. This representation of retail prices ensures tractability and is a common abstraction of the reality in the retail market. For instance, given a specific brand position, the retail price of a fashion product is usually set within a certain price range, such as US$19.99[19] to US$39.99[20] for an organic cotton sweater at Mango. Correspondingly, in this paper, an organic cotton sweater selling at US$19.99 represents the case with a low retail price, and one selling at US$39.99 represents the case with a high retail price. Besides, since the prior literature like Pinçe et al. (2016) has shown that the consumer return rates are very consistent in real world retail businesses (i.e., follows the range of 8–12%), the consumer return rate remains as exogenous in this section. In the meantime, product quality and price are considered as the elements of a specific fashion brand, which are stable from the long term and will not affect the exogenous consumer return rate.

## 6.1 Case 1: One Single Retailer

We begin our discussion with the case of one single retailer, i.e., retailer 1 only. As shown in Figure 2 in Section 4.1, fashion retailer 1 charges a unit retail price $p_1$ for its own fashion product, and the market demand is: $q_1(b_1, p_1) = \alpha + b_1 - p_1$.

The fashion retailer can charge target consumers either a high retail price $p_H$ or a low retail price $p_L$. We investigate the scenarios one by one.

*(1) Scenario H: Scenario with a high retail price* $p_H$

[19] Refer to https://shop.mango.com/us/men/cardigans-and-sweaters-sweaters/organic-cotton-sweater_23055646.html?c=08&n=1&s=search (accessed on July 24, 2018).

[20] https://shop.mango.com/us/men/cardigans-and-sweaters-sweaters/flecked-cotton-blend-sweater_33081046.html?c=91&n=1&s=search (accessed on July 24, 2018).

When the fashion retailer charges $p_H$, the fashion retailer and manufacturer solve:

$$\max_{b_1} \pi_{r1}^H = [p_H - w_1 - \lambda p_H + (t + kb_1)\lambda] \cdot (\alpha + b_1 - p_H) - \frac{\xi b_1^2}{2},$$

$$\max_{w_1} \pi_m^H = (w_1 - c_m - \theta b_1) \cdot (\alpha + b_1 - p_H).$$

Under the condition $\xi > 2k\lambda$, the optimal product greenness level $b_1$ and wholesale price $w_1$ are:

$$b_1^{H*} = \frac{[1+D-(1+k)\lambda+\theta]p_H-(D-k\lambda+\theta)\alpha-t\lambda-c_m}{2(D+\theta)},$$ and

$$w_1^{H*} = \frac{[D(\xi-k\lambda)+\theta\xi]\alpha+[D(1+k\lambda-\lambda-\xi)+\theta(2-2\lambda-\xi)]p_H+(D+2\theta)t\lambda+Dc_m}{2(D+\theta)}.$$

*(2) Scenario L: Scenario with a low retail price* $p_L$

Similarly, when the fashion retailer charges $p_L$, the optimal product greenness level $b_1$ and the optimal wholesale price $w_1$ are:

$$b_1^{L*} = \frac{[1+D-(1+k)\lambda+\theta]p_L-(D-k\lambda+\theta)\alpha-t\lambda-c_m}{2(D+\theta)}$$ and

$$w_1^{L*} = \frac{[D(\xi-k\lambda)+\theta\xi]\alpha+[D(1+k\lambda-\lambda-\xi)+\theta(2-2\lambda-\xi)]p_L+(D+2\theta)t\lambda+Dc_m}{2(D+\theta)}.$$

*(3) Comparisons between Scenarios H and L*

We compare the two scenarios as follows.

**LEMMA 6.1** *In the case of one single retailer: i) the optimal product greenness level of retailer 1, (i.e.,* ${b_1}^*$*) is always higher in Scenario H than in Scenario L; and ii) if* $\lambda$ *is moderate, Scenario L is optimal to both retailer 1 and the upstream manufacturer.*

Lemma 6.1 indicates a crucially practical implication for the case without market competition: given the price sensitivity of consumers, a higher product greenness level is not always beneficial to supply chain members. Instead, the scenario with a low retail price $p_L$ (i.e., Scenario L) is optimal to both supply chain members when the consumer return rate is moderate. Lemma 6.1 reveals that the fashion retailer should balance their decisions about retail pricing and the product greenness level when consumers are sensitive to both.

## 6.2 Case 2: Two Competing Retailers

In this subsection, the fashion supply chain consists of two symmetric competing retailers (see Figure 4), under which retailers 1 and 2 offer either a high price equilibrium (both choose $p_H$) or a low price equilibrium (both choose $p_L$). A complete list of abbreviations is given in Table B2 (in Appendix B).

### 6.2.1 Retail Competition in Scenario I (High Price Equilibrium)

When both retailers 1 and 2 choose a high retail price $p_H$, the two retailers and their upstream manufacturer arrive at the following optimal solution:

$$\max_{b_1} \pi_{r1}^I = [p_H - w_1 - \lambda p_H + (t + kb_1)\lambda] \cdot (\alpha + b_1 - \gamma b_2 - p_H + yp_H) - \frac{\xi {b_1}^2}{2},$$

$$\max_{b_2} \pi_{r2}^I = [p_H - w_2 - \lambda p_H + (t + kb_2)\lambda] \cdot (\alpha + b_2 - \gamma b_1 - p_H + yp_H) - \frac{\xi {b_2}^2}{2},$$ and

$$\max_{w_1,w_2} \pi_m^I = (w_1 - c_m - \theta b_1) \cdot (\alpha + b_1 - \gamma b_2 - p_H + yp_H) + (w_2 - c_m - \theta b_2) \cdot (\alpha + b_2 - \gamma b_1 - p_H + yp_H).$$

Correspondingly, when $\xi > (2+\gamma)k\lambda$:

$$b_1{}^{I*} = b_2{}^{I*} = \frac{C[(1-\gamma)(1-\lambda-k\lambda+\gamma k\lambda)B+(1+\gamma)(B+\theta)C]p_H}{2(1-\gamma)BC(C+\theta)} - S, \text{ and}$$

$$w_1{}^{I*} = w_2{}^{I*} = \frac{[(1-\gamma)(C+2\theta)B(1-\lambda-k\lambda+\gamma k\lambda)-(1+\gamma)C^2(B+\theta)]p_H}{2(1-\gamma)(C+\theta)C} + R.$$

**6.2.2 Retail Competition in Scenario II (Low Price Equilibrium)**

Under Scenario II, both retailers 1 and 2 offer a low retail price $p_L$. Following the same logic in Section 6.2.1, the corresponding optimal solutions are as follows:

$$b_1{}^{II*} = b_2{}^{II*} = \frac{C[(1-\gamma)(1-\lambda-k\lambda+\gamma k\lambda)B+(1+\gamma)(B+\theta)C]p_L}{2(1-\gamma)BC(C+\theta)} - S, \text{ and}$$

$$w_1{}^{II*} = w_2{}^{II*} = \frac{[(1-\gamma)(C+2\theta)B(1-\lambda-k\lambda+\gamma k\lambda)-(1+\gamma)C^2(B+\theta)]p_L}{2(1-\gamma)(C+\theta)C} + R.$$

The optimal solutions of Scenarios I and II are summarized in Table B4 in Appendix B.

## 6.3 Discussions

**6.3.1 Equilibrium Structure of the Decentralized System**

In the following, analytical comparisons of the equilibrium results of Scenarios I and II are conducted. As retailers 1 and 2 are homogenous, only the results from retailer 1's side are shown.

**PROPOSITION 6.1.** *When* $0 < \lambda < \frac{1}{1+(1-\gamma)k}$*: i) the optimal product greenness level of retailer 1, (i.e.,* $b_1{}^{(j)*}$*, j=I, II) is always higher in Scenario I than in Scenario II; and ii) if* $\gamma$ *is moderate, Scenario I is optimal to both retailer 1 and the upstream manufacturer.*

Managerial insights for the case with market competition are revealed in Proposition 6.1. Proposition 6.1 shows that given the price sensitivity of consumers, when there are consumer returns in the segment market and the consumer return rate is not sufficiently high, all supply chain members can earn more profits from a higher product greenness level if the degree of product greenness competition is neither too weak nor too intensive. Otherwise, for instance, if the market is overly green-oriented, huge amount of green product development investment is needed. This inevitably induces the higher wholesale and retail prices, and consequently mitigates the positive impacts of a higher product greenness level on market demand. As a result, none of the supply chain members is better off under Scenario I. In fact, this partially explains why the optimal product greenness level can be negatively correlated with the level of product greenness competition $\gamma$ in all basic models. Proposition 6.1 therefore provides guidance on which proactive approaches fashion retailers should adopt in a segment market filled with consumers who are sensitive to both the product greenness level and retail prices.

**6.3.2 Equilibrium Structure of the Centralized System**

We proceed to analyze the optimal solutions from the perspective of the whole channel.

**PROPOSITION 6.2.** *For the whole fashion supply chain, when the target market is sensitive to both product greenness and price competition: i) the optimal greenness level for products 1 and 2, which is the same, is always higher in Scenario I than in Scenario II; and ii) if* $\frac{p_L-c_m}{p_L-t} < \lambda < \frac{(1-\gamma)-\theta(1-\gamma)}{(1-\gamma)-k(1-\gamma)}$*, then Scenario I is optimal.*

Proposition 6.2 reveals that when the competitive market is sensitive to both the product greenness level and retail prices, the centralized optimal product greenness level in the high retail price case is higher than that in the low retail price case. This is because with a higher retail price, the fashion supply chain can extract more profits and have a higher overall investment capacity (e.g., current assets) for green product development. Therefore, supply chain members are encouraged to adopt greener materials. This finding implies that fast fashion retailers such as Zara keep product greenness levels low but adopt vertical integration strategies. Besides, when the consumer returns rate is moderate (i.e., $\frac{p_L-c_m}{p_L-t}<\lambda<\frac{(1-\gamma)-\theta(1-y)}{(1-\gamma)-k(1-y)}$), Scenario I is optimal since the extra operations cost induced by consumer returns can be partially repaid by the enhanced salvage value of consumer returns (due to a higher product greenness level).

# 7. Comparisons and Insights: Numerical Analysis

We compare Case 1 (one single retailer) with Case 2 (two competing retailers) through numerical studies.

## 7.1 Optimal Profits for Supply Chain Members

Findings on the optimal profits for supply chain members under both the product greenness level and retail price competition are presented next (more details can be found in Table B5 in Appendix B).

**OBSERVATION 7.1.** *In a fashion market with two symmetric retailers competing over both the product greenness level and retail prices, the retailers and the manufacturer have different preferences, and win-win coordination mechanisms should be implemented.*

Observation 7.1 is reasonable. Regardless of consumers' different sensitivity to the product greenness level (i.e., the coefficient $\gamma$), retail prices (i.e., the coefficient $y$), and the product greenness investment at the retail level (i.e., the coefficient $\xi$), retailer 1's profit is highest in Scenario I and the manufacturer's profit is highest in Scenario II (see Table B5). This reveals the potentially different preferences between retailer 1 and the manufacturer in the decentralized supply chain. That is, considering the additional green product development investment at the retail level, retailer 1 always tends to charge a higher retail price, which is the most direct way to compensate the partial extra green product development investment in retail operations. However, market demand is reduced by the higher retail price, this may not be optimal for the manufacturer and the supply chain. As a result, using supply chain contracts like the two-part tariff contract discussed in Section 5.2 is preferable in all retail competition scenarios, which can help achieve a win-win outcome.

**Practitioners' post hoc critique of Observation 7.1:** *M1 verified the findings in Observation 7.1. He argued that although consumers like green products, they still refused to pay too much for green products (as when the costs of green fashion products were high, the retail price would also be high). No green consumption eventually hurts the collaborative relationship between retailer and manufacturer.*

## 7.2. Sensitivity Analysis

We now proceed to the numerical investigation (see more details in Online Supplementary Appendix A.2) on the impacts of consumer returns and retail competition games.

***(1) Influences of the price competition game***

**OBSERVATION 7.2.** *In both Scenarios I and II, i) The optimal product greenness level of the fashion products increases along with the level of price competition* $y$*. In addition, the optimal product greenness level in*

*Scenario I is always higher than that in Scenario II; ii) If the product greenness competition coefficient $\gamma$ is higher, the optimal product greenness level of the fashion products decreases.*

The findings in Observation 7.2 i) shows that an increased retail price is helpful in stimulating more green product development efforts at the retail level. Besides, Observation 7.2 ii) proves the robustness of our previous findings in the case with product greenness competition only (i.e., Section 5.1).

**Practitioners' post hoc critique of Observation 7.2:** *SC1 confirmed both the findings and explanations of Observation 7.2, and addressed that as the retail price consisted of both costs and profit margin, the retail price can definitely influence the retailer's capacity for increasing green product development efforts.*

***(2) Influence of consumer returns***

The influence of consumer returns is consistent with the case without price competition (i.e., the discussion in Section 5), which proves both the reliability of our findings in Section 5.2 and the ubiquitous significance of consumer returns management in all retail competition scenarios.

# 8. Conclusion

Motivated by the inconsistencies between the increasing environmental consciousness among customers and fashion companies, the low green product development effort level of fashion companies, and the research gap in the literature, we present analyses of a fashion supply chain consisting of one manufacturer and two fashion retailers who compete over the greenness level of their perishable products. This paper is the first to explore the product greenness competition game under a quantified product greenness level of a fashion product. Influences of retail competition and consumer returns are deeply investigated. By adopting the MMA, both the assumptions and findings in this paper are supported by real industrial practices with either public information (e.g., industry publications) or industrial interviews with managers from different fashion companies. Interestingly, we find that the optimal greenness level of a fashion product is negatively correlated with the level of product greenness competition and the consumer return rate in a green-oriented market in all base models. In the extended models (i.e., with both product greenness and price competition), the optimal product greenness level for the whole channel is always higher than in the case where both retailers charge a high retail price than the case of a low retail price.

The specific managerial and theoretical implications are discussed in the following together with real-world support (a summarized table is available in Table B6 in Appendix B), which provides new insights into the underexplored area of product greenness competition and explains why green product development effort levels remain low in the fashion industry. These counterintuitive and novel findings present in-depth managerial insights for industries and can also serve as references for future studies of the product greenness competition game in the fashion industry and other retail contexts.

## 8.1 Key Findings and Real-World Implications

### 8.1.1 Influences of Different Retail Competition Scenarios

**a)** ***Level of product greenness competition:*** Surprisingly, our analyses show that when the market is sensitive only to the product greenness level, the level of product greenness competition decreases the optimal product greenness level, in both the case with product greenness competition only, and the case with joint competition on product greenness and retail prices.

***Real-world support and implications***: When the target consumers are very green sensitive, superior green products can bring more profits only when the product greenness gap between those products and inferior green products is substantially high. As the costs of superior green products are extremely high, both competitors prefer a low product greenness level, that is, lowering the overall competition degree. In practice, as competing fashion companies may belong to one same group, these large groups can establish a co-opetition relationship with each other to lessen the huge burden of product greenness investment. To alleviate the substantial competition burden, competing brands (e.g., in the fast fashion segment) can also cooperate and jointly improve the green product development performance of the whole industry with a low overall greenness investment.

**b)** ***Level of price competition:*** In light of the retail price competition, the optimal product greenness level increases along with the level of price competition.

***Real-world support and implications***: With an increased retail price induced by price competition, fashion retailers can have a higher overall investment capacity (e.g., more available current assets). For example, when fast fashion brands such as H&M acquire more available capital for green product development investment, as other fashion brands do, it can offer extra incentives to its manufacturer and encourage it to use more green materials (refer to H&M's 2017 Sustainability Report). As a result, fashion retailers should improve their own overall capacity, which is influential in the product greenness competition game.

#### 8.1.2 Influences of Consumer Returns

Concerning the influences of consumer returns, our analysis demonstrates that when the salvage value of a consumer return is relatively low, any additional increase in the consumer return rate reduces the optimal product greenness level. In addition, when the salvage value of consumer-returned items increases, the optimal product greenness level also increases.

***Real-world support and implications***: Green fashion products offered by fast fashion companies usually have low heterogeneity levels and low retail prices (e.g., US$19.99 for three basic T-shirts at H&M). Such products are generally not likely to have a very high salvage value once they have been partially used and returned. As a result, any additional increase in the consumer return rate substantially reduces the final profits of these retailers. To avoid this kind of risk in retail operations, fashion retailers such as H&M and Mango should not only enhance their capability of reducing their consumer return rate (e.g., through store assistants), but also increase the salvage value from these returned items (e.g., recycle them into new textile fibers).

## 8.2 Limitations and Future Research

While our model captures the essential elements of the product greenness competition game in the retail market, other aspects should be considered in the future. First, we restrict our attention to the forward product development process while the reverse channel of consumer returns is not explored. In the future, we may consider the case when each consumer return is a waste and investigate the retailers' tradeoff between increasing the market demand by raising the product greenness level and bearing the induced larger number of consumer returns. Second, we examine supply chain operations with symmetric information. However, in practice, fashion companies may not obtain all the related information. Therefore, it will be interesting to explore the product greenness competition game in an information asymmetric situation and uncover the value of information sharing (Teunter et al. 2018). Third, this paper focuses on the product greenness competition game at the retail level. In practice, various powerful manufacturers have direct channels to consumers; thus, supplier encroachment issues in product greenness deserve further research.

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# Appendix A – Technical Proofs

**Proof of Proposition 5.4.** For Case 1, the optimization function of the whole channel is:

$\max\limits_{b_1} \pi_{SC}^{G1} = [p - c_m - \theta b_1 - \lambda p + (t + kb_1)\lambda] \cdot (\alpha + b_1) - \frac{\xi b_1^2}{2}.$

Correspondingly, it can be found that the optimal solution for the whole channel is: $b_1^{(G1)T*} = \frac{A - c_m - \theta\alpha}{D + 2\theta}$.

Therefore, the whole channel can achieve win-win coordination under the term of $(w_1^{(G1)T*}, \phi_1^{G1})$, where: $w_1^{(G1)T*} = c_m + \theta b_1^{(G1)T*} = c_m + \theta \frac{A - c_m - \theta\alpha}{D + 2\theta}$, $\underline{\phi_1^{G1}} < \phi_1^{G1} < \overline{\phi_1^{G1}}$, and $\overline{\phi_1^{G1}} = \pi_{r1}^{(G1)T}\left(b_1^{(G1)T*}, w_1^{(G1)T*}\right) - \pi_{r1}^{G1}\left(b_1^{G1*}, w_1^{G1*}\right) = [\tau + (\xi + \mu)\alpha]\left\{\frac{(\xi+\mu)\tau + \mu^2\alpha}{(D+2\theta)^2} - \frac{(\xi - k\lambda)\tau - [\xi(D+\theta) + k\lambda\mu]\alpha}{4(D+\theta)^2}\right\} - \frac{\xi}{2}\left\{\frac{(\tau - \mu\alpha)^2}{(D+2\theta)^2} - \frac{[\tau - (D+\theta)\alpha]^2}{4(D+\theta)^2}\right\}$,

$\underline{\phi_1^{G1}} = \pi_m^{(G1)T}\left(b_1^{(G1)T*}, w_1^{(G1)T*}\right) - \pi_m^{G1}\left(b_1^{G1*}, w_1^{G1*}\right) = \frac{[\tau + (\xi+\mu)\alpha]^2}{4(D+\theta)}.$

Then for Case 2, it is obvious that the optimization problem of the whole channel is:

$\max\limits_{b_1, b_2} \pi_{SC}^{G2} = [p - c_m - \theta b_1 - \lambda p + (t + kb_1)\lambda] \cdot (\alpha + b_1 - \gamma b_2) - \frac{\xi b_1^2}{2} + [p - c_m - \theta b_2 - \lambda p + (t +$

$kb_2)\lambda] \cdot (\alpha + b_2 - \gamma b_1) - \frac{\xi b_2^2}{2}$.

The Hessian Matrix $|\hat{H}| = \begin{vmatrix} \frac{d^2\pi_{SC}^{G2}}{db_1^2} & \frac{d^2\pi_{SC}^{G2}}{db_1 b_2} \\ \frac{d^2\pi_{SC}^{G2}}{db_2 b_1} & \frac{d^2\pi_{SC}^{G2}}{db_2^2} \end{vmatrix} = \begin{vmatrix} -(2\mu+\xi) & 2\gamma\mu \\ 2\gamma\mu & -(2\mu+\xi) \end{vmatrix}$ is negative definite. The whole channel therefore can achieve win-win coordination with $(w_i^{(G2)T*}, \phi_i^{G2})$, where: $w_i^{(G2)T*} = c_m + \theta b_i^{(G2)T*} = c_m + \theta \frac{(1-\gamma)\tau - \mu\alpha}{\xi + 2(1-\gamma)\mu}$, $\underline{\phi_i^{G2}} < \phi_i^{G2} < \overline{\phi_i^{G2}}$, and $\overline{\phi_i^{G2}} = \pi_{ri}^{(G2)T}\left(b_i^{(G2)T*}, b_{3-i}^{(G2)T*}, w_i^{(G2)T*}, w_{3-i}^{(G2)T*}\right) - \pi_{ri}^{G2}\left(b_i^{G2*}, b_{3-i}^{G2*}, w_i^{G2*}, w_{3-i}^{G2*}\right) = \Big\{\frac{\{[\xi+(1-\gamma)\mu]\tau+\mu^2\alpha\}\{(1-\gamma)^2\tau+[\xi+(1-\gamma)\mu]\alpha\}}{[\xi+2(1-\gamma)\mu]^2} - \frac{\{(1-\gamma)[\xi-(1-\gamma)k\lambda]\tau-[(C+\theta)\xi+(1-\gamma)k\lambda\mu]\alpha\}[(1-\gamma)^2\tau+(1-\gamma)(\xi+\mu)\alpha]}{[2(1-\gamma)(C+\theta)]^2}\Big\} - \frac{\xi}{2}\Big\{\frac{[(1-\gamma)\tau-\mu\alpha]^2}{[\xi+2(1-\gamma)\mu]^2} - \frac{\{(1-\gamma)\tau-[C+\theta-(1-\gamma)k\lambda]\alpha\}^2}{[2(1-\gamma)(C+\theta)]^2}\Big\}$,

$\underline{\phi_i^{G2}} = \pi_m^{(G2)T}\left(b_i^{(G2)T*}, b_{3-i}^{(G2)T*}, w_i^{(G2)T*}, w_{3-i}^{(G2)T*}\right) - \pi_m^{G2}\left(b_i^{G2*}, b_{3-i}^{G2*}, w_i^{G2*}, w_{3-i}^{G2*}\right) = \frac{[(1-\gamma)\tau+(\xi+\mu)\alpha]^2}{4(1-\gamma)(C+\theta)}$, $i$=1, 2.

Similarly, for Case 3, the whole channel can achieve win-win coordination by setting $w_i^{(G3)T*} = c_m + \theta b_i^{(G3)T*} = c_m + \theta \frac{[\xi-\gamma^2\mu_i+(2-\gamma^2)\mu_{3-i}]\tau_i-\gamma(\xi-\mu_i+\mu_{3-i})\tau_{3-i}-[\mu_i\xi+(2+\gamma)\mu_i\mu_{3-i}+\gamma^2\mu_{3-i}]\alpha}{(\xi+2\mu_i)(\xi+2\mu_{3-i})-\gamma^2(\mu_i+\mu_{3-i})^2}$, and $\underline{\phi_i^{G3}} < \phi_i^{G3} < \overline{\phi_i^{G3}}$, where $\overline{\phi_i^{G3}} = \pi_{ri}^{(G3)T}\left(b_i^{(G3)T*}, b_{3-i}^{(G3)T*}, w_i^{(G3)T*}, w_{3-i}^{(G3)T*}\right) - \pi_{ri}^{G3}\left(b_i^{G3*}, b_{3-i}^{G3*}, w_i^{G3*}, w_{3-i}^{G3*}\right) > 0$ and $\underline{\phi_i^{G3}} + \underline{\phi_i^{G3}} = \pi_m^{(G3)T}\left(b_i^{(G3)T*}, b_{3-i}^{(G3)T*}, w_i^{(G3)T*}, w_{3-i}^{(G3)T*}\right) - \pi_m^{G3}\left(b_i^{G3*}, b_{3-i}^{G3*}, w_i^{G3*}, w_{3-i}^{G3*}\right) > 0$. (Q.E.D.)

**Proof of Lemma 6.1:** Lemma 6.1 i) is intuitive because as can be observed from the comparisons between ${b_1}^{H*}$ and ${b_1}^{L*}$, if $0 < \lambda < \frac{1+\theta+\xi}{1-k}$, then ${b_1}^{H*} > {b_1}^{L*}$ always holds since $\lambda$ must satisfy $0 < \lambda < 1$.

Lemma 6.1 ii) can be proved by comparing the optimal profits of retailer 1 and the manufacturer under these two scenarios, it can be found that: If $max(\frac{\xi-k(1-\theta)+4\theta}{k(1-k)}, \frac{1-\xi-\theta}{1-k}) < \lambda < min(\frac{\xi(1+\xi)+\theta(4-\xi)}{2k(1+\xi)}, 1)$, then $\pi_{r1}^{L*} > \pi_{r1}^{H*}$; and $\pi_m^{L*} > \pi_m^{H*}$ if $\lambda\, max(\frac{1-\xi}{1-k}, \frac{1-2\xi-\theta}{1-3k})$.

**Proof of Proposition 6.2:** Proposition 6.2 i) is intuitive because if $0 < \lambda < \frac{1}{1+(1-y)k}$, then ${b_1}^{I*} > {b_1}^{II*}$ always holds since $\gamma$ must satisfy $0 < \gamma < 1$.

Proposition 6.2 ii) can be proved by comparing the optimal profits of retailer 1 and the manufacturer under Scenario I with Scenario II, it can be found that: If $0 < \lambda < \frac{1}{1+(1-y)k}$, then $\pi_{r1}^{I*} > \pi_{r1}^{II*}$ if $\gamma < 1 - \frac{L}{(1-\lambda-k\lambda+yk\lambda)B}$, $\gamma > 1 - \frac{N}{1-\lambda-k\lambda+yk\lambda}$ and $\gamma > 1 - \frac{P}{1-\lambda-k\lambda+yk\lambda}$; $\pi_m^{I*} > \pi_m^{II*}$ if $\gamma < 1 - \frac{M}{(1-\lambda-k\lambda+yk\lambda)B}$ and $\gamma < 1 - \frac{L}{(1-\lambda-k\lambda+yk\lambda)B}$. (Q.E.D.)

# Appendix B - Supplementary Tables

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

| Literature | Consumer returns | Greenness | Salvage value | Competition game | Greenness competition |
|---|---|---|---|---|---|
| Allon and Federgruen (2009) | × | × | × | ✓ | × |
| Buell et al. (2016) | × | × | × | ✓ | × |
| Cachon and Swinney (2011) | × | × | ✓ | × | × |
| Donohue (2000) | × | × | ✓ | × | × |
| Galbreth and Ghosh (2012) | × | ✓ | × | ✓ | ✓ |
| Kogan and Chernonog (2019) | × | × | × | ✓ | × |
| Liu et al. (2012) | × | ✓ | × | ✓ | ✓ |
| Murali et al. (2018) | × | ✓ | × | ✓ | ✓ |
| Phadnis and Fine (2017) | ✓ | × | ✓ | × | × |
| Rao et al., (2018) | ✓ | × | × | ✓ | × |
| Savaskan and Van Wassenhove (2006) | ✓ | × | × | ✓ | × |
| Shang et al., (2017) | ✓ | × | ✓ | × | × |
| Shulman et al., (2011) | ✓ | × | × | ✓ | × |
| Swinney (2011) | ✓ | × | × | × | × |
| Su (2009) | ✓ | × | ✓ | × | × |
| This paper | ✓ | ✓ | ✓ | ✓ | ✓ |

**Table B2. All abbreviations.**

| | |
|---|---|
| $A = (1-\lambda)p + t\lambda + k\lambda\alpha$ | $B = \xi - (2+\gamma)k\lambda$ |
| $C = \xi - (2-\gamma)k\lambda$ | $D_{(i)} = \xi - 2k\lambda_{(i)}$ |
| $E_i = \xi - (2-\gamma^2)k\lambda_i$ | $F_i = (\xi - 2k\lambda_{3-i})\lambda_i - \gamma k\lambda_i\lambda_{3-i}$ |
| $H_i = (4X_iX_{3-i} - \gamma^2U^2)F_i - \varpi_i\varepsilon_{3-i} - \gamma\varrho_{3-i}\varepsilon_i$ | $I_i = \gamma\varrho_{3-i}(Z+\theta B_i) + \varpi_i(Z+\theta B_{3-i})$ |
| $J_i = (2X_i\varepsilon_{3-i} + \gamma U\varepsilon_i)$ | $K_i = 2X_i(Z+\theta B_{3-i}) + \gamma U(Z+\theta B_i)$ |
| $L = 2B(C+\theta)(1+y) - (1+y)(B+\theta)C$ | $M = \dfrac{(1+y)(B+\theta)^2C^2}{B^2C + B\theta(B-2\gamma k\lambda)}$ |
| $N = \dfrac{(1+y)(B+\theta)C^2}{B(C+2\theta)}$ | $P = \dfrac{4BS(1-\gamma)(C+\theta) - C(1+y)(B+\theta)(p_H+p_L)}{p_H+p_L}$ |
| $O_i = D_i - \gamma k\lambda_{3-i} - F_{3-i}$ | $Q_i = Z + 2\theta E_i$ |
| $R = \{(1+\gamma)B^2C^2(B+\theta)[(1-\gamma)C\cdot c_m + (C+\theta)C\alpha + (1-\gamma)(C+2\theta)t\lambda]\}/N$ | |
| $S = \{(1+\gamma)(B+\theta)B^3C^2[(1-\gamma)C\cdot c_m + (C+\theta)C\alpha + (1-\gamma)(3C+4\theta)t\lambda]\}/(NBC)$ | |
| $T_i = Z + 2\theta(\xi - k\lambda_i)$ | $U = (Z+\theta D_2)(\xi-k\lambda_1) + (Z+\theta D_1)(\xi-k\lambda_2) + \theta k\lambda_2E_1 + \theta k\lambda_1E_2$ |
| $X_i = (Z+\theta D_i)E_i + \theta\gamma^2k\lambda_i(\xi-k\lambda_i)$ | $Y_i = (2Q_{3-i}X_i - \gamma^2UT_i)O_{3-i} - \gamma(2T_{3-i}X_i - UQ_i)O_i$ |
| $Z = D_1D_2 - \gamma^2k^2\lambda_1\lambda_2$ | $\varepsilon_i = Q_iF_{3-i} - \gamma T_iF_i$ |
| $\varrho_i = D_iU - 2k\lambda_{3-i}X_i$ | $\varpi_i = 2D_iX_i - \gamma^2k\lambda_iU$ |
| $\eta_i = [4X_iX_{3-i} - \gamma^2U^2 - D_{3-i}(2Q_{3-i}X_i - \gamma^2UT_i) - \gamma^2k\lambda_i(2T_iX_{3-i} - UQ_{3-i})]O_{3-i} + \gamma[D_{3-i}(2T_{3-i}X_i - UQ_i) + k\lambda_i(2Q_iX_{3-i} - \gamma^2UT_{3-i})]O_i$ | |
| $\tau_{(i)} = (1-\lambda_{(i)})p + t\lambda_{(i)} - c_m$ | $\mu_{(i)} = \theta - k\lambda_{(i)}$ |
| $t_w^{G1} = \dfrac{(p-k\alpha)(D^2+3\theta D+2\theta^2) - 2k\alpha D(\theta+D-2) + 2k\theta(\alpha+c_m-A)}{D^2+3\theta D+2\theta^2}$ | $t_w^{G2} = \dfrac{(1-\gamma)(C^2+3\theta C+2\theta^2)p + k\alpha\{\theta[2C-(1-\gamma)\xi+\gamma\theta] + C^2\} + \theta k\,(1-\gamma)(2-\gamma)c_m}{(1-\gamma)[\theta(\xi+2C+2\theta)+C^2]}$ |
| $t_b^{G1} = \dfrac{(\xi+\theta)(p-k\alpha) - 2k(p-c_m)}{\xi+\theta}$ | $t_b^{G2} = \dfrac{(\xi+\theta)(p-k\alpha) - k(2-\gamma)(p-c_m)}{\xi+\theta}$ |

### Table B3. The first order derivatives of Case 1 and Case 2 in Section 4.

| **Cases** | **Case 1: One Single Retailer** | **Case 2: Two homologous retailers** |
|---|---|---|
| ${w_{(i)}}^*$ | $\frac{d{w_1}^{G1*}}{d\lambda}=\frac{2k\theta A-(p-t-k\alpha)(D+2\theta)(D+\theta)-2k\theta c_m+[D(D+\theta-2)-\theta]2k\alpha}{2(D+\theta)^2}$, | $\frac{d{w_1}^{G2*}}{d\lambda}=\frac{d{w_2}^{G2*}}{d\lambda}=$ $\frac{-\{(2-\gamma)k\alpha(C+\theta)^2-k\theta(2-\gamma)(1-\gamma)(p-c_m)+(1-\gamma)(p-t-k\alpha)[C^2+3\xi\theta-2(2-\gamma)k\lambda\theta+2\theta^2]\}}{2(1-\gamma)(C+\theta)^2}$; |
| | $\frac{d{w_1}^{G1*}}{d\theta}=\frac{(A-c_m)(\xi-2k\lambda)}{2(\xi-2k\lambda+\theta)^2}$; | $\frac{d{w_1}^{G2*}}{d\theta}=\frac{d{w_2}^{G2*}}{d\theta}=\frac{C(A-c_m)}{2(C+\theta)^2}$; |
| ${b_{(i)}}^*$ | $\frac{d{b_1}^{G1*}}{d\lambda}=\frac{2k(A-c_m)-(p-t-k\alpha)(\xi-2k\lambda+\theta)}{2(\xi-2k\lambda+\theta)^2}$; | $\frac{d{b_1}^{G2*}}{d\lambda}=\frac{d{b_2}^{G2*}}{d\lambda}=\frac{(2-\gamma)k(p-c_m)-(p-t-k\alpha)(\xi+\theta)}{2(C+\theta)^2}$; |
| | $\frac{d{b_1}^{G1*}}{dt}=\frac{\lambda}{2(\xi-2k\lambda+\theta)}$;) | $\frac{d{b_1}^{G2*}}{dt}=\frac{d{b_2}^{G2*}}{dt}=\frac{\lambda}{2(C+\theta)}$; |
| | $\frac{d{b_1}^{G1*}}{dk}=\frac{2\lambda(A-c_m)+\lambda\alpha(\xi-2k\lambda+\theta)}{2(\xi-2k\lambda+\theta)}$; | $\frac{d{b_1}^{G2*}}{dk}=\frac{d{b_2}^{G2*}}{dk}=\frac{\lambda(2-\gamma)[(1-\lambda)p+t\lambda-c_m]+(\xi+\theta)\lambda\alpha}{2(C+\theta)^2}$; |
| | $\frac{d{b_1}^{G1*}}{d\xi}=\frac{-(A-c_m)}{2(\xi-2k\lambda+\theta)^2}$; | $\frac{d{b_1}^{G2*}}{d\xi}=\frac{d{b_2}^{G2*}}{d\xi}=\frac{-(A-c_m)}{2(C+\theta)^2}$; |
| | *Nil* | $\frac{d{b_1}^{G2*}}{d\gamma}=\frac{d{b_2}^{G2*}}{d\gamma}=\frac{-(1-\gamma)^2k\lambda(A-c_m)-(C+\theta)^2\alpha}{2(1-\gamma)^2(C+\theta)^2}$; |

### Table B4. Optimal solutions in Section 5[21].

| **Scenarios** | ${w_1}^{(j)*}$ | ${b_1}^{(j)*}$ |
|---|---|---|
| ***Scenario I:*** Both retailer 1 and retailer 2 choose $p_H$ | ${w_1}^{I*}=\frac{[(1-\gamma)(C+2\theta)B(1-\lambda-k\lambda+yk\lambda)-(1+y)C^2(B+\theta)]p_H}{2(1-\gamma)(C+\theta)C}+R$; | ${b_1}^{I*}=\frac{C[(1-\gamma)(1-\lambda-k\lambda+yk\lambda)B+(1+y)(B+\theta)C]p_H}{2(1-\gamma)BC(C+\theta)}-S$; |
| ***Scenario II:*** Both retailer 1 and retailer 2 choose $p_L$ | ${w_1}^{II*}=\frac{[(1-\gamma)(C+2\theta)B(1-\lambda-k\lambda+yk\lambda)-(1+y)C^2(B+\theta)]p_L}{2(1-\gamma)(C+\theta)C}+R$; | ${b_1}^{II*}=\frac{C[(1-\gamma)(1-\lambda-k\lambda+yk\lambda)B+(1+y)(B+\theta)C]p_L}{2(1-\gamma)BC(C+\theta)}-S$; |

### Table B5. Comparisons between Different Competition Scenarios Under Case 2
**(Note:** "$*$" means the scenario is "optimal"; "$-$" means the scenario is "not optimal".)

| **Situation** | | **Optimal profit of fashion retailer 1** | | **Optimal profit of the manufacturer** | |
|---|---|---|---|---|---|
| | | **Scenario I** $p_H : p_H$ | **Scenario II** $p_L : p_L$ | **Scenario I** $p_H : p_H$ | **Scenario II** $p_L : p_L$ |
| $\gamma > y$ | $\xi$ **is sufficiently large** | $*$ | $-$ | $-$ | $*$ |
| | $\xi$ **is relatively small** | $*$ | $-$ | $-$ | $*$ |
| $\gamma < y$ | $\xi$ **is sufficiently large** | $*$ | $-$ | $-$ | $*$ |
| | $\xi$ **is relatively small** | $*$ | $-$ | $-$ | $*$ |
| $\gamma = y$ | $\xi$ **is sufficiently large** | $*$ | $-$ | $-$ | $*$ |
| | $\xi$ **is relatively small** | $*$ | $-$ | $-$ | $*$ |

[21] Notice that *j*=*I*, *II*.

## Table B6. Key findings and real world implications.

| Research Questions | Findings | Real World Support | Real World Implications |
|---|---|---|---|
| 1. What is the influence of different retail competition games on green product development among various fashion companies? | a) The optimal product greenness level is negatively correlated to the level of product greenness competition in both the case with product greenness competition only and the case with joint competition on product greenness and retail prices. | It is rational since when the target consumers are very green sensitive, superior green products can bring more profits only when the product greenness gap with the inferior green ones is substantially high, the costs of which are extremely high. As a result, both competitors will prefer a low product greenness level so as to lower the overall competition degree. | In practice, different competing fashion companies sometimes can be a member of a same organization. For instance, as can be observed from the official website of Textile Exchange[22], which emphasizes green product development of the textile industry, fashion brands like H&M, M&S, and Inditex are all its members. These companies therefore can establish a co-opetition relationship with each other within this organization so as to lessen the huge burden of green product development investment and improve the product greenness performance of the whole industry. |
| | b) The optimal product greenness level increases with the raise in the level of price competition. | With an increased retail price, the fashion retailers can have a higher overall investment capacity (e.g., more available current assets). For example, when fast fashion brands like H&M can have more available capital for green product development as other fashion brands, it can then offer extra incentives to its suppliers so as to encourage them to use more green materials, which is in fact one of H&M's sustainable strategies as stated in its 2017 Sustainability Report. | The green product development process is capital intensive, and fashion retailers who are engaged in the product greenness competition game are suggested to improve their overall capital for green operations, including the available cash and cash equivalent as well as other current assets. |
| | c) The optimal product greenness level in Scenario I (i.e., both retailer 1 and retailer 2 choose $p_H$) is always the higher than Scenario II (i.e., both retailer 1 and retailer 2 choose $p_L$). | | |
| 2. What is the influence of consumer returns? | a) When the salvage value of a consumer return is relatively low, any additional increase in the consumer return rate reduces the optimal product greenness level. | Green fashion products offered by fast fashion companies usually have low heterogeneity levels and low retail prices (e.g., US$19.99 for three basic T-shirts at H&M). Such products are generally not likely to have a very high salvage value once they have been partially used and returned. As a result, any additional increase in the consumer return rate substantially reduces the final profits of these retailers. | Fashion retailers such as H&M and Mango should not only enhance their capability of reducing their consumer returns rate (e.g., through store assistants), but also increase the salvage value from these returned items (e.g., recycle them into new textile fibers). |
| | b) When the salvage value of consumer-returned items increases, the optimal product greenness level also increases. | | |

[22] Refer to http://textileexchange.org/members/. (Accessed on March 30, 2018)