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IMPACTS OF HETEROGENEOUS ENVIRONMENT AWARENESS AND POWER STRUCTURE ON GREEN SUPPLY CHAIN

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Abstract. In this study, we employ a game-theory-based framework to model power structure and consumers' heterogeneity toward the environmental level of products in a green supply chain and examine how consumer's heterogeneity and power structure affect green product development and the performance of green supply chain. The key findings indicate that it can be optimal for the retailer to charge a higher selling price in the integrated supply chain, which is contrast to previous finding in the literature. Importantly, we identify a condition where there is no power conflict in the green supply chain, which indicates that the manufacturer is willing to drop its power while the retailer is willing to possess power resulting in a "power equilibrium". Also, heterogeneous environment awareness of consumer considerably affect the value of channel integration. Overlooking heterogeneous responses would result in either undercutting or overestimating the benefit from channel integration.

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1. Introduction

Consumers would be asking more questions about the products they are going to purchase with the public awareness of environmental issues becoming soaring. The questions that how green their manufacturing processes and supply chain are, how big their carbon footprint is, and how they recycle the product will have to be expected by companies. Consumers' awareness in environment has been seen as a plus, and some companies are able to convert consumers' awareness in products green into increased profits. It is shown by many companies that there is a proof of the link between improved environmental performance of the products and financial gains. A number of companies have scanned their supply chain to find areas where improvements in the way they operate can bring profits. For instance, through establishing a reusable container program with their suppliers, General Motors (GM) reduced disposal costs by 12 million. GM, perhaps, may have been less interested in green issues, but GM found that the cost reductions they identified complemented the company's commitment to the environment in an attempt to make their supply chain more greener [21]. Through constructing a green supply chain, from purchasing, planning to shipping and distributing their final products, companies can find that implementing green policies are often identified as a benefit.

Keywords and phrases: Green supply chain, heterogeneous environment awareness, power structure, game theory.

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Green supply chain, which addresses environmental issues by product design and innovation, has been received lots of attention from consumers, industries, and governments around the word. The demand-pull of consumers with new attitudes toward environmental values stimulates green product development in the green supply chain [27]. In the market, consumers may show different response to the environmental attitude of product. Simmons Market Research Bureau [23] has proposed to segment consumers according to their environmental awareness. A survey conducted by the Gallup International Institute (1992) indicates that 65% of Americans, 59% of Germans, and 31% Japanese express their willingness to pay a green premium on an eco-safe product. According to the report by Wang [32], about 60 percent of Chinese want the government to give priority to environmental protection when boosting economic growth. All these dates demonstrate that consumers may show heterogeneous response to the environmental level of the product.

In addition, from the standpoint of green supply chain, the green supply chain may have different power structure. To our best knowledge, most of the studies in the subject of green supply chain have assumed a dominant manufacturer, *i.e.*, the manufacturer as the leader and the retailer as the follower, such as Zhu and He [39] and Dai *et al.* [4]. However, in the past two decades, powerful retailers such as Wal-Mart and Tesco have emerged. With their powerful position in the supply chain, these powerful retailers can impel the supply chain to change and influence supply chain performance. For example, Wal-Mart and Tesco have the leverage to insist that their suppliers reduce carbon emission levels in production and transportation [22]. The emergence of power retailers motivates that the rise of power retailers has generated a significant amount of debate concerning its impacts on the performance of supply chain members [26]. However, the leader in the supply chain is able to rely on its dominant position to reap more profit than the follower. This means that no supply chain members desirably drop its power to be a follower in the supply chain. There usually exist power conflict in the supply chain.

Although green supply chain has drawn lots of attention in literature, unfortunately, there has been lack of analytical study to examine the impact of consumer heterogeneity toward the environmental level of products and power structure on green product development and the performance of green supply chain. In view of this gap, this work try to answer the following questions: (i) How does power structure and consumer heterogeneity toward the environmental level affect pricing and environmental level decisions in the green supply chain? (ii) How does consumer heterogeneity toward the environmental level and power structure affect the performance of supply chain members and supply chain efficiency? (iii) Does there exist a condition under which the green supply chain has no power conflict?

To answer these research questions, a game-theoretic approach is employed. Taking into account both the consumer heterogeneity toward the environmental level of products and power structure in the green supply chain, managerial implications and insights are discussed to corporate executives for making decisions related to green product and green supply chain design on the basis of the analytical results. The main results are as follows. First, our result indicates that the integrated green supply chain can lead to a higher selling price, which is in contrast to previous findings in the literature. Second, we find that there exists a condition under which there is no power conflict in the green supply chain. Specifically, manufacturer desirably prefer to be the follower than to be the leader of the green supply chain, which means that the manufacturer is willing to drop its power while the retailer is willing to possess power resulting in a "power equilibrium" in the green supply chain. Third, we also find that accounting for different consumer heterogeneity across segments when we make pricing and the environmental quality decisions in the green channel is essential. Overlooking such heterogeneity would result in either undercutting or overestimating the benefit from channel integration, and an inaccurate adjustment of pricing and the environmental quality strategies.

The remainder of this paper is organized as follows. In Section 2, we review the existing literature related to this study. In Sections 3 and 4, we explain the game theoretic models; In Section 5, we make analysis on the channels strategies and performance. Section 6 analyzes the effect of consumer heterogeneity toward the environmental quality. The conclusion is provided in Section 7.

2. Literature review

Literature related to this study mainly exists in two areas: green supply chain and supply chain power structure. A growing body of literature has paid attention to the issue of green supply chain. Klassen and Vachon [15] show that supply chain collaboration may improve the environmental technology investment. At both tactical and strategic levels, Vachon and Klassen [31] discuss the green supply chain integration. Metta and Badurdeen [20] and Tseng *et al.* [30] present different green supply chain evaluation frameworks. Liu *et al.* [19] present a channel coordination model to reach the equilibrium condition applying a game theory approach in a hybrid-product (traditional and green product) supply chain when demand is a function of consumer environmental awareness. Jacobs and Subramanian [14] apply a two-echelon model consisting of a supplier and a manufacturer to determine the impacts of product collection and recycling mandates on the incentive to recycle and resulting profits in the integrated and decentralized supply chains. Ghosh and Shah [7] use a two-part tariff contract to coordinate a channel in which the demand is a function of price, environmental quality, and consumer environmental awareness. Swami and Shah [29] study the problem of coordination of a manufacturer and a retailer in a vertical supply chain, who put in efforts for greening their operations. Zhang and Liu [37] focus on the pricing decisions in the green supply chain and show that channel coordination can be achieved in a three-level green supply chain by applying a revenue sharing contract. In Zhang *et al.* [38], consumer environmental awareness is assumed to be a stochastic variable as the coefficient of green quality, and a return policy is applied in a two-stage green supply chain with two substitutable products (traditional and green product) where the product demand is a function of price and green quality. Ghosh and Shah [8] give a cost-sharing contract to initiate the manufacturer to improve the greening level of product, but the proposed mechanism is not capable to reach the centralized case. Li *et al.* [18] apply a two-part tariff contract to coordinate a competitive dual channel green supply chain where the market demand is a deterministic function of product price and greenness level. Zhu and He [39] investigate the green product design in supply chains under competition. Basiri and Heydari [1] consider a green supply chain which sells a non-green traditional product and also plans for releasing a new substitutable green product beside the current traditional product, and investigate the green channel coordination issue. Although green supply chain has gained lots of attention in literature, investigations of the heterogeneity of consumer environmental awareness and different power structure in the context of green supply chain have not sufficient attention. In view of this gap, this study investigates the impact of consumer heterogeneity toward the environmental level of products and power structure on green product development and the performance of green supply chain.

In the context of power structure in supply chain, Shaffer [24] investigates how to maximize profit of channel when multi product retailers can bargain bilaterally with manufacturers. Iyer and Villas-Boas [11] measure the effect of the bargaining relationship between a manufacturer and a retailer on channel coordination. Gu and Chen [9] investigate the effect of bargaining power on the incentive of information sharing between supply chain members. Dukes *et al.* [5] show that manufacturers' profits may increase when a retailer gains an exogenous cost advantage over its rival retailer with taking into account the competition among retailers. Inderst and Wey [13] investigate the effect of a retailer's increasing bargaining power on the upstream supplier's incentives to engage in product or process innovation, while Inderst and Shaffer [12] focus on how it affects the supplier's product differentiation. Shi *et al.* [26] use a game-theory-based framework to model power in a supply chain with random and price dependent demand and examine how power structure and demand models (expected demand and demand shock) affect supply chain members' performance. Xue *et al.* [34] study channel structures with a dominant manufacturer, a dominant retailer, and no single-agent dominance to understand how different power schemes affect the supply chain partners performance and consumer surplus. With capturing the heterogeneity of consumer environmental awareness, this paper provides a framework to understand how power structure affects the performance and decisions in green supply chain, which contributes to the growing body of research on the power structure.

3. Model formulation

We consider a green supply chain which consists of a manufacturer and a retailer. The manufacturer produces a green product and sells the product to the retailer at a wholesale price w. The retailer decides the selling price p to sell the product to consumers. The manufacturer also controls the environmental quality level of the product denoted by q with a cost $c(q)$. The environmental quality level can be explained as "degree of greenness" or "green index" [39]. Without loss of generality, it is assumed that the cost $c(q)$ takes a quadratic function of the environmental quality level q, *i.e.*, $c(q) = \frac{k}{2}q^2$, where $k > 0$ implies the increasing marginal costs of quality improvement. Such quadratic function reflecting the decreasing returns to scale is popular in the literature, *e.g.*, Chen [3], Shi *et al.* [25], Zhang *et al.* [38] and Dai *et al.* [4].

Following Xu *et al.* [33] and Yu *et al.* [36], we assume that each consumer in the market consumes one unit of the product as long as his/her utility surplus is positive. Let v denote consumers' common reservation value, which represents consumers willingness to pay for the product [17]. In the market, consumers may show heterogeneous response to the environmental quality level. In order to capture heterogeneous response to the environmental quality level in the consumers' utility function, it is assumed that there are two market segments: a high valuation segment and a low valuation segment. Consumers belong to either a high valuation segment or a low valuation segment, which differ in their valuation for the environmental quality level. Let h and l index the high valuation and the low valuation market segment, respectively. A fraction α $(0 < \alpha < 1)$ of consumers in segment h has a marginal valuation θ_h for per unit environmental quality while the remaining fraction $1 - \alpha$ in segment l has a marginal valuation θ_l for per unit environmental quality with $\theta_h > \theta_l > 0$. To simplify the notation, let $A = \alpha(\theta_h - \theta_l) + \theta_l$.

According to the Hotelling model [10], we suppose that consumers in each segment are uniformly distributed on $[0, 1]$. Without loss of generality, it is assumed that the market size is normalized to 1. For a consumer belonging to the segment s $(s = h, l)$, a disutility cost is incurred when each consumer deviates from his/her ideal product that is located at point zero. Let t denote the disutility cost. To ensure positive equilibrium strategies and profits, an assumption is proposed such that $kt > \frac{A^2}{2}$. A consumer in each segment is located at distance $x \in [0, 1]$ from his/her ideal point, is charged at a selling price p for the product and his/her utility function U_s is given by

$$U_h = v + \theta_h q - tx - p,$$
$$U_l = v + \theta_l q - tx - p.$$

Consumers who has no purchase incur zero utility. For the consumes belonging to the segment s $(s = h, l)$, they are indifferent between consume the product and buying nothing if only if $U_s = 0$, which then derives

$$x_h = \frac{v + \theta_h q - p}{t}, \tag{3.1}$$

$$x_l = \frac{v + \theta_l q - p}{t}. \tag{3.2}$$

where the consumers' location x_s $(s = h, l)$ represents the penetration rate of the product in each segment. The total demand D for the product can be then given by

$$D = \alpha x_h + (1 - \alpha)x_l.$$

In order to investigate the effect of heterogeneous consumers and different power structure on supply chain performance, four different structures are defined in the supply chain. According to El-Ansary and Stern [6], the power of a supply chain member is expressed by its ability to control the decision variables of another member at a different level. In this study, we follow this definition. The different decisions sequences determined by the manufacturer and the retailer represents the power structure. Particularly, an integrated supply chain is employed to model both channel members agree to cooperate and maximize the profits of the whole system. Manufacturer and retailer Stackelberg games are employed to model supply chains dominated by the manufacturer and retailer, respectively. And a Nash game is employed to model the supply chain in which a balanced power structure exists between the manufacturer and retailer.

Integrated supply chain (Model c). In this scenario, all decisions are centralized at one level of the channel.

Manufacturer Stackelberg (Model m). In this scenario, as the Stackelberg leader, the manufacturer firstly sets the wholesale price and the environmental quality of the product. As the follower, after receiving the wholesale price and the environmental quality level, the retailer decides on the selling price.

Nash (Model n). In this scenario, the manufacturer and the retailer make decisions simultaneously.

Retailer Stackelberg (Model r). In this scenario, as the Stackelberg leader, the retailer firstly sets the selling price. As the follower, after receiving the selling price, the manufacturer firstly sets the wholesale price and the environmental quality level.

There are empirical studies and industry practices that can support the way we model power structure in the supply chain. Sudhir [28] applies empirical studies to indicate that a manufacturer Stackelberg game is a nice fit for some consumer product categories for which supply chains are dominated by manufacturers. The Nash game can model the strategic interaction between supply chain members among a number of product categories [2]. The retailer Stackelberg game can reflect the industry practice where some large retailers demand "guaranteed profit margins" from manufacturers [16].

4. Game analysis

In this section, the equilibriums of four models are characterized.

4.1. Integrated supply chain

Firstly, the integrated supply chain (Model c) is examined, in which the manufacturer and the retailer are integrated as one firm. In this case, the decision maker chooses the optimal selling price p and the product quality level q to maximize the firm's profit. For a given retail price p and product quality level q, the firm's profit is expressed by

$$\pi_c = pD - \frac{k}{2}q^2. \tag{4.1}$$

The following proposition provides the optimal solution to the optimization problem (4.1). All proofs are given in Appendix.

Proposition 4.1. *The optimal selling price and the environmental quality in the centralized channel are*

$$p_c^* = \frac{ktv}{2kt - A^2}, \quad q_c^* = \frac{vA}{2kt - A^2}, \tag{4.2}$$

and the optimal profit is given by

$$\pi_c^* = \frac{kv^2}{4kt - 2A^2}. \tag{4.3}$$

4.2. Manufacturer Stackelberg (Model m)

In this section, the relationship between the manufacturer and the retailer is described as a sequential non-cooperative game. As the leader, the manufacturer decides the wholesale price and the environmental quality level. The profit of the manufacturer is calculated as

$$\pi_{1m} = wD - \frac{k}{2}q^2. \tag{4.4}$$

As the follower, the retailer responds by setting the optimal selling price. The profit of the retailer is calculated as

$$\pi_{2m} = (p - w)D. \tag{4.5}$$

The stackelberg equilibrium is characterized by the following proposition.

Proposition 4.2. *At the equilibrium, the wholesale price, the environmental quality level, and the selling price are, respectively,*

$$w_m^* = \frac{2ktv}{4kt - A^2}, \tag{4.6}$$

$$q_m^* = \frac{vA}{4kt - A^2}, \tag{4.7}$$

$$p_m^* = \frac{3ktv}{4kt - A^2}, \tag{4.8}$$

and the corresponding profits of the manufacturer and the retailer are respectively given by

$$\pi_{1m}^* = \frac{kv^2}{2(4kt - A^2)}, \tag{4.9}$$

$$\pi_{2m}^* = \frac{k^2v^2t}{(4kt - A^2)^2}. \tag{4.10}$$

4.3. Nash (Model n)

In this case, the manufacturer and the retailer have the same power. The optimal strategies are determined independently and simultaneous to maximize the profits (4.4) and (4.5). The following proposition gives a unique pure-strategy Nash equilibrium of this game.

Proposition 4.3. *At the unique pure-strategy Nash equilibrium, the wholesale price, the environmental quality level, and the selling price are, respectively,*

$$w_n^* = \frac{ktv}{3kt - A^2}, \tag{4.11}$$

$$q_n^* = \frac{vA}{3kt - A^2}, \tag{4.12}$$

$$p_n^* = \frac{2ktv}{3kt - A^2}, \tag{4.13}$$

and the corresponding profits of the manufacturer and the retailer are respectively given by

$$\pi_{1n}^* = \frac{kv^2(2kt - A^2)}{2(3kt - A^2)^2}, \tag{4.14}$$

$$\pi_{2n}^* = \frac{k^2v^2t}{(3kt - A^2)^2}. \tag{4.15}$$

4.4. Retailer Stackelberg (Model r)

In this case, the relationship between the manufacturer and the retailer is modeled as a non-cooperative game where the retailer is the leader in the supply chain and moves first by determining the optimal selling price to maximize its profit (4.5). The manufacturer responds with choosing the wholesale price and the environmental quality level to maximize its profit (4.4). The equilibrium for this game is characterized by the following proposition.

Proposition 4.4. *At the equilibrium, the wholesale price, the environmental quality, and the selling price are, respectively,*

$$w_r^* = \frac{ktv}{2(2kt - A^2)}, \tag{4.16}$$

$$q_r^* = \frac{vA}{2(2kt - A^2)}, \tag{4.17}$$

$$p_r^* = \frac{v(3kt - A^2)}{2(2kt - A^2)}, \tag{4.18}$$

and the corresponding profits of the manufacturer and the retailer are respectively given by

$$\pi_{1r}^* = \frac{kv^2}{8(2kt - A^2)}, \tag{4.19}$$

$$\pi_{2r}^* = \frac{kv^2}{4(2kt - A^2)}. \tag{4.20}$$

5. Analysis of the results

In this section, we will discuss the comparisons among the equilibrium outcomes of the four models.

The following proposition characterizes the impact of different structure of the green supply chain on the environmental quality level.

Proposition 5.1. *(i) when* $\frac{A^2}{2} < kt \leq A^2$, $q_c^* > q_r^* \geq q_n^* > q_m^*$; *(ii) when* $kt > A^2$, $q_c^* > q_n^* > q_r^* > q_m^*$.

Proposition 5.1 lies in the fact that it provides lights on how structure of the green supply chain affects the environmental quality level at the equilibrium. Proposition 5.1 indicates that the manufacturer provides the highest environmental quality level in the cooperative green supply chain. In other words, a decentralized green supply chain limits the manufacturer's efficiency in environmental quality improvement resulting in decreasing the environmental quality of the product. The incorporation of consumer's heterogeneous response to the environmental quality does not alter this insight. This finding is in line with previous studies, such as Yan [35]. Proposition 5.1 also shows that the manufacturer provides the lowest environmental quality level in the Manufacturer Stackelberg green supply chain. When the manufacturer possesses more power in the green supply chain, the manufacturer does not want to invest more to improve the environmental quality of the product, *i.e.*, the manufacturer is able to squeeze the retailer relying on its dominant position in the supply chain.

Furthermore, it can be found that when kt is small, the manufacturer decides a higher environmental quality level in the supply chain in which the retailer has more power than that in the supply chain where the manufacturer has the same power. This is because the manufacturer, as the follower, is able to soften its inferior position by improving the environmental quality with a lower cost. From the manufacturer's perspective, the greatest incentive comes from its own willingness to increase performance of the product to contend against the powerful retailer. When kt is large, it is found from Proposition 5.1 that the environmental quality of the product is inverted-U shaped as a function of manufacturer's power in the decentralized supply chain. Although the manufacturer is in an inferior position in the supply chain where the retailer has more power, it is not willing to spend more to improve the environmental quality with a higher cost. Thus, the manufacturer chooses a lower environmental quality level.

The next proposition compares the wholesale prices in the decentralized games.

Proposition 5.2. *(i) when* $\frac{A^2}{2} < kt \leq \frac{3A^2}{4}$, $w_r^* \geq w_m^* > w_n^*$; *(ii) when* $\frac{3A^2}{4} < kt \leq A^2$, $w_m^* > w_r^* \geq w_n^*$; *(iii) when* $kt > A^2$, $w_m^* > w_n^* > w_r^*$.

Proposition 5.2 indicates that, as the power shifts from the retailer to the manufacturer, the wholesale price dose not always increase. This finding is in contrast to Shi *et al.* [26] which states that the wholesale price increases as the manufacturer's power rise in the supply chain. The case that the wholesale price increases as the manufacturer's power rise in the supply chain only happens when kt is large. When kt is small, it is indicated that the manufacturer would charge the highest wholesale price when it is the follower of the supply chain. When kt is moderate, the wholesale price is U-shaped as a function of manufacturer's power, *i.e.*, as the power shifts from the manufacturer to the retailer, the wholesale price decreases first and then increases. In Figure 1, the conditions in Propositions 5.1 and 5.2 are illustrated graphically in order to clearly explain them.

In the decentralized green supply chain, if kt is large, the manufacturer chooses the lowest environmental quality level when it is dominant in the green supply chain. However, the manufacturer would prefer to charge a higher wholesale price under Mode m to keep profit. The analogous result happens when kt is moderate. With doing this, the manufacturer is able to reap profit replying on its dominance. This results in the most inefficient supply chain system, which will be shown in Proposition 5.5. In the Model r, when kt is small, the manufacturer chooses the highest environmental quality level. Naturally, the manufacturer would prefer to charge a higher wholesale price under to keep profit. Surprisingly, when kt is moderate, a higher environmental quality level does not indicate that the manufacturer would charge a higher wholesale price. When the manufacturer is the follower, *i.e.*, in Model r, the manufacturer would provide the highest level of the environmental quality while charge a lower wholesale price in order to soften its inferior position. The analogous result always happens when the manufacturer and the retailer have the same power in the green supply chain.

The next proposition compares the optimal selling prices in the four models.

Proposition 5.3. *(i) when* $\frac{A^2}{2} < kt \leq A^2$, $p_c^* \geq p_r^* \geq p_n^* \geq p_m^*$; *(ii) when* $kt > A^2$, $p_m^* > p_r^* > p_n^* > p_c^*$.

Proposition 5.3 suggests a new insight about the selling price in the cooperative green supply chain. It is traditional to find that the selling price decreases in the integrated green supply chain thanks to the double marginalization based savings. In contrast to the traditional finding that the integrated supply chain always has

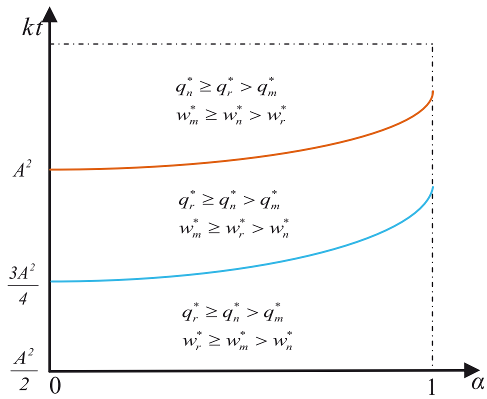

FIGURE 1. An illustration of Propositions 5.1 and 5.2. (Color online.)

the lowest retail price [26], however, our result indicates that charging a higher selling price in the integrated green supply chain can be optimal. Indeed, an increase in selling price is mainly due to the role of environmental quality in improving consumer's utility. In the integrated channel, the environmental quality of the product is higher creating added consumer's utility, which is also beneficial for the channel to boost the selling price. From Proposition 5.3, it is noted that this case only happens when the kt is low compared to the average unit benefit from the environmental quality of the product across consumer segment. Under this condition, the utility of consumer would not loss significantly due to a higher selling price and consumers are willing to bear the disutility cost (t) to consume a greener product, which leads to higher penetration rates in each consumer's segment, ultimately boosting product's demand and profit of the integrated green supply chain.

The performance of each individual supply chain member in different power structure is characterized by the following proposition.

Proposition 5.4. *Comparing the manufacturer's profit in different power structure, we can obtain that*

(i) when $\frac{A^2}{2} < kt \leq \frac{3A^2}{4}$, $\pi_{1r}^* \geq \pi_{1m}^* > \pi_{1n}^*$;
(ii) when $\frac{3A^2}{4} < kt \leq A^2$, $\pi_{1m}^* > \pi_{1r}^* \geq \pi_{1n}^*$;
(iii) when $kt > A^2$, $\pi_{1m}^* > \pi_{1n}^* > \pi_{1r}^*$.

Comparing the retailer's profit in different power structure, we can obtain that $\pi_{2r}^* > \pi_{2n}^* \geq \pi_{2m}^*$.

Proposition 5.4 indicates that the retailer's profit increases as it becomes dominant in the supply chain. For the retailer, obtaining dominant position in the supply chain means a higher profit. This finding is in line with Shi *et al.* [26]. However, Proposition 5.4 provides a new insight that, for the manufacturer, dominant position in the supply chain does not always imply a higher profit. In particular, when the kt is low, being a follower not a leader in the green supply chain, the manufacturer can reap the highest profit. Under this condition, we surprisingly find that there is no power conflict in the green supply chain. The manufacturer desirably prefers to be the retailer's follower than to be the leader of the green supply chain. In other words, the manufacturer is willing to drop its power while the retailer is willing to possess power, which results in a "power equilibrium" in the green supply chain because both the manufacturer and the retailer are able to obtain the highest profit.

Proposition 5.4 therefore makes contribution to the literature. It gives the result in the green supply chain to identify a condition for which the manufacturer and the retailer are able to reach an agreement on the power structure of the supply chain. Proposition 5.4 has important application. It can be calculated that the length of the interval where no power conflict exists is $L = \frac{1}{4}A^2$. One can easily obtain $\frac{\mathrm{dL}}{\mathrm{d}\theta_{\mathrm{h}}}, \frac{\mathrm{dL}}{\mathrm{d}\theta_{\mathrm{l}}} > 0$. This indicates that through improving consumer's awareness of environmental protection, the region of "power equilibrium" can be expanded, which suggests that boosting consumer's green awareness can reduce power conflict in the green supply chain.

TABLE 1. The analytical results of Δp_i, Δq_i and $\Delta \pi_i$.

i	m	n	r
Δp_i	$\frac{2ktv(A^2-kt)}{(4kt-A^2)(2kt-A^2)}$	$\frac{ktv(A^2-kt)}{(3kt-A^2)(2kt-A^2)}$	$\frac{v(A^2-kt)}{2(2kt-A^2)}$
Δq_i	$\frac{2ktvA^2}{(4kt-A^2)(2kt-A^2)}$	$\frac{ktvA^2}{(3kt-A^2)(2kt-A^2)}$	$\frac{vA^2}{2(2kt-A^2)}$
$\Delta \pi_i$	$\frac{2k^3t^2v^2}{(4kt-A^2)^2(2kt-A^2)}$	$\frac{k^3t^2v^2}{2(3kt-A^2)^2(2kt-A^2)}$	$\frac{kv^2}{8(2kt-A^2)}$

Next we compare the overall performance of the green supply chain. The profit of the whole supply chain for Manufacturer Stackelberg can be calculated as $\pi_I^m = \frac{kv^2(6kt-A^2)}{2(4kt-A^2)^2}$. The profit of the whole supply chain for Nash game can be calculated as $\pi_I^n = \frac{kv^2(4kt-A^2)}{2(3kt-A^2)^2}$. The profit of the whole supply chain for Retailer Stackelberg can be calculated as $\pi_I^r = \frac{3kv^2}{8(2kt-A^2)}$.

We can obtain the following proposition by comparing the profit of the whole supply chain in four models.

Proposition 5.5. *Through comparing π_c^*, π_I^m, π_I^n and π_I^r, we can obtain the following results*

(i) π_c^* *is always larger than* π_I^m, π_I^n *and* π_I^r;

(ii) when $\frac{A^2}{2} < kt \le A^2$, $\pi_I^r \ge \pi_I^n > \pi_I^m$, *when* $kt > A^2$, $\pi_I^n > \pi_I^r > \pi_I^m$.

The integrated supply chain always has the highest total supply chain profit. Capturing consumer's heterogeneous response to the environmental quality does not alter this insight. However, Proposition 5.5 indicates that the green supply chain has different performance in the decentralized case. When kt is small, the total supply chain profit is on the highest level in the Stackelberg game with the retailer being the leader. And the overall performance of the green supply chain decays in retailer's power, *i.e.*, the supply chain becomes inefficient as the power shifts from the retailer to the manufacturer.

When kt is large, surprisingly, the total supply chain profit is higher in the Nash game, which shows that the overall performance of the green supply chain improves when neither firm dominates in the supply chain and then decays when the retailer or the manufacturer gains more power. This result suggests that, to target at a more efficient green supply chain, both the manufacturer and the retailer should be equality and mutual benefit rather than striving for dominance in the green supply chain when kt is large.

Proposition 5.5 also indicates that the performance of the whole supply chain is the worst when the manufacturer is dominant. As shown in the above analysis, being the leader, the manufacturer would provide a lower level of the environmental quality while charge the highest wholesale price resulting in damnifying the overall performance of the green supply chain.

6. Effect of consumer heterogeneity about the environmental quality

Note that, in our study, consumer's heterogeneity about the environmental quality level is captured in the models. We would evaluate the sensitivity to consumer response of the environmental quality level for expressions $\Delta p_i = p_c^* - p_i^*$, $\Delta q_i = q_c^* - q_i^*$ and $\Delta \pi_i = \pi_c^* - \pi_I^i$, $i = m, n, r$. The analytical results of Δp_i, Δq_i and $\Delta \pi_i$ are summarized in Table 1.

When channel members overlook consumer's heterogeneity about the environmental quality level, consumer's response is estimated to be equal according to segments. Thus, consumer's response to the environmental quality is taken equal to the high segment (θ_h) or the low segment (θ_l) when channel members do not account for consumer heterogeneity. Indeed, capturing consumer's heterogeneity means that channel members consider the weighted average of consumer's response to the environmental quality ($A = \alpha(\theta_h - \theta_l) + \theta_l$) to decide equilibrium strategies. Through calculating the derivatives of the expressions Δp_i, Δq_i and $\Delta \pi_i$ ($i = m, n, r$) in A, we can obtain the following proposition.

Proposition 6.1. *By comparing the derivatives of the expressions Δp_i, Δq_i and $\Delta\pi_i$ ($i = m, n, r$) in A, the following result holds: Δp_i, Δq_i and $\Delta\pi_i$ are all increasing in A.*

Proof. With obtaining Δp_i, Δq_i and $\Delta\pi_i$ ($i = m, n, r$) and calculating the derivatives of the expressions Δp_i, Δq_i and $\Delta\pi_i$ in A, one can easily get the results. □

Proposition 6.1 indicates that the performance of channel integration is heightened when the consumer's sensitivity to the environmental quality is boosted. In a market characterized by high sensitivity to the environmental quality, the green supply chain can reap additional profits through coordinating strategies decisions making.

Moreover, from Proposition 6.1, it can be seen that if consumer's sensitivity to the environmental quality is overestimated (equal to θ_h), the benefits from channel integration would be inaccurately exaggerated. In addition, there would exist an excessive adjustment in selling price (in absolute value) and the environmental quality, which may be dampened to the channel's performance. If consumer's sensitivity to the environmental quality is underestimated (equal to θ_l), the outcome realized from channel integration would be inaccurately lessened,which would lead to an inaccurate adjustment of pricing and the environmental quality. These results demonstrate that capturing heterogenous consumer response to the environmental quality is valuable. It is of importance to account for different consumer sensitivity across segments when we make pricing and the environmental quality decisions in the green channel, and analyze the effect of channel integration on these decisions as well as on the performance of the whole green supply chain.

7. Conclusion

This study investigates the impact of consumer heterogeneity toward the environmental level of products and power structure on green product development and the performance of green supply chain. The game theoretic models that explain consumer heterogeneity in the utility function of consumer are developed, and the equilibrium strategies for different power structure in the green supply chain are obtained. We compare the outputs and assess the effect of consumer heterogeneity toward the environmental level of products and different power structure on these results. Our findings indicate that it is of importance to account for the heterogeneity of consumers responses toward the environmental level of products in order to better understand the implications of pricing and environmental product design in the green supply chain. In particular, we show that not only does heterogeneity and power structure impact the optimal level of strategies and profits, but that they also considerably affect the value of channel integration.

More importantly, the information about consumer response heterogeneity toward environmental level of products allows a better estimation of channel integration effects on strategies and profits. Supply chain integration has been known that it would result in a lower selling price, but result from our utility-based model indicates that it can also be optimal for the retailer to charge a higher price. Also, we find that there exist a condition where there is no power conflict in the green supply chain. This indicates that the manufacturer is willing to drop its power while the retailer is willing to possess power resulting in a "power equilibrium" in the green supply chain. These findings are important for channel managers concerned about choosing the reasonable channel strategies which would both maximize their profits and provide maximum utility to consumers.

Our work can be extended in several directions. This work does not consider the coordination mechanisms. Future research can examine the effect of consumer response heterogeneity on channel coordination contracts, such as quantity discounts contract, cost sharing contract. One can also consider the competition between green supply chain to investigate the channel structure strategy with consumer heterogeneity toward the environmental level of products.

Appendix A. Proof of Proposition 4.1

Let $A = \alpha(\theta_h - \theta_l) + \theta_l$ to simplify notation. It can be proved that the profit of the integrated supply chain (4.1) is jointly concave in p and q. We apply the first-order condition to maximize the profit (4.1) w.r.t. the decision variables p and q, obtaining

$$p^* = \frac{1}{2}(v + qA), \quad q^* = \frac{pA}{kt}. \tag{A.1}$$

Solving equations (A.1) simultaneously, we obtain the optimal price and the environmental level of product

$$p_c^* = \frac{ktv}{2kt - A^2}, \quad q_c^* = \frac{vA}{2kt - A^2}. \tag{A.2}$$

Substituting equations (A.2) into the objective function (4.1), we can obtain the optimal profit $\pi_c^* = \frac{kv^2}{4kt-2A}$. □

Appendix B. Proof of Proposition 4.2

The first-order condition of the objective function (4.5) in p reacting to the wholesale price w and the environmental level of product q gives

$$p^* = \frac{1}{2}(v + qA + w). \tag{B.1}$$

Substituting equation (B.1) into the manufacturer's objective function (4.4), we get

$$\pi_{1m} = \frac{-ktq^2 + w(v - w + qA)}{2t}. \tag{B.2}$$

The manufacturer chooses w and q to maximize its profit. Applying the first-order condition, we obtain

$$w^* = \frac{1}{2}(v + qA), \quad q^* = \frac{wA}{2kt}. \tag{B.3}$$

Solving equations (B.3) simultaneously, we obtain that

$$w_m^* = \frac{2ktv}{4kt - A^2}, \quad q_m^* = \frac{vA}{4kt - A^2}. \tag{B.4}$$

Substituting equation (B.4) into (B.1), we can get the optimal price p_m^*. With the optimal wholesale price w_m^*, the environmental level of product q_m^* and optimal selling prices p_m^*, we can easily get the optimal profit of the manufacturer π_{1m}^* and the optimal profit of the retailer π_{2m}^*. □

Appendix C. Proof of Proposition 4.3

In the Nash game, the retailer determines its retail margin m with $m = p - w$. The retailer and the manufacturer chooses m, w and q to maximize its profits 4.5 and 4.4. We employ the first-order condition to maximize the profit value w.r.t. the decision variables m, w and q, giving

$$m^* = \frac{1}{2}(v - w + qA), \quad w^* = \frac{1}{2}(v - m + qA), \quad q^* = \frac{wA}{kt}. \tag{C.1}$$

Solving equations (C.1) simultaneously, we can obtain that

$$m_n^* = \frac{ktv}{3kt - A^2}, \quad w_n^* = \frac{ktv}{3kt - A^2}, \quad q_n^* = \frac{vA}{3kt - A^2}. \tag{C.2}$$

Thus, the optimal selling price $p_n^* = m_n^* + w_n^* = \frac{2ktv}{3kt-A^2}$. With the optimal wholesale price w_n^*, the environmental level of product q_n^* and optimal selling price p_n^*, we can easily get the optimal manufacturer's profit π_{1n}^* and the optimal retailer's profit π_{2n}^*. $\square$

Appendix D. Proof of Proposition 4.4

In the retailer Stackelberg game, the retailer determines its retail margin m with $m = p - w$. For a given retail margin m, the manufacturer chooses w and q to maximize its profit 4.4. We apply the first-order condition to maximize the manufacturer's profit value w.r.t. the decision variables w and q, giving

$$w^* = \frac{1}{2}(v - m + qA), \quad q^* = \frac{wA}{kt}. \tag{D.1}$$

Solving equations (D.1) simultaneously, we obtain that

$$w^* = \frac{kt(v-m)}{2kt - A^2}, \quad q^* = \frac{(v-m)A}{2kt - A^2}. \tag{D.2}$$

Substituting equations (D.2) into (4.5), we can get the retailer's profit as

$$\pi_r = \frac{km(v-m)}{2kt - A^2}. \tag{D.3}$$

We apply the first-order condition to maximize the profit (D.3) w.r.t. the decision variable m, obtaining $m^* = \frac{v}{2}$. Substituting m^* into (D.2), we can get w_r^* and q_r^*. The optimal selling price $p_r^* = m^* + w_r^* = \frac{v(3kt-A^2)}{2(2kt-A^2)}$. With the optimal wholesale price w_r^*, the environmental level of product q_r^* and optimal selling price p_r^*, we can easily get the optimal profit of the manufacturer π_{1r}^* and the optimal profit of the retailer π_{2r}^*. $\square$

Appendix E. Proof of Proposition 5.1

One can easily obtain that q_c^* is always larger than q_r^*, q_n^* and q_m^*. And q_r^*, q_n^* is always larger than q_m^*. It can be calculated that $q_n^* - q_r^* = \frac{vA(kt-A^2)}{(3kt-A^2)(4kt-2A^2)}$. Thus, when $\frac{A^2}{2} < kt \le A^2$, $q_c^* > q_r^* \ge q_n^* > q_m^*$; when $kt > A^2$, $q_c^* > q_n^* > q_r^* > q_m^*$. $\square$

Appendix F. Proof of Proposition 5.2

It can be calculated that $w_m^* - w_n^* = \frac{ktv(2kt-A^2)}{(4kt-A^2)(3kt-A^2)} > 0$. And $w_n^* - w_r^* = \frac{ktv(kt-A^2)}{(3kt-A^2)(4kt-2A^2)}$, $w_m^* - w_r^* = \frac{ktv(4kt-3A^2)}{(4kt-A^2)(4kt-2A^2)}$. Thus, we can obtain that when $\frac{A^2}{2} < kt \le \frac{3A^2}{4}$, $w_r^* \ge w_m^* > w_n^*$; when $\frac{3A^2}{4} < kt \le A^2$, $w_m^* > w_r^* \ge w_n^*$; when $kt > A^2$, $w_m^* > w_n^* > w_r^*$. $\square$

Appendix G. Proof of Proposition 5.3

It can be calculated that $p_n^* - p_r^* < 0$, thus $p_n^* < p_r^*$. And $p_c^* - p_m^* = \frac{2ktv(-kt+A^2)}{(2kt-A^2)(4kt-A^2)}$, $p_m^* - p_n^* = \frac{ktv(kt-A^2)}{(4kt-A^2)(3kt-A^2)}$, $p_c^* - p_n^* = \frac{ktv(-kt+A^2)}{(2kt-A^2)(3kt-A^2)}$, $p_m^* - p_r^* = \frac{vA^2(kt-A^2)}{(4kt-A^2)(4kt-2A^2)}$ and $p_c^* - p_r^* = \frac{v(A^2-kt)}{4kt-2A^2}$. Thus, we can obtain that when $\frac{A^2}{2} < kt \le A^2$, $p_c^* \ge p_r^* \ge p_n^* \ge p_m^*$; when $kt > A^2$, $p_m^* > p_r^* > p_n^* > p_c^*$. $\square$

Appendix H. Proof of Proposition 5.4

For the manufacturer's profit, it can be obtained that $\pi_{1m}^* - \pi_{1n}^* = \frac{k^3t^2v^2}{2(4kt-A^2)(3kt-A^2)^2} > 0$. And $\pi_{1n}^* - \pi_{1r}^* = \frac{kv^2(7kt-3A^2)(kt-A^2)}{2(3kt-A^2)^2(8kt-4A^2)}$, $\pi_{1m}^* - \pi_{1r}^* = \frac{kv^2(8kt-6A^2)}{(8kt-2A^2)(16kt-8A^2)}$. Thus, one can get that when $\frac{A^2}{2} < kt \leq \frac{3A^2}{4}$, $\pi_{1r}^* \geq \pi_{1m}^* > \pi_{1n}^*$; when $\frac{3A^2}{4} < kt \leq A^2$, $\pi_{1m}^* > \pi_{1r}^* \geq \pi_{1n}^*$; when $kt > A^2$, $\pi_{1m}^* > \pi_{1n}^* > \pi_{1r}^*$. □

For the retailer's profit, one can easily obtain the result.

Appendix I. Proof of Proposition 5.5

The profit of the whole supply chain for Manufacturer Stackelberg is calculated as $\pi_I^m = \frac{kv^2(6kt-A^2)}{2(4kt-A^2)^2}$. The profit of the whole supply chain for Nash game is calculated as $\pi_I^n = \frac{kv^2(4kt-A^2)}{2(3kt-A^2)^2}$. The profit of the whole supply chain for Retailer Stackelberg is calculated as $\pi_I^r = \frac{3kv^2}{8(2kt-A^2)}$. One can easily obtain that π_c^* is always larger than π_I^m, π_I^n and π_I^r. We can calculate that $\pi_I^m - \pi_I^r = \frac{kv^2A^2(A^2-8kt)}{8(4kt-A^2)^2(2kt-A^2)} < 0$, $\pi_I^m - \pi_I^n = \frac{k^3v^2t^2(3A^2-10kt)}{2(4kt-A^2)^2(3kt-A^2)^2}$. And $\pi_I^n - \pi_I^r = \frac{kv^2(5(kt)^2-6A^2kt+A^4)}{8(3kt-A^2)^2(2kt-A^2)}$. One can get that when $\frac{A^2}{2} < kt \leq A^2$, $5(kt)^2 - 6A^2kt + A^4 \leq 0$; when $kt > A^2$, $5(kt)^2 - 6A^2kt + A^4 > 0$. Thus, we can obtain that when $\frac{A^2}{2} < kt \leq A^2$, $\pi_I^r \geq \pi_I^n > \pi_I^m$, when $kt > A^2$, $\pi_I^n > \pi_I^r > \pi_I^m$. □

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