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Title Page

Quality information acquisition and disclosure in a closed-loop supply chain

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Quality Information Acquisition and Disclosure with Green Manufacturing in a Closed-Loop Supply Chain

Abstract: Green manufacturers are faced with decision problems whether to acquire the quality information from third-party assessment agencies and to disclose the quality information to other supply chain members. While the existing research of closed-loop supply chain (CLSC) has not considered the voluntary and mandatory information disclosure, this study considers the quality information disclosure strategies of a green manufacturer after acquiring the quality information in the closed-loop supply chain. (1) The study first evaluates the performance of this new closed-loop supply chain system considering the quality information disclosure and acquisition, by new models integrating the quality information decisions with the remanufacturing operational decisions. To our knowledge, this paper is an early research of closed-loop supply chain to consider and compare voluntary information disclosure and mandatory information disclosure. (2) The study provides a new decision tool to assist green manufacturers in making decisions on acquiring the quality information from a third-party quality assessment agency before disclosing the quality information. Interestingly, the study finds that the profits of closed-loop supply chain members are higher under the mandatory information disclosure when the green manufacturer refuses to assess the product quality and acquire the information from a third-part quality assessment agency. (3) The study further considers the consumer preference of green products, and get useful managerial insights that the green manufacturer is willing to pay a higher information acquisition cost to acquire the quality information when consumers prefer high quality. (4) Finally, the study provides the practical implications and finds the new condition under which a green manufacturer is willing to disclose the product quality information in closed-loop supply chains.

Keywords: supply chain management; closed-loop supply chain; remanufacturing; information acquisition; information disclosure; quality information

1. Introduction

Our study is partially motivated by the evidence that green manufacturers regularly get the product quality information through third-party assessment agencies in the practice of closed-loop supply chains (CLSC). Closed-loop supply chain refers to the complete supply chain cycle from purchase to final sale, including reverse logistics of product recovery and life cycle support (Govindan et al., 2015). The green automobile manufacturers regularly take part in the Network Test System (NTS) to get the quality information of the

networks and electrical devices (Cao et al., 2020), and to get the quality information of new green cars for the closed-loop supply chains from European New Car Assessment Programme (Kumar et al., 2020; Choi et al., 2020). For example, Volkswagen recycles used cars or car parts such as engines and gearboxes and tyres from the market for remanufacturing, and also takes part in European New Car Assessment Programme to acquire the quality information about some parts of new cars, such as the information of safety features for sustainability. Information acquisition refers to the activity and process of acquiring original information around a certain target and within a certain range through certain technical means and methods (Chen et al., 2020). Acquiring accurate product quality information is a profitable activity for green manufacturers and retailers (Guo, 2009a). However, to acquire accurate quality information, a green manufacturer needs to pay an information acquisition cost from sending the product to the agency and paying a certificate or assessment fee to the agency. Therefore, information acquisition and disclosure decisions and remanufacturing operations integrate each other in a CLSC, and acquiring and disclosing the product quality information are important decisions for green manufacturers to improve the profits.

The previous study in supply chain considers the information disclosure, and information disclosure means that a company discloses specific information to members of the supply chain and the public in some form (He et al., 2019). Then existing researches of manufacturing focus on the recycling decision and recycling competition in the CLSC (Hong et al., 2017). Green remanufacturing is the process of remanufacturing an old machine using a special process to achieve the performance of a new product (Yang et al., 2020). However, there is a literature gap in understanding voluntary and the mandatory quality information disclosure for green products in a CLSC. This gap is important since the green manufacturer's quality information decisions in disclosure and acquisition will influence the profits of supply chain members. To fill in the literature gap, our research question is: (1) *Under which condition does the green manufacturer acquires the product quality information in CLSCs?* (2) *How does the green manufacturer disclose the product quality information in CLSCs?* (3) *How does consumers' quality preference affect the green manufacturer's quality information decisions in disclosure and acquisition?*

To address the questions, the study builds a CLSC model incorporating quality information disclosure and acquisition. The study captures features where the green manufacturer saves production costs by remanufacturing used products and decides on whether to disclose the quality information. Product quality information is *ex ante* unknown to the consumers, the retailer, and the green manufacturer. The green manufacturer makes a decision on if the green manufacturer should acquire the quality information from the

third-party assessment agency. The green manufacturer needs to make decisions in information acquisition, information disclosure, and remanufacturing operations.¹ Since the mandatory quality information disclosure and voluntary quality information disclosure for green products disclosure are two main mechanisms for disclosing the quality information, the study discusses the green manufacturer's recycling decision under different disclosure mechanisms.

The study makes the following contributions: (1) The study evaluates the performance of a new type of CLSC systems considering the quality information disclosure and acquisition, by a new model integrating the quality information decisions with the remanufacturing decisions. (2) The study provides a new decision tool for green manufacturers to assist them to make decisions on acquiring the quality information before disclosing the quality information. (3) This paper enriches the literature of CLSC by discussing two mechanisms of disclosing quality information, the voluntary vs. mandatory quality information disclosure for green products. To our knowledge, this is the early study of remanufacturing to consider two disclosure mechanisms. (4) The study further considers the consumer preference of green products, and get useful managerial insights that the green manufacturer is willing to pay a higher information acquisition cost to acquire the quality information when consumers prefer high quality. (5) The study has a new finding that the profits of the green manufacturer and the associated retailer of the CLSC are higher with the mandatory quality information disclosure for green products, compared with that in the voluntary quality information disclosure for green products, when the green manufacturer refuses to assess the product quality and acquire the information from the third-part quality assessment agency. This makes difference with the previous supply chain study that the voluntary quality information disclosure for green products is always the better mode of information disclosure.

2. Literature Review

2.1 Information disclosure

The first relevant stream is about information disclosure, including demand information disclosure and quality information disclosure, among others (He et al., 2018; Zhang et al., 2019). Existing research suggests that retailers have an advantage over manufacturers in terms of demand information because retailers are closer to

¹For many enterprises, information acquisition and disclosure strategies and remanufacturing are all decisions that enterprises need to consider in a balanced way in the CLSC. For example, the automotive manufacturing industry determines the acquisition and disclosure strategies of quality information in the forward supply chain and optimizes the recycling and remanufacturing of used products in the reverse supply chain (Choi et al., 2020; Cao et al., 2020).

consumers (Shang et al., 2015; Zhang and Zhang, 2020). When the market demand is uncertain, the retailer anticipates market demand and makes a decision on if the retailer needs to share it with the manufacturer (Mishra et al., 2009; Zhang et al., 2019).

Unlike demand information shared by retailers, quality information is usually shared by the manufacturer with the retailer (Ghosh and Galbreth, 2013; Scheele et al., 2018). It is important for retailers and consumers that manufacturers observe the quality products and make a decision on the quality information disclosure (Guan and Chen, 2015; Liu et al., 2019). Markopoulos and Hosanagar (2018) consider that consumers can acquire product quality information from the outside in addition to the manufacturer. The studies above discuss the voluntary quality information disclosure for green products by manufacturers (Guo and Zhao, 2009; Hotz and Xiao 2013). Dahm et al. (2016) consider the mandatory quality information disclosure for green products when there is a rule to force it. For retailers, acquiring product quality information is conducive to decision-making and improving profits (Guo, 2009b; Tang and Girotra, 2017). The above studies assume that manufacturers know the quality information (Sarkar et al., 2018b). Different from them, our model can admit that the green manufacturer discloses the quality information after sending the product to a third-party assessment agency to assess its quality in CLSCs.

2.2 Information acquisition

The second stream is about information acquisition. Information acquisition and information disclosure are relevant, and some researches consider both processes (Iyer and Singh, 2018). Manufacturers should view their quality information acquisition and disclosure decisions as a comprehensive process (Gao et al., 2014; Huang and Yang, 2016).

Some studies investigate the interaction between information acquisition and information disclosure strategies of manufacturers (Guo and Iyer, 2010; Guan and Chen, 2017). Li and Peeters (2017) study the motivations of competitors to obtain and disclose information about the quality of competing products. Cao et al. (2020) expand the interaction between information acquisition and information disclosure and further studied the performance of the supply chain with the voluntary and mandatory quality information disclosure for green products. Previous research shows that, with the mandatory quality information disclosure for green products mechanism, the manufacturer's initiative to disclose quality information is significantly reduced, resulting in the reduction of product quality information that the supply chain acquired. All the above researches are discussed in the forward supply chain. However, the previous researches have not considered

the information acquisition in the CLSC, and our work fill in this literature gap.

2.3 The interface between CLSC and information management

The CLSC and remanufacturing includes the considerable literature (Feng et al., 2017; Modak and Kelle, 2019), and the study just discusses the relevant research in the interface between CLSC and information management. Some researchers (Teunter et al., 2008; He et al., 2019) study the recycling information for second-hand products. For example, Tang and Robert (2005) study a remanufacturing system with demand and return information sharing. Hosoda et al. (2015) investigate a decentralized CLSP with information sharing. Lei et al. (2014) consider the shared demand information among multiple retailers. Huang and Wang (2017) consider that the retailer has private demand information and information sharing always enhances the profit of manufacturers. Tang et al. (2020) and Ahmed and Sarkar (2019) study the CLSC systems considering the pricing decisions for green products.

The aforementioned researches provide the important foundation in demand information sharing and remanufacturing. While few studies have considered the green manufacturer's decisions about product quality information disclosure and acquisition, our paper further considers the remanufacturing with information disclosure and acquisition of the quality information, and compares the impact of two disclosure mechanisms of the quality information on the profits and decisions of CLSC members. The study shows the contributions of different authors in Table 1.

Table 1. Contributions of different authors

Author(s)	information disclosure	information acquisition	quality information	remanufacturing
Huang et al. (2018)	√			
Albert et al. (2017)	√		√	
Markopoulos and Hosanagar (2018)	√	√	√	
Li et al. (2014)	√	√		
Cao et al. (2020)	√	√	√	
Guo and Iyer (2010)	√	√		
Guan and Chen (2017)	√	√	√	
Huang and Wang (2017)	√			√
Ahmed and Sarkar (2018)				√
Sarkar et al. (2018a)				√
Hong et al. (2017)				√
Modak and Kelle (2019)		√		√
This work	√	√	√	√

3. Models and Analysis

3.1 Model

3.1.1 Notation

The parameters in this article and their meanings are presented in Table 2.

Table 2. The description of the notations

Notations	Descriptions
U	The utility of the consumers (nonnegative number)
D	Market demand (units)
q	The quality of the product (nonnegative number)
\bar{q}	Expected quality of the product (nonnegative number)
q_{nd}	Threshold for the quality of disclosure (nonnegative number)
θ	The consumers' preference for product quality (nonnegative number)
c_m	Unit production cost of new product (\$/unit)
c_r	Unit production cost of remanufactured product (\$/unit)
Δ	Cost saving from per unit remanufactured product (\$/unit)
w	Wholesale price (\$/unit)
p	Retail price (\$/unit)
b	The transfer fee that the green manufacturer pays to the retailer for the recycle of used products from the retailer (\$/unit)
τ	The recycling rate that the percentage of the market that the retailer recycles used products (nonnegative number)
a	The probability of acquiring quality information by the green manufacturer (nonnegative number)
z	The cost of acquiring quality information from assessment agency by the green manufacturer (\$/unit)
\sim	The voluntary quality information disclosure for green products (condition)
\wedge	The mandatory quality information disclosure for green products (condition)
Π	The green manufacturer's profit (\$/unit)
π	The retailer's profit (\$/unit)
CS	Consumer surplus (units)

3.1.2 Problem definition

The study considers a CLSC with a green manufacturer and a retailer to characterize two disclosure mechanisms, the voluntary quality information disclosure and mandatory quality information disclosure for green products. The study builds models that characterizes information disclosure and information acquisition,

and then discuss the impact of two disclosure mechanisms by the green manufacturer on remanufacturing. Fig. 1 shows the model structure of this research, including the model with the voluntary quality information disclosure for green products (the left figure) and the model with the mandatory quality information disclosure for green products (the right figure).

Recycling decision parts of Fig.1 show the decisions relevant with the CLSC operations. The green manufacturer sells products through the retailer at a wholesale price w . The consumers buy the product from the retailer at a retail price p . In the reverse channel, the retailer recycles used products from consumers, with the recycling rate τ . Then, the green manufacturer recycles the used product from the retailer at a transfer price b .

Information decision parts of Fig. 1 show the decisions relevant with the information acquisition and disclosure. The green manufacturer makes a decision if the green manufacturer should assess the product quality for the information acquisition from the third-party quality assessment agency. The study uses the superscript a to denote the information acquisition and the superscript na for non-acquisition. The green manufacturer pays the information acquisition cost z to the third-party assessment agency if the green manufacturer sends the product to the agency and get assessment information on product quality. The information acquisition cost z is related to acquisition method and accuracy of product quality, where z is a random variable and follows the uniform distribution $z \sim U(0, Z)$ (Arya et al., 2014; Cao et al., 2020). Then the green manufacturer makes a decision on if the green manufacturer discloses the quality information after assessing quality information. In practice, the mandatory quality information disclosure and the voluntary quality information disclosure for green products are two main mechanisms for disclosing the quality information (Board, 2009). The voluntary quality information disclosure for green products means that green manufacturers have the right to decide whether or not to disclose the quality information to other members (retailers and consumers). Then the mandatory quality information disclosure for green products means that once the green manufacturer makes a decision on assessing the product quality and acquiring the information from the third-party assessment agency, the evaluation results of product quality are made public. Then quality information is no longer the green manufacturer's private information, retailers and consumers also know the product quality information. The study uses the superscript d for disclosure and the superscript nd for non-disclosure.

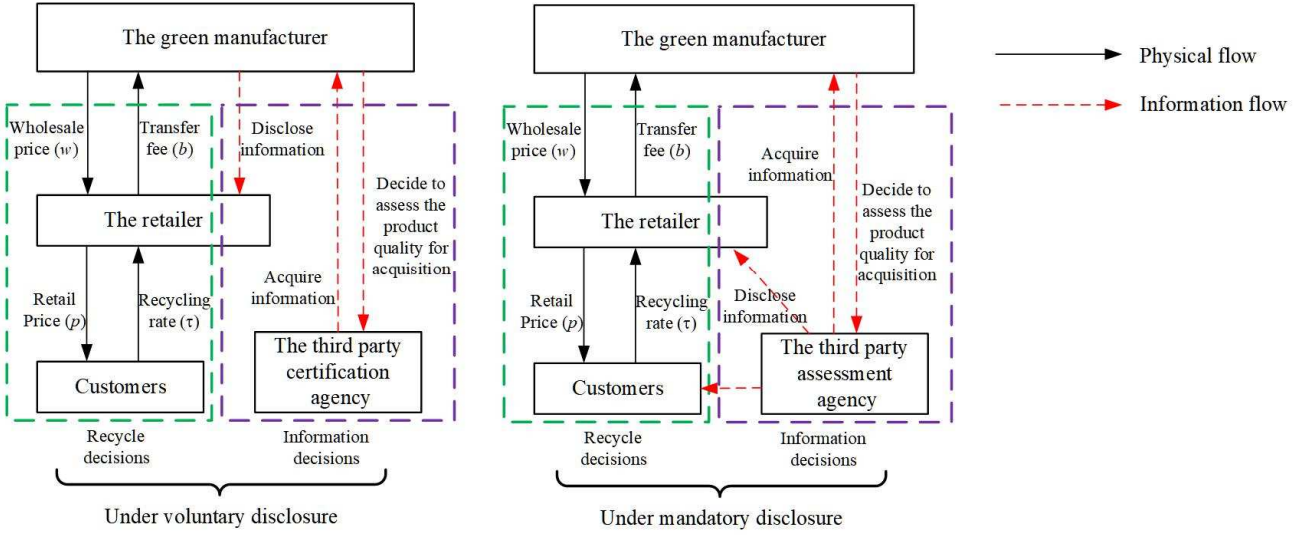


Fig. 1. The model structure of the study

The green manufacturers' production activities include the production of new products from raw materials and the production of remanufactured products from used products. The unit production cost for a new product c_m is higher than the unit production cost for a product made from used products c_r (that is $c_m > c_r$). The study makes $\Delta = c_m - c_r$ and $\Delta > 0$, which is the unit production cost saved by producing remanufactured products from the used products. The unit production cost is $c_m - \Delta\tau$, where τ is the recycling rate that the percentage of the market that the retailer recycles used products. The study assumes that consumers have a consistent preference for new and remanufactured products. According to Huang et al. (2013), the study considers remanufactured products are indistinguishable from new products in terms of quality and function. They enter the market through the same channels and at the same retail price. The utility function of the consumer is $U = (\theta q)D - \frac{1}{2}D^2 - pD$ (Singh and Vives, 1984), where D denotes the market demand, q is the quality of the product, which follows the uniform distribution $q \sim U(0,1)$. By taking the derivative of the utility function the study gets the demand function $D = \theta q - p$, where p is the market cleaning price of the product, and θ is consumers' preference for product quality.

To facilitate modeling, our model takes place in a single period (Shi et al., 2020; Esenduran et al., 2017). The single period model occurs when a product repeatedly enters the market or when the product production is in the mature life cycle stage (when the recycling rate and the price are stable). The recycling cost is $\alpha\tau(\theta q - p)^2$, $\alpha \geq 0$ (Ferguson and Toktay, 2006; Ovchinnikov, 2011; Atalay and Gilvan, 2013). Atalay and Gilvan (2013) prove that $\alpha\tau(\theta q - p)^2$ is consistent with the actual recycling cost of the enterprise in their study.

In our study the green manufacturer pays the retailer a transfer fee b when recycling used products from the retailer, where $0 \leq b \leq \Delta$. In order to simplify the derivation of the model, the study assumes that the fee for paying consumers is zero, which has no change on the conclusion of our study (see Savaskan and Van Wassenhove (2006)).

The green manufacturer undertakes the production of remanufactured and new products. The study uses Π to present the green manufacturer's profit. The green manufacturer recycles used products through the retailer by paying the transfer fee b to the retailer. The green manufacturer maximizes the profit by optimizing wholesale price w and transfer fee b . According to the setting above, the study gives the basic model of the green manufacturer's profit function without considering information disclosure and acquisition as follows:

$$\text{Max}_{w,b} \Pi = (w - c_m + \Delta\tau)(\theta q - p) - b\tau(\theta q - p). \quad (1)$$

The first term of equation (1) is the green manufacturer's profit from sales, and the second term is the total transfer fee paid to the retailer for recycling used products from the retailer.

The retailer undertakes the business of selling products and recycling used products from consumers. The study uses π to denote the retailer's profit. The retailer maximizes the profit by optimizing retail price p and recycling rate τ . The study gives the basic model of the retailer's profit function without considering information disclosure and acquisition as follows:

$$\text{Max}_{p,\tau} \pi = (p - w)(\theta q - p) + b\tau(\theta q - p) - \alpha\tau^2(\theta q - p)^2. \quad (2)$$

The first term of equation (2) is the retailer's profit from sales, the second term is the extra revenue from recycling used products, and the last term is the total recycling cost.

If there is no transaction, the profits of supply chain members and the utility of the consumer are zero. Following Iyer and Singh (2018) and Guan and Chen (2017), the study assumes that quality information acquisition and disclosure of the green manufacturer is truthful and effective.

3.2 Voluntary quality information disclosure for green products

The study assumes that, through information acquisition, the green manufacturer can learn the actual quality information q . The retailer has the same quality information q if the green manufacturer discloses it to her. In this scenario, the retailer's profit is $\tilde{\pi} = (p - w)(\theta q - p) + b\tau(\theta q - p) - \alpha\tau^2(\theta q - p)^2$ for a given wholesale price w and transfer fee b . The first order condition of retailer profit function describes that the optimal retail price and recycling rate are $\tilde{p}^d = \frac{\theta q + w}{2}$ and $\tilde{\tau}^d = \frac{b}{\alpha(\theta q - w)}$ respectively. The optimal profit function for the green manufacturer is $\tilde{\Pi} = (w - c_m + \Delta\tau)(\theta q - p) - b\tau(\theta q - p)$. Again, the best wholesale

price and transfer fee for the green manufacturer is $\tilde{w}^d = \frac{\theta q + c_m}{2}$ and $\tilde{b}^d = \frac{\Delta}{2}$. The study gets the results as Theorem 1.

Theorem 1. *With the voluntary quality information disclosure for green products, if the information disclosure occurs, the optimal retail price \tilde{p}^{d*} , the wholesale price \tilde{w}^{d*} , the recycling rate $\tilde{\tau}^{d*}$ and the transfer fee \tilde{b}^{d*} are given by*

$$\tilde{p}^{d*} = \frac{3\theta q + c_m}{4}, \tilde{w}^{d*} = \frac{\theta q + c_m}{2}, \tilde{\tau}^{d*} = \frac{\Delta}{\alpha(\theta q - c_m)} \text{ and } \tilde{b}^{d*} = \frac{\Delta}{2}. \text{ (For proof, see Appendix)}$$

Given the range of the recycling rate is $0 < \tau < 1$, the study gets that the retailer recycles the used product from the market only when $q > \frac{c_m}{\theta}$. The retailer recycles the used product only when the quality of product is high. Although the recycling cost is omitted in this model, there are recycling costs for the recycling business due to factors such as the transportation cost and labor cost. In addition, the green manufacturer tries to recycle high quality products that meet the recycling standards for remanufacturing. For the products with low quality, used products may not be able to meet recycling standards (the study assumes that the quality of products decreases with the increase of use time). Therefore, the retailer only recycles high quality products for the purpose of recycling. However, when the product quality reaches a certain height, the recycling rate decreases. High product quality means high recycling cost.

Proposition 1. *With the voluntary quality information disclosure for green products, the retailer recycles the used product from the market only when the product quality q meets the recycling standard, i.e., $q > \frac{c_m}{\theta}$. (For proof, see Appendix)*

With the voluntary quality information disclosure for green products, if the information disclosure occurs, the profits of the green manufacturer and retailer are $\tilde{\Pi}^d = \frac{(\theta q - c_m)^2}{8} + \frac{\Delta^2}{8\alpha}$ and $\tilde{\pi}^d = \frac{(\theta q - c_m)^2}{16} + \frac{\Delta^2}{16\alpha}$ respectively.

The retailer has the quality information q_{nd} if the information disclosure does not occur. In this case, the retailer's profit is $\tilde{\pi} = (p - w)(\theta q_{nd} - p) + b\tau(\theta q_{nd} - p) - \alpha\tau^2(\theta q_{nd} - p)^2$ for a given wholesale price w and transfer fee b . By the first order condition of retailer profit function, the study can get the optimal retail price and recycling rate are $\tilde{p}^{nd} = \frac{\theta q_{nd} + w}{2}$ and $\tilde{\tau}^{nd} = \frac{b}{\alpha(\theta q_{nd} - w)}$ respectively. The optimal profit function for the green manufacturer is $\tilde{\Pi} = (w - c_m + \Delta\tau)(\theta q_{nd} - p) - b\tau(\theta q_{nd} - p)$. Again, the

optimal wholesale price and transfer cost for the green manufacturer are $\tilde{w}^{nd} = \frac{\theta q_{nd} + c_m}{2}$ and $\tilde{b}^{nd} = \frac{\Delta}{2}$. The study gets the results in Theorem 2.

Theorem 2. *With the voluntary quality information disclosure for green products, if information disclosure does not occur, the optimal retail price \tilde{p}^{nd*} , the wholesale price \tilde{w}^{nd*} , the recycling rate $\tilde{\tau}^{nd*}$ and the transfer fee \tilde{b}^{nd*} are given by*

$$\tilde{p}^{nd*} = \frac{3\theta q_{nd} + c_m}{4}, \quad \tilde{w}^{nd*} = \frac{\theta q_{nd} + c_m}{2}, \quad \tilde{\tau}^{nd*} = \frac{\Delta}{\alpha(\theta q_{nd} - c_m)} \quad \text{and} \quad \tilde{b}^{nd*} = \frac{\Delta}{2}. \quad (\text{For proof, see Appendix})$$

The profit of the green manufacturer is $\tilde{\Pi}^{nd} = \frac{(\theta q_{nd} - c_m)^2}{8} + \frac{\Delta^2}{8\alpha}$ when the green manufacturer refuses to disclose the quality information. The profit of the retailer is $\tilde{\pi}^{nd} = \frac{(\theta q_{nd} - c_m)^2}{16} + \frac{\Delta^2}{16\alpha}$ when the green manufacturer refuses to disclose the quality information.

The study derives Proposition 2 by comparing the green manufacturer's profits in the case of disclosing quality information and not disclosing quality information.

Proposition 2. *The green manufacturer voluntarily discloses his quality information to the retailer iff product quality q is higher than the quality disclosure threshold, i.e., $q \geq q_{nd}$. (For proof, see Appendix)*

After knowing the information acquisition cost, the study assumes that the probability that the green manufacturer acquire quality information is a , where $0 \leq a \leq 1$. The information acquisition cost z follows the uniform distribution $z \sim U(0, Z)$. With the voluntary quality information disclosure for green products, the green manufacturer may conceal the quality information for two reasons. One is because the information acquisition cost is too high that the green manufacturer refuses to assess product quality from third-party assessment agency. Second, the product quality is lower than the disclosure threshold after the green manufacturer refuses to assess product quality from third-party assessment agency. In this case, the retailer's expectation of quality is as follows

$$q_{nd} = \frac{1-a}{(1-a)+aF(q_{nd})} E(q) + \frac{aF(q_{nd})}{(1-a)+aF(q_{nd})} E(q|q \leq q_{nd}).$$

Given that product quality follows the uniform distribution $q \sim U(0,1)$, $E(q) = \frac{1}{2}$, $E(q|q \leq q_{nd}) = \frac{q_{nd}}{2}$ and $F(q_{nd}) = q_{nd}$. The study derives that the quality threshold for green manufacturer disclosure is as follows (Cao et al., 2020)

$$q_{nd} = \frac{\sqrt{1-a} - (1-a)}{a}. \quad (3)$$

The threshold of the green manufacturer's disclosure of quality information decreases monotonously with the probability of acquiring product information. If $a = 0$, the probability of the green manufacturer acquiring quality information is zero. That means the green manufacturer does not acquire the quality information at any time. q_{nd} equals its expected value (i.e. $q_{nd} = E(q) = \frac{1}{2}$), therefore $0 < q_{nd} < \frac{1}{2}$. On the other hand, if $a = 1$, which means the green manufacturer always acquires the quality information.

Product quality q follows the uniform distribution $q \sim U(0,1)$, thus, $F(q) = q$. If information acquisition occurs, then the profit of the green manufacture is $\tilde{\Pi}^a = \int_0^{q_{nd}} \tilde{\Pi}^{nd} dF(q) + \int_{q_{nd}}^1 \tilde{\Pi}^d dF(q) - z$. If information acquisition does not occur, the profit of the green manufacturer is $\tilde{\Pi}^{na} = \int_0^1 \tilde{\Pi}^{nd} dF(q)$. With the voluntary quality information disclosure for green products, the profit functions of the green manufacturer in acquiring and not acquiring quality information are as follows:

$$\tilde{\Pi}^a = \frac{1}{8} \left(\frac{2}{3} \theta^2 q_{nd}^3 - c_m \theta q_{nd}^2 + \frac{1}{3} \theta^2 - c_m \theta + c_m^2 + \frac{\Delta^2}{\alpha} \right) - z, \quad (4)$$

$$\tilde{\Pi}^{na} = \frac{1}{8} \left[(\theta q_{nd} - c_m)^2 + \frac{\Delta^2}{\alpha} \right]. \quad (5)$$

From Eqs. (4) and (5), the study has $\tilde{\Pi}^a - \tilde{\Pi}^{na} = \frac{1}{24} (2\theta^2 q_{nd}^3 - 3c_m \theta q_{nd}^2 - 3\theta^2 q_{nd}^2 + 6c_m \theta q_{nd} + \theta^2 - 3c_m \theta) - z$. The green manufacturer acquires quality information only when $\tilde{\Pi}^a - \tilde{\Pi}^{na} \geq 0$. Hence, the green manufacturer's information acquisition cost range for acquiring quality information is as follows:

$$z \leq \tilde{z} = \frac{1}{24} (2\theta^2 q_{nd}^3 - 3c_m \theta q_{nd}^2 - 3\theta^2 q_{nd}^2 + 6c_m \theta q_{nd} + \theta^2 - 3c_m \theta), \quad (6)$$

where \tilde{z} denotes the information acquisition cost threshold of the green manufacturer when the voluntary quality information disclosure for green products occurs.

Proposition 3. *With the voluntary quality information disclosure for green products, the green manufacturer will acquire quality information iff the information acquisition cost z is less than the acquisition threshold, i.e., $z \leq \tilde{z} = \frac{1}{24} (2\theta^2 q_{nd}^3 - 3c_m \theta q_{nd}^2 - 3\theta^2 q_{nd}^2 + 6c_m \theta q_{nd} + \theta^2 - 3c_m \theta)$. (For proof, see Appendix)*

By comparing Propositions 1 and 2, the study finds that the retail price p and the wholesale price w are higher (i.e., $\tilde{p}^d > \tilde{p}^{nd}$ and $\tilde{w}^d > \tilde{w}^{nd}$) when quality information disclosure occurs with the voluntary quality information disclosure for green products. Conversely, the recycling rate is lower (i.e., $\tilde{\tau}^d < \tilde{\tau}^{nd}$). The green manufacturer's quality disclosure decision has no effect on the transfer fee b ($\tilde{b}^d = \tilde{b}^{nd}$) because the transfer fee that the green manufacturer pays to the retailer relates only to the production cost savings for the green manufacturer by the remanufacturing operation.

3.3 Mandatory quality information disclosure for green products

In this case, the study assumes that the green manufacturer can be mandated to disclose the quality information when the green manufacturer acquires it. The retailer updates quality information as q with acquiring quality information by the green manufacturer. The retailer updates quality information as \bar{q} without acquire quality information by the green manufacturer, and $\bar{q} = E(q) = \frac{1}{2}$.

The retailer's profit is $\hat{\pi} = (p - w)(\theta q - p) + b\tau(\theta q - p) - \alpha\tau^2(\theta q - p)^2$ for a given wholesale price w and transfer fee b if the green manufacturer discloses quality information. By the first order condition of retailer profit function, the optimal retail price and recycling rate are $\hat{p}^d = \frac{\theta q + w}{2}$ and $\hat{\tau}^d = \frac{b}{\alpha(\theta q - w)}$ respectively. The optimal profit function for the green manufacturer is $\hat{\Pi} = (w - c_m + \Delta\tau)(\theta q - p) - b\tau(\theta q - p)$. Again, the optimal wholesale price and transfer fee for the green manufacturer is $\hat{w}^d = \frac{\theta q + c_m}{2}$ and $\hat{b}^d = \frac{\Delta}{2}$. The study gets the results in Theorem 3.

Theorem 3. *With the mandatory quality information disclosure for green products, if the green manufacturer conceals quality information, the optimal retail price \hat{p}^{d*} , the wholesale price \hat{w}^{d*} , the recycling rate $\hat{\tau}^{d*}$ and the transfer fee \hat{b}^{d*} are given by*

$$\hat{p}^{d*} = \frac{3\theta q + c_m}{4}, \hat{w}^{d*} = \frac{\theta q + c_m}{2}, \hat{\tau}^{d*} = \frac{\Delta}{\alpha(\theta q - c_m)} \text{ and } \hat{b}^{d*} = \frac{\Delta}{2}.$$

(For proof, see Appendix)

The profit of the green manufacturer is $\hat{\Pi}^d = \frac{(\theta q - c_m)^2}{8} + \frac{\Delta^2}{8\alpha}$ with disclosing quality information by the green manufacturer. The profit of the retailer is $\hat{\pi}^d = \frac{(\theta q - c_m)^2}{16} + \frac{\Delta^2}{16\alpha}$ with disclosing quality information by the green manufacturer.

If the green manufacturer conceals quality information, the retailer's profit is $\hat{\pi} = (p - w)(\theta\bar{q} - p) + b\tau(\theta\bar{q} - p) - \alpha\tau^2(\theta\bar{q} - p)^2$, for a given wholesale price w and transfer fee b . The first order condition of retailer profit function describes that the optimal retail price and recycling rate are $\hat{p}^{nd} = \frac{\theta\bar{q} + w}{2}$ and $\hat{\tau}^{nd} = \frac{b}{\alpha(\theta\bar{q} - w)}$ respectively. The optimal profit function for the green manufacturer is $\hat{\Pi} = (w - c_m + \Delta\tau)(\theta\bar{q} - p) - b\tau(\theta\bar{q} - p)$. Again, the best wholesale price and transfer cost for the green manufacturer is $\hat{w}^{nd} = \frac{\theta\bar{q} + c_m}{2}$ and $\hat{b}^{nd} = \frac{\Delta}{2}$. The study gets the results as Theorem 4.

Theorem 4. *With the mandatory quality information disclosure for green products, if the green manufacturer*

conceals quality information, the optimal retail price \hat{p}^{nd*} , the wholesale price \hat{w}^{nd*} , the recycling rate \hat{t}^{nd*} and the transfer fee \hat{b}^{nd*} are given by

$$\hat{p}^{nd*} = \frac{3\theta\bar{q}+c_m}{4}, \hat{w}^{nd*} = \frac{\theta\bar{q}+c_m}{2}, \hat{t}^{nd*} = \frac{\Delta}{\alpha(\bar{q}-c_m)} \text{ and } \hat{b}^{nd*} = \frac{\Delta}{2}. \text{ (For proof, see Appendix)}$$

With the mandatory quality information disclosure for green products, the profit of the green manufacturer is $\hat{\Pi}^{nd} = \frac{(\theta\bar{q}-c_m)^2}{8} + \frac{\Delta^2}{8\alpha}$ when the green manufacturer conceals quality information. The profit of the retailer is $\hat{\pi}^{nd} = \frac{(\theta\bar{q}-c_m)^2}{16} + \frac{\Delta^2}{16\alpha}$ when the green manufacturer conceals quality information.

The profit of the green manufacturer with acquiring the quality information is $\hat{\Pi}^a = \int_0^1 \hat{\Pi}^d dF(q) - z$. The profit of the green manufacturer without acquiring the quality information is $\hat{\Pi}^{na} = \int_0^1 \hat{\Pi}^{nd} dF(q)$. Product quality q follows the uniform distribution $q \sim U(0,1)$, thus, $F(q) = q$, $\bar{q} = E(q) = \frac{1}{2}$. With the mandatory quality information disclosure for green products, the green manufacturer's profit functions in acquiring and not acquiring quality information are as follows:

$$\hat{\Pi}^a = \frac{1}{8} \left(\frac{1}{3} \theta^2 - c_m \theta + c_m^2 + \frac{\Delta^2}{\alpha} \right) - z \quad (7)$$

$$\hat{\Pi}^{na} = \frac{1}{8} \left(\frac{1}{4} \theta^2 - c_m \theta + c_m^2 + \frac{\Delta^2}{\alpha} \right) \quad (8)$$

The difference between the green manufacturer's profit with and without acquiring quality information is $\hat{\Pi}^a - \hat{\Pi}^{na} = \frac{\theta^2}{96} - z$. The green manufacturer acquires quality information only when $\hat{\Pi}^a - \hat{\Pi}^{na} \geq 0$. The study uses \hat{z} to denote the information acquisition cost threshold to acquire quality information. The green manufacturer's information acquisition cost range for acquiring quality information is as follows:

$$z \leq \hat{z} = \frac{\theta^2}{96} \quad (9)$$

Proposition 4. *With the mandatory quality information disclosure for green products, the condition under which the green manufacturer gets quality information is that the information acquisition cost z is less than the acquisition threshold, i.e., $z \leq \hat{z} = \frac{\theta^2}{96}$. (For proof, see Appendix)*

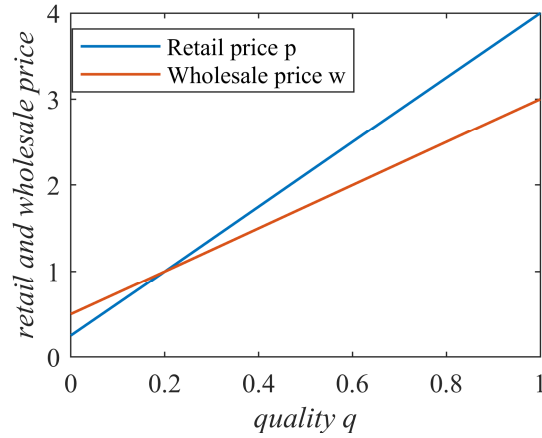


Fig. 2. Relationship between the price and the quality q under completely transparent

The study presents the impact of the product quality on the retail price and the wholesale price when quality information is completely transparent in Fig. 2. Obviously, the green manufacturer and the retailer can charge higher prices when the product is of high quality. The retailer is profitable when the retail price is higher than the wholesale price. However, the retail price is lower than the wholesale price when the product is of low quality. Hence, the retailer only buys and sells products that meet the quality standards. In other words, there is no market for low-quality products when quality information is completely transparent.

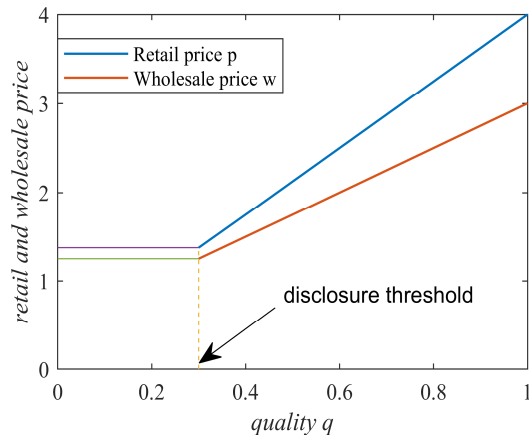


Fig. 3. Relationship between the price and the quality q under voluntary disclosure

The study shows the impact of the product quality on the retail price and the wholesale price under voluntary disclosure in Fig. 3. Under voluntary disclosure, green manufacturers have the right to choose whether or not to disclose product quality information. When the product quality is high, the disclosure of quality information can enable the green manufacturer to set higher wholesale price. Hence, the green manufacturer chooses to disclose product quality information when product quality is above the disclosure threshold. According to Fig. 2, there is no demand for quality products. When the product quality is low, the

green manufacturer charges higher wholesale price without disclosing the product quality information. Hence, when the product quality is low, the green manufacturer hides the product quality information. The retail price is higher than the wholesale price and the retailer has an incentive to participate in sales activities under voluntary disclosure.

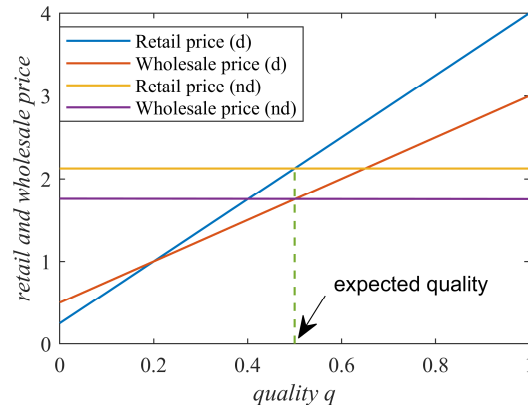


Fig. 4. Relationship between the price and the quality q under mandatory disclosure

Fig. 4 presents the impact of the product quality on the retail price and the wholesale price under mandatory disclosure. When the green manufacturer is forced to disclose quality information, similarly, low-quality products cannot be sold, while high-quality products can bring higher profits. Hence, when the product quality is high, disclosing product quality information is more profitable to the green manufacturer under mandatory disclosure. On the other hand, when the product quality is not disclosed, the green manufacturer can only set the same wholesale price regardless of the product quality. When product quality information is disclosed, the retailer selectively participates in the sales activities according to the product quality.

The study compares the decisions of supply chain members under different disclosure mechanisms. The quality information acquired by supply chain members is true with disclosing quality information by the green manufacturer. Supply chain members make decisions based on product quality levels. Therefore, disclosure mechanisms have no effect on the recycle and price decisions. When the green manufacturer refuses to reveal quality information, the price of wholesale and the price of retail are lower with the voluntary quality information disclosure for green products. The recycling rate is higher with the voluntary quality information disclosure for green products.

3.4 The profits of supply chain members

In this section the study discusses the profits of supply chain members under different disclosure mechanisms of quality information.

3.4.1 Voluntary quality information disclosure for green products

According to Proposition 3, when the voluntary quality information disclosure for green products occurs, the profits of the green manufacturer and the retailer are:

$$\begin{aligned}\tilde{\Pi} &= \underbrace{\int_0^{q_{nd}} \left[\frac{(\theta q_{nd} - c_m)^2}{8} + \frac{\Delta^2}{8\alpha} \right] dF(q)}_{\text{Non-disclosure}} + \underbrace{\int_{q_{nd}}^1 \left[\frac{(\theta q - c_m)^2}{8} + \frac{\Delta^2}{8\alpha} \right] dF(q)}_{\text{disclosure}} - z, \text{ and} \\ \tilde{\pi} &= \underbrace{\int_0^{q_{nd}} \left[\frac{(\theta q_{nd} - c_m)^2}{16} + \frac{\Delta^2}{16\alpha} \right] dF(q)}_{\text{Non-disclosure}} + \underbrace{\int_{q_{nd}}^1 \left[\frac{(\theta q - c_m)^2}{16} + \frac{\Delta^2}{16\alpha} \right] dF(q)}_{\text{disclosure}}.\end{aligned}$$

The green manufacturer refuses to acquire the quality information when the information acquisition cost $z \in (\tilde{z}, Z)$. His profit is $\tilde{\Pi} = \frac{(\theta q_{nd} - c_m)^2}{8} + \frac{\Delta^2}{8\alpha}$. And the retailer's profit is $\tilde{\pi} = \frac{(\theta q_{nd} - c_m)^2}{16} + \frac{\Delta^2}{16\alpha}$.

3.4.2 Mandatory quality information disclosure for green products

In this case, the green manufacturer acquires quality information at the information acquisition cost z , where $z \in (0, \tilde{z})$. His profit is $\hat{\Pi} = \int_0^1 \left[\frac{(\theta q - c_m)^2}{8} + \frac{\Delta^2}{8\alpha} \right] dF(q) - z$. The retailer's profit is $\hat{\pi} = \int_0^1 \left[\frac{(\theta q - c_m)^2}{16} + \frac{\Delta^2}{16\alpha} \right] dF(q)$.

The green manufacturer refuses to acquire quality information when the information acquisition cost $z \in (\tilde{z}, Z)$. His profit is $\hat{\Pi} = \frac{(\theta \bar{q} - c_m)^2}{8} + \frac{\Delta^2}{8\alpha}$. The retailer's profit is $\hat{\pi} = \frac{(\theta \bar{q} - c_m)^2}{16} + \frac{\Delta^2}{16\alpha}$.

By comparing the profits of supply chain members under different disclosure mechanisms, the study gets the Proposition 5.

Proposition 5. *With acquiring quality information by the green manufacturer, the profits of Π supply chain members are higher than that with the voluntary quality information disclosure for green products when consumers have the preference θ for high quality, i.e., $\tilde{\Pi} > \hat{\Pi}$ and $\tilde{\pi} > \hat{\pi}$ when $\theta q_{nd} > \frac{3}{2}c_m$; the profits Π of supply chain members are higher with the mandatory quality information disclosure for green products when consumers have the preference θ for low quality, i.e., $\hat{\Pi} > \tilde{\Pi}$ and $\hat{\pi} > \tilde{\pi}$ when $c_m < \theta q_{nd} < \frac{3}{2}c_m$. (For proof, see Appendix)*

With acquiring quality information by the green manufacturer, the profits of supply chain members are

higher with the mandatory quality information disclosure for green products when $c_m < \theta q_{nd} < \frac{3}{2}c_m$.

When $\theta q_{nd} > \frac{3}{2}c_m$, the profits of supply chain members are higher with the voluntary quality information disclosure for green products. The green manufacturer assesses the product quality for the information acquisition from the third-party quality assessment agency but conceals quality information. With the voluntary quality information disclosure for green products, if the green manufacturer conceals quality information, consumers think the product is of low quality. If consumers are not sensitive to the product quality, the price of low-quality products is lower, and the lower price stimulates consumers to buy. On the contrary, if consumers are sensitive to the product quality, low-quality products will reduce consumers' desire to buy. Therefore, the voluntary quality information disclosure for green products is better for the green manufacturer and the retailer, in the face of consumers who has the preference for low quality, when the green manufacturer acquires the quality information.

Proposition 6. *If the green manufacturer does not assess the product quality for acquisition from the third-part assessment agency, profits Π of supply chain members are higher with the mandatory quality information disclosure for green products, i.e., $\hat{\Pi} > \tilde{\Pi}$ and $\hat{\pi} > \tilde{\pi}$. (For proof, see Appendix)*

If the green manufacturer does not assess the product quality for acquisition from the third-part assessment agency, the profits of supply chain members are higher with the mandatory quality information disclosure for green products has two main reasons. First, the wholesale price and the retail price are higher if the green manufacturer does not assess the product quality for acquisition from the third-part assessment agency. The profits of supply chain members are directly proportional to the price. In addition, when the voluntary quality information disclosure for green products occurs, if the green manufacturer conceals quality information, consumers consider that the green manufacturer deliberately conceals the product quality information because the product is of low quality. That reduces consumers' desire to buy. Therefore, the profits of supply chain members with the mandatory quality information disclosure for green products is higher.

3.5 Consumer surplus

The study analyses the impact of quality information disclosure and acquisition on consumer surplus in the CLSC. With the voluntary quality information disclosure for green products, the consumer surplus is $\widetilde{CS}^d = (\theta q - p)\widetilde{D}^d - \frac{1}{2}\widetilde{D}^{d2} = \frac{(\theta q - c_m)^2}{32}$ with disclosing quality information by the green manufacturer. Conversely, if the green manufacturer conceals the quality information, the consumer surplus is $\widetilde{CS}^{nd} = (\theta q_{nd} -$

$p_{nd})\tilde{D}^{nd} - \frac{1}{2}\tilde{D}^{nd^2} = \frac{(\theta q_{nd} - c_m)^2}{32}$. Thus, with the voluntary quality information disclosure for green products, the expected consumer surplus is as follows:

$$\tilde{ECS} = G(\tilde{z}) \left\{ \int_0^{q_{nd}} \left[\frac{(\theta q_{nd} - c_m)^2}{32} \right] dF(q) \right\} + G(\tilde{z}) \left\{ \int_{q_{nd}}^1 \left[\frac{(\theta q - c_m)^2}{32} \right] dF(q) \right\} + [1 - G(\tilde{z})] \frac{(\theta q_{nd} - c_m)^2}{32}.$$

With the mandatory quality information disclosure for green products, the consumer surplus is $\widehat{CS}^d = (\theta q - p)\widehat{D}^d - \frac{1}{2}\widehat{D}^{d^2} = \frac{(\theta q - c_m)^2}{32}$ with disclosing quality information by the green manufacturer. Conversely, the consumer surplus is $\widehat{CS}^{nd} = (\theta \bar{q} - p_{nd})\widehat{D}^{nd} - \frac{1}{2}\widehat{D}^{nd^2} = \frac{(\theta \bar{q} - c_m)^2}{32}$ without disclosing quality information by the green manufacturer. Thus, with the voluntary quality information disclosure for green products, the expected consumer surplus is as follow:

$$\widehat{ECS} = G(\hat{z}) \left\{ \int_0^1 \left[\frac{(\theta q - c_m)^2}{32} \right] dF(q) \right\} + [1 - G(\hat{z})] \frac{(\theta \bar{q} - c_m)^2}{32}. \quad (10)$$

Proposition 7. *With the mandatory quality information disclosure for green products is better than with the voluntary quality information disclosure for green products from the perspective of consumer surplus ECS, i.e., $\widehat{ECS} > \tilde{ECS}$. (For proof, see Appendix)*

When the product quality information is uncertain, the probability that a consumer buys a product that does not match his demand is large. In order to reduce risks, consumers are more inclined to buy products with transparent quality information. With the mandatory quality information disclosure for green products, quality information is disclosed by a third-party assessment agency. Consumers place more trust in quality information publicly disclosed by the third-party assessment agency. The authenticity of the information reduces the risk of consumers purchasing products that do not match their demands. Therefore, the consumer surplus is higher with the mandatory quality information disclosure for green products.

4. Numerical Study

To gain management insight, the study conducts numerical experiments to examine the impact of the mandatory and voluntary quality information disclosure for green products on decisions of CLSC members. Referring to Cao et al. (2020) and Wang et al. (2020), the study sets parameters as $c_m = 1$, $\Delta = 0.5$, $b = 0.5$, $\alpha = 1$, $\theta = 5$ and $Z = 1$. Unless otherwise specified, the numerical experiments follow the baseline setting.

4.1 The threshold of disclosing quality information

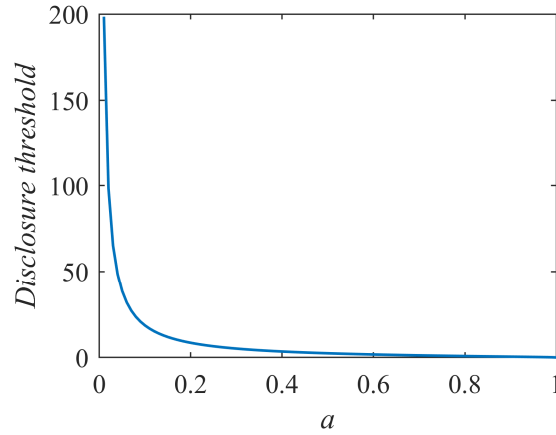


Fig. 5. Relationship between the threshold of quality information disclosure q_{nd} and the probability of acquiring quality information a

The study presents the relationship between the threshold of disclosing quality information and the probability of acquiring quality information by the green manufacturer in Fig.5. The threshold of quality information disclosure decreases monotonously with the probability of acquiring product information. If $a = 0$, the probability of the green manufacturer acquiring quality information is zero. That means the green manufacturer do not acquire quality information at any time and the disclosure threshold is very large. On the other hand, if $a = 1$, which means the green manufacturer always acquires quality information and the disclosure threshold is zero.

4.2 The threshold of acquiring quality information

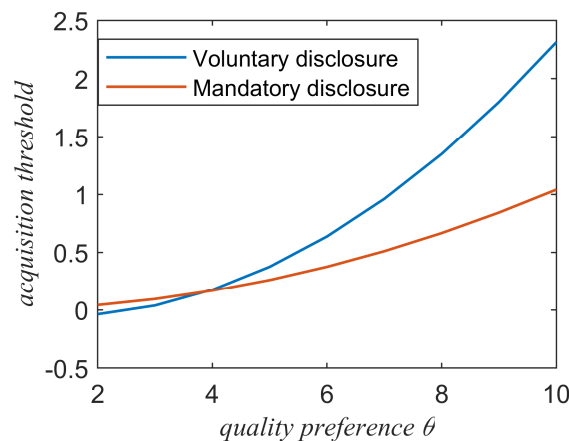


Fig. 6. Relationship between the threshold of acquiring quality information and the quality preference θ of consumers

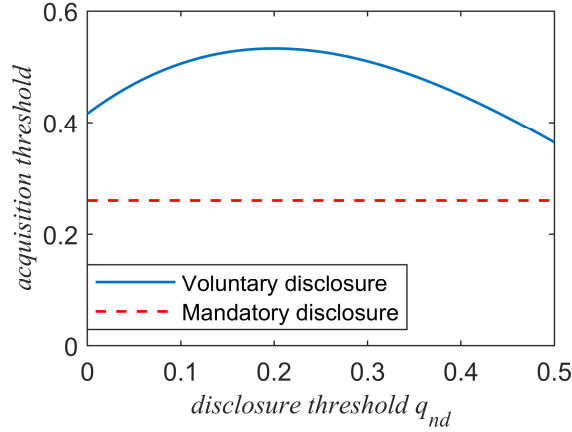


Fig. 7. Relationship between the threshold of acquiring quality information and the threshold of quality information disclosure q_{nd}

Fig. 6 presents the relationship between the threshold (\tilde{z} and \hat{z}) of acquiring quality information and quality preference θ of consumers. The acquisition threshold (\tilde{z} and \hat{z}) increases with quality preference θ of consumers. The green manufacturer acquires quality information if the information acquisition cost z is below the acquisition threshold (\tilde{z} and \hat{z}). The acquisition threshold (\tilde{z} and \hat{z}) is small when the consumers have a preference for low quality q . The green manufacturer is not active in acquiring quality information because consumers do not care about product quality. On the contrary, the acquisition threshold (\tilde{z} and \hat{z}) is large when consumers have a preference for high quality q . The green manufacturer is more willing to acquire quality information even though the information acquisition cost z is higher because consumers care about the quality of the product. The green manufacturer is active in acquiring the quality information when consumers have a preference for high quality.

The study shows the relationship between the threshold of acquiring quality information (\tilde{z} and \hat{z}) and the disclosure threshold q_{nd} in Fig.7. With the mandatory quality information disclosure for green products, the threshold (\tilde{z} and \hat{z}) of acquiring quality information has nothing to do with the threshold of quality information disclosure q_{nd} . Combined with Fig.6, it can be seen that the threshold (\tilde{z} and \hat{z}) of acquiring quality information is only related to quality preference θ of consumers. Under the condition of the voluntary quality information disclosure for green products, the relationship between the threshold (\tilde{z} and \hat{z}) of acquiring quality information and the disclosure threshold q_{nd} is quadratic function. In the traditional concept, the higher the product quality q , the more the green manufacturer is willing to assess the quality information for acquisition. However, our research shows that when product is of high quality, the green manufacturer is willing to pay less cost z for quality information assessment. Because high-quality q

products require higher production costs, the green manufacturer is willing to pay the cost z of information assessment to reduce.

4.3 The profit of the green manufacturer

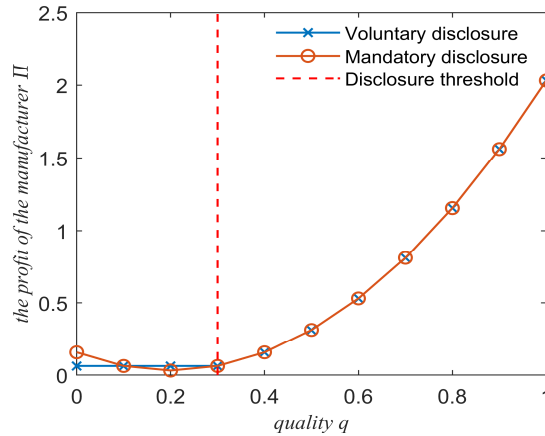


Fig. 8. The profit Π of the green manufacturer and the product quality q

Fig. 8 presents the relationship between product quality q and the green manufacturer's profit Π when the green manufacturer assesses the product quality from the third-part assessment agency. The green manufacturer conceals the quality information with the voluntary quality information disclosure for green products when the quality q is lower than the quality information disclosure threshold q_{nd} . For consumers the product quality q is homogeneous because consumers do not know the product quality q . The product quality q has no effect on the green manufacturer's profit Π . Similarly, consumers know that the product is of low quality q . With the mandatory quality information disclosure for green products, the green manufacturer's profit Π is related to the product quality q because consumers know quality information. When the product quality q is above the quality information disclosure threshold q_{nd} , the green manufacturer's profit Π is the same. Because the green manufacturer always discloses product quality information when the product quality q is high.

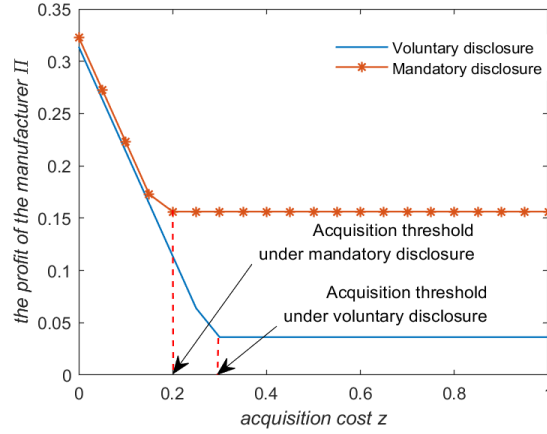


Fig.9. Relationship between the profit Π of the green manufacturer and the information acquisition cost z

Fig. 8 only analyzes the green manufacturer's profit Π on the basis that the green manufacturer knows the product quality. In Fig. 9, the study discusses the relationship between the green manufacturer's decision on information acquisition and the green manufacturer's profit Π when the green manufacturer does not know the quality information. This paper presents relationship between the profit Π of the green manufacturer and the information acquisition cost z in Fig. 9. Here the study verifies the profit Π of the green manufacturers in the face of consumers that have a preference θ for low quality q ($c_m < \theta q_{nd} < \frac{3}{2}c_m$). When the information acquisition cost z is lower than the acquisition threshold (\tilde{z} and \hat{z}), the green manufacturer's profit Π decreases with the information acquisition cost z . At this time, the information disclosure mechanism has little impact on the green manufacturer's profit Π . When the information acquisition cost z is higher than the acquisition threshold (\tilde{z} and \hat{z}), information disclosure mechanism rather than the information acquisition cost z is the main factor affecting the green manufacturer's profit Π .

The study presents the green manufacturer's profit Π about the information acquisition cost z and the disclosure threshold q_{nd} of quality information with the voluntary quality information disclosure for green products in Fig. 10. Here the study verifies the profit of the green manufacturer in the face of consumers that have a preference θ for high quality ($\theta q_{nd} > \frac{3}{2}c_m$). When the information acquisition cost z is below the acquisition threshold, the green manufacturer acquires quality information. The green manufacturer's profit decreases with the information acquisition cost z . The green manufacturer refuses to acquire quality information when the information acquisition cost z is higher than the acquisition threshold (\tilde{z} and \hat{z}). The information acquisition cost z has no effect on the green manufacturer's profit Π . In addition, the green manufacturer's profit Π and disclosure threshold q_{nd} is nonmonotonic. Combined with Fig. 7, the profit Π

of the green manufacturer is negatively correlated with the information acquisition cost z . The information acquisition cost z is the highest at the lowest point in the green manufacturer's profit.

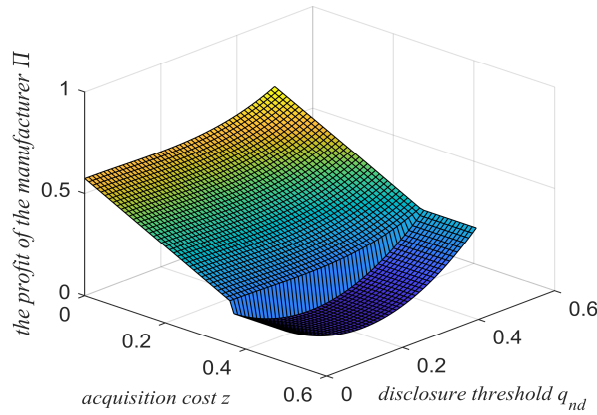


Fig. 10. The profit Π of the green manufacturer with the voluntary quality information disclosure for green products

Through the numerical analysis, the management insights are as follow: (1) Whether the green manufacturer acquires quality information from third-party assessment agency depends on the information acquisition cost. The green manufacturer tends to acquire the quality information when the information acquisition cost is low. (2) The threshold for the green manufacturer to acquire the quality information is related to quality preference of consumers. When consumers have a preference for high quality, the green manufacturer is willing to pay higher the information acquisition cost to acquire quality information. (3) The mandatory quality information disclosure for green products model is better for the supply chain members in the face of consumers that have a preference for low quality when the green manufacturer acquiring quality information.

5. Sensitivity Analysis

Due to product quality, the consumers' preference for quality, production cost, recovery cost coefficient and other factors affect the profit of the CLSC members. It is necessary to perform sensitivity analysis to present the influence of parameter changes on the profits of the green manufacturer and the retailer. As shown in Table 3 and Table 4, the study analyses the impact of changes in parameters -50%, -25%, +25% and +50% on the profits of the green manufacturer and the retailer, respectively (Sarkar et al., 2019b). The sensitivity analysis of 5 parameters are as follows:

Table 3. Sensitivity analysis to the manufacturer's profit

Sr. no.	Notation	Parameters	Original value	% change in value	New value	% effect on profit
1	θ	The consumers' preference for product quality	5	-50	2.5	-87.49
				-25	3.75	-59.36
				+25	6.25	+90.62
				+50	7.5	+212.51
2	q	The quality of the product	0.5	-50	0.25	-87.49
				-25	0.375	-59.36
				+25	0.625	+90.62
				+50	0.75	+212.51
3	c_m	Unit production cost of new product	1	-50	0.5	+70.02
				-25	0.75	+32.51
				+25	1.25	-27.49
				+50	1.5	-49.98
4	Δ	Cost saving from per unit remanufactured product	0.5	-50	0.25	-7.49
				-25	0.375	-4.38
				+25	0.625	+5.63
				+50	0.75	+12.51
5	α	Coefficient of recycle cost	1	-50	0.5	+10.02
				-25	0.75	+3.33
				+25	1.25	-1.98
				+50	1.5	-3.33

Table 4. Sensitivity analysis to the retailer's profit

Sr. no.	Notation	Parameters	Original value	% change in value	New value	% effect on profit
1	θ	Consumers' preference for product quality	5	-50	2.5	-87.52
				-25	3.75	-59.37
				+25	6.25	+90.60
				+50	7.5	+212.41
2	q	The quality of the product	0.5	-50	0.25	-87.52
				-25	0.375	-59.37
				+25	0.625	+90.60
				+50	0.75	+212.41
3	c_m	Unit production cost of new product	1	-50	0.5	+69.93
				-25	0.75	+32.44
				+25	1.25	-27.51
				+50	1.5	-50.03
4	Δ	Cost saving from per unit remanufactured product	0.5	-50	0.25	-7.55
				-25	0.375	-4.41
				+25	0.625	+5.57
				+50	0.75	+12.48
5	α	Coefficient of recycle cost	1	-50	0.5	+9.98
				-25	0.75	+3.33

+25	1.25	-2.05
+50	1.5	-3.39

(1) Consumers' preference for product quality θ : By changing consumers' preference for product quality from -50% to +50%, the results show a positive relationship and a change of -87.49% to +212.51% of the green manufacturer's profit respectively. Consumers' preference for the product quality has an asymmetric positive effect on the profit of the green manufacturer. In particular, a +50% increase in consumers' preference for product quality has a dramatic impact on the profit, changing to +212.51%. Consumers' high preference for product quality stimulates the sharp increase of the profits of the green manufacturer. Similarly, by changing the consumers' preference for the product quality from -50% to +50%, the results present a positive change, showing a change of -87.52% to + 212.41% in the retailer's profit. Consumers' preference for the product quality is one of the important factors in the study. The comparison shows that the change of consumers' preference for product quality has almost the same effect on the profits of the green manufacturer and the retailer. The green manufacturer and the retailer can obtain higher profits from consumers with high-quality preference when the products have the same quality.

(2) The quality of the product q : By changing the product quality from -50% to +50%, the results show a positive relationship and a change of -87.49% to +212.51% of the green manufacturer's profit. The quality of the product has an asymmetric positive effect on the profit of the green manufacturer. The product quality stimulates the sharp increase of the profits of the green manufacturer. High-quality products can bring more profit to the green manufacturer. Similarly, by changing the product quality from -50% to +50%, the results present a positive change, showing a change of -87.52% to + 212.41% in the retailer's profit. High-quality products can significantly increase the retailer's profit by reducing the cost of sales effort. Compared with consumers' preference for product quality, changes in product quality have almost the same effect on the profits of the green manufacturer and the retailer. The implication for the green manufacturer and the retailer is that improving product quality can have a significant impact on profits. However, in practice, due to the constraints of production technology and production cost, it becomes more difficult for the green manufacturer to improve the product quality.

(3) Unit production cost of new product c_m : Based on the sensitivity analysis of the unit production cost of new product, the green manufacturer's profit changes dramatically by +70.02% and +32.51% respectively through changing the unit production cost of new product by -50% and -25%. In contrast, changes in the unit production cost of new product of +25% and +50% lead to changes in the green manufacturer's profit of

-27.49% and -49.98%, respectively. The unit production cost of new product has an asymmetric negative effect on the profit of the green manufacturer. The production cost is one of the important variables in the study and includes all the production-related costs such as labor, transportation and time cost. Similarly, by changing the unit production cost of new product from -50% to +50%, the results present an inverse change, showing a change of +69.93% to -50.03% in the retailer's profit. Production cost is the direct cost to the manufacturer, and therefore, the impact of production costs on the green manufacturer is greater than the impact on the retailer. The unit production cost of new product is an important factor that cannot be ignored in the production decision of the green manufacturer. For the green manufacturer, the increase in profit from the lower unit production cost of new product is greater than the decrease in profit from the higher unit production cost of new product. Hence, the green manufacturer tends to reduce the unit production cost of new product to generate higher profit.

(4) Cost saving from per unit remanufactured product Δ : The change of the cost saving from per unit remanufactured product have less impact on the profits of the green manufacturer and the retailer than the unit production cost of new product. By changing the cost savings of per unit remanufactured product from -50% to +50%, the results show a positive relationship and a change of -7.49% to +12.51% of the green manufacturer's profit. The cost savings of per unit remanufactured product has an asymmetric positive effect on the profit of the green manufacturer. Similarly, by changing the cost savings of per unit remanufactured product from -50% to +50%, the results present a positive change, showing a change of -7.55% to + 12.48% in the retailer's profit. The cost savings of per unit remanufactured product is an important variable in measuring remanufacturing. Mature remanufacturing technologies bring more profit to the green manufacturer and the retailer by reducing the cost of remanufacturing. However, the output of new products is much larger than the output of remanufactured products, reducing the unit production cost of new product significantly increases the profits of the green manufacturer and retailer in a CLSC.

(5) Coefficient of recycle cost α : The coefficient of recycle cost has very small effect on the profits of the green manufacturer and the retailer. From the sensitivity analysis, the green manufacturer's profit changes slightly by +10.02% and +3.33% respectively through changing the coefficient of recycle cost by -50% and -25%. In contrast, changes in the coefficient of recycle cost of +25% and +50% lead to changes in the green manufacturer's profit of -1.98% and -3.33%, respectively. The coefficient of recycle cost has an asymmetric negative effect on the profit of the green manufacturer. Similarly, by changing the coefficient of recycle cost from -50% to +50%, the results present an inverse change, showing a change of +9.98% to -3.39% in the

retailer's profit. The coefficient of recycle cost is one of the important variables in the study, because recycling used products is a key part of the remanufacturing business. The cost of recycling used products has less impact on the profits of the green manufacturer and the retailer than the unit production cost of new product. Therefore, companies should focus on reducing the production cost of new products, even if it is difficult on the technical level.

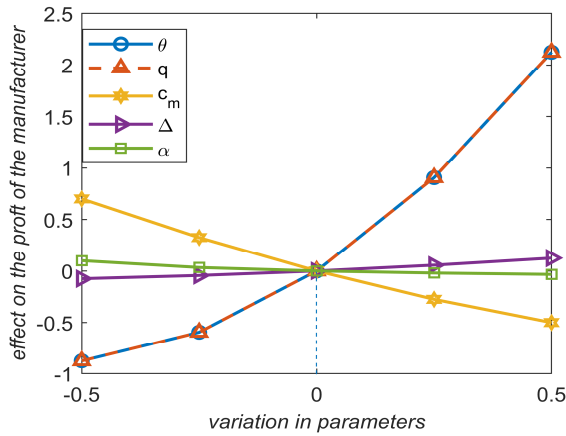


Fig. 11. The effect of variation of parameter on the green manufacturer's profit

In order to clearly observe the weight of each factor on the green manufacturer's profit, we present the sensitivity analysis of key variables in Fig. 11. The figure related to sensitivity analysis shows that the product quality and consumers' preferences for product quality have the greatest impact on the profits of the green manufacturer and the retailer. The most effective way for enterprises to improve profits is to constantly optimize product quality through technology research and development. High quality products are the key factors for enterprises to gain core competitiveness in the market. This result supports that the research on quality information acquisition and disclosure of this paper is very necessary in a CLSC. In addition, reducing the unit production cost of new product is also the key to increasing the profits of the green manufacturer and the retailer. The cost of recycling used products has less impact on the profits of the green manufacturer and the retailer than the unit production cost of new product. The remanufacturing business can improve the profits of the green manufacturer by reducing the production cost in a CLSC. However, the output of new products is much larger than the output of remanufactured products, reducing the unit production cost of new product significantly increases the profits of the green manufacturer and retailer.

6. Concluding remarks

6.1 Conclusions

This paper studies the information acquisition decision and two disclosure mechanisms of the green manufacturer in the CLSC. First, the study discusses the influence of information disclosure mechanism on the recycling and pricing decisions of supply chain members in the CLSC, and then the study analyzes the effect of the information acquisition cost on the green manufacturer's profit under different disclosure mechanisms. The study combines features where the green manufacturer saves production costs by remanufacturing used products and information disclosure mechanism. The main findings of the study are as follows:

Regarding research question (1), the study finds condition under which the green manufacturer acquires the product quality information in CLSCs. The green manufacturer assesses quality information for acquisition from the third-party assessment agency when the information acquisition cost is lower than the acquisition threshold. In addition, the acquisition threshold is related to quality preference of consumers. When facing consumers with a preference for high quality, the green manufacturer can accept higher information acquisition cost.

Regarding research question (2), the study finds the condition under which the green manufacturer discloses the product quality information in CLSCs. The results show that the profits of CLSC members considering the mandatory quality information disclosure for green products is higher when the green manufacturer refuses to assess product quality and acquire the quality information from the third-party assessment agency. The green manufacturer voluntarily discloses the quality information if and only if $q \geq q_{nd}$ after the green manufacturer assesses the product quality and acquires the quality information from the third-party assessment agency. When the green manufacturer discloses the quality information, the disclosure mechanisms have no effect on price and recovery decisions. When quality information disclosure does not occur, the wholesale price and the retail price are lower. In addition, the consumer surplus is higher with the mandatory quality information disclosure for green products.

Regarding research question (3), our research shows that consumers' preference for quality influences the green manufacturer's information decisions (acquisition and disclosure) and profit. When consumers prefer high quality, the green manufacturers are willing to pay higher the information acquisition cost to assess quality information from the third-part assessment agency. However, for green manufacturers, mandatory disclosure is better than voluntary disclosure when consumers' preference for product quality is low.

6.2 Managerial insights

The study gets some managerial insights by considering the consumer preference of green products: (1) The threshold for the green manufacturer to acquire the quality information is related to quality preference of consumers. The green manufacturer is willing to pay a higher information acquisition cost to acquire the quality information when consumers prefer high quality. (2) The profits of the green manufacturer and the associated retailer of the CLSC are higher with the mandatory quality information disclosure for green products, compared with that in the voluntary quality information disclosure for green products, when the green manufacturer refuses to assess the product quality and acquire the information from the third-party quality assessment agency. The mandatory quality information disclosure for green products model is better for the supply chain members in the face of consumers that prefer low quality when the green manufacturer acquiring quality information. (3) Whether the green manufacturer acquires quality information from third-party assessment agency depends on the information acquisition cost. The green manufacturer tends to acquire the quality information when the information acquisition cost is low. (4) When product quality information is disclosed, consumers have no demand for low-quality green products. Hence, the green manufacturer strives to improve product quality in order to gain more market share under the condition of quality information disclosure. In the absence of public information on quality, the green manufacturer may pay less attention to product quality.

6.3 Future research

Some limitations exist in our research. First, the study considers that the quality information acquired by the green manufacturer reflects the actual quality of the product, and the green manufacturer has no concealment or false disclosure when disclosing information. The future research could consider the regulation of information disclosure or imperfect information disclosure. Second, the study considers the way in which consumers acquire the accurate quality information from the green manufacturer. However, consumers can access the product quality information in other ways. For example, consumers acquire quality information through online reviews. Future research could examine the impact of online reviews on remanufacturing. Third, the study considers the manufacturer's quality information decision in a two-echelon CLSC consisting of a manufacturer and a retailer. Existing research shows that the two-echelon supply chain model has its research value and practical significance (Sarkar et al., 2019a; Sarkar et al., 2020). It is interesting to further consider the manufacturer's quality information decisions in a multi-echelon supply chain. Finally, the study considers how to optimize information decision by the manufacturer under

Stackelberg game model (Noh et al., 2019). Future research can compare the benefit for asymmetric and symmetric power of SCM players.

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Appendix

The basic model of the green manufacturer's profit function without considering information disclosure and acquisition as follows:

$$\text{Max}_{w,b} \Pi = (w - c_m + \Delta\tau)(\theta q - p) - b\tau(\theta q - p). \quad (\text{A1})$$

First, the study proves that profit function Π is concave on w for a given b for Π satisfy conditions $\frac{\partial \Pi^2}{\partial w^2} = -2 < 0$, which enables us to optimize w for the green manufacturer of a given b , and then check the effect of b .

The basic model of the retailer's profit function without considering information disclosure and acquisition as follows:

$$\text{Max}_{p,\tau} \pi = (p - w)(\theta q - p) + b\tau(\theta q - p) - \alpha\tau^2(\theta q - p)^2. \quad (\text{A2})$$

The Hessian matrix of π is

$$H = \begin{pmatrix} \frac{\partial \pi^2}{\partial \tau^2} & \frac{\partial \pi^2}{\partial \tau \partial p} \\ \frac{\partial \pi^2}{\partial \tau \partial p} & \frac{\partial \pi^2}{\partial p^2} \end{pmatrix} = \begin{pmatrix} -2 - 2\alpha\tau^2 & 2\alpha\tau(\theta q - p) - b \\ 2\alpha\tau(\theta q - p) - b & -2\alpha(\theta q - p)^2 \end{pmatrix}. \quad (\text{A3})$$

For π to be concave in p and τ , π should satisfy conditions (i) $\frac{\partial \pi^2}{\partial \tau^2} < 0$, (ii) $\frac{\partial \pi^2}{\partial p^2} < 0$, and (iii) $(\frac{\partial \pi^2}{\partial \tau^2})(\frac{\partial \pi^2}{\partial p^2}) > (\frac{\partial \pi^2}{\partial \tau \partial p})^2$. Note that (i) holds since $\frac{\partial \pi^2}{\partial \tau^2} = -2 - 2\alpha\tau^2 < 0$. Similarly, (ii) holds since $\frac{\partial \pi^2}{\partial p^2} = -2\alpha(\theta q - p)^2 < 0$. The study needs $4\alpha(1 + \alpha\tau^2)(\theta q - p)^2 > [2\alpha\tau(\theta q - p) - b]^2$ for condition (iii) to hold. Hence, π is jointly concave in p and τ if $4\alpha(1 + \alpha\tau^2)(\theta q - p)^2 > [2\alpha\tau(\theta q - p) - b]^2$.

The proof of Theorem 1

With the voluntary quality information disclosure for green products, $\tilde{\pi} = (p - w)(\theta q - p) + b\tau(\theta q - p) - \alpha\tau^2(\theta q - p)^2$ with disclosing quality information.

The first order condition of $\tilde{\pi}$ describes that the retail price and recycling rate are $p = \frac{\theta q + w}{2}$ and $\tau = \frac{b}{\alpha(\theta q - w)}$ respectively based on π is jointly concave in τ and p .

$\tilde{\Pi} = (w - c_m + \Delta\tau)(\theta q - p) - b\tau(\theta q - p)$. The study substitutes p and τ into $\tilde{\Pi}$, $\tilde{\Pi} = \frac{1}{2}(w - c_m)(\theta q - w) - \frac{b\Delta - b^2}{2\alpha}$. The first order condition of $\tilde{\Pi}$ describes the optimal $\tilde{w}^d = \frac{\theta q + c_m}{2}$ and $\tilde{b}^d = \frac{\Delta}{2}$. The

study gets the optimal $\tilde{p}^d = \frac{3\theta q + c_m}{4}$ and the optimal $\tilde{\tau}^d = \frac{\Delta}{\alpha(\theta q - c_m)}$ by substituting \tilde{w}^d and \tilde{b}^d into p and τ .

With the voluntary quality information disclosure for green products, the profit of the green manufacturer with disclosing quality information is $\tilde{\Pi}^d = \frac{(\theta q - c_m)^2}{8} + \frac{\Delta^2}{8\alpha}$. The profit of the retailer with disclosing quality information is $\tilde{\pi}^d = \frac{(\theta q - c_m)^2}{16} + \frac{\Delta^2}{16\alpha}$.

The proof of Theorem 2

If quality information disclosure does not occur, the retailer has the quality information q_{nd} . In this case, $\tilde{\pi} = (p - w)(\theta q_{nd} - p) + b\tau(\theta q_{nd} - p) - \alpha\tau^2(\theta q_{nd} - p)^2$.

The first order condition of retailer profit function describes that the retail price and recycling rate are $p = \frac{\theta q_{nd} + w}{2}$ and $\tau = \frac{b}{\alpha(\theta q_{nd} - w)}$ respectively based on π is jointly concave in τ and p . $\tilde{\Pi} = (w - c_m + \Delta\tau)(\theta q_{nd} - p) - b\tau(\theta q_{nd} - p)$. The study substitutes p and τ into $\tilde{\Pi}$, $\tilde{\Pi} = \frac{1}{2}(w - c_m)(\theta q_{nd} - w) - \frac{b\Delta - b^2}{2\alpha}$. The first order condition of $\tilde{\Pi}$ describes that the optimal $\tilde{w}^{nd} = \frac{\theta q_{nd} + c_m}{2}$ and $\tilde{b}^{nd} = \frac{\Delta}{2}$. The study gets the optimal $\tilde{p}^{nd} = \frac{3\theta q_{nd} + c_m}{4}$ and the optimal $\tilde{\tau}^{nd} = \frac{\Delta}{\alpha(\theta q_{nd} - c_m)}$ by substituting \tilde{w}^{nd} and \tilde{b}^{nd} into p and τ .

The profit of the green manufacturer without disclosing quality information is $\tilde{\Pi}^{nd} = \frac{(\theta q_{nd} - c_m)^2}{8} + \frac{\Delta^2}{8\alpha}$.

The profit of the retailer without disclosing quality information is $\tilde{\pi}^{nd} = \frac{(\theta q_{nd} - c_m)^2}{16} + \frac{\Delta^2}{16\alpha}$.

The proof of Proposition 2

$\tilde{\Pi}^d > \tilde{\Pi}^{nd} = \left[\frac{(\theta q - c_m)^2}{8} + \frac{\Delta^2}{8\alpha} \right] > \left[\frac{(\theta q_{nd} - c_m)^2}{8} + \frac{\Delta^2}{8\alpha} \right] \Rightarrow q \geq q_{nd}$. Therefore, the green manufacturer discloses the quality information if and only if $q \geq q_{nd}$.

The proof of Proposition 3

With the voluntary quality information disclosure for green products, the profit of the green manufacturer with acquiring the quality information is $\tilde{\Pi}^a = \int_0^{q_{nd}} \tilde{\Pi}^{nd} dF(q) + \int_{q_{nd}}^1 \tilde{\Pi}^d dF(q) - z$. Where, $F(q) = q$, $\tilde{\Pi}^d = \frac{(\theta q - c_m)^2}{8} + \frac{\Delta^2}{8\alpha}$ and $\tilde{\Pi}^{nd} = \frac{(\theta q_{nd} - c_m)^2}{8} + \frac{\Delta^2}{8\alpha}$. The profit functions of the green manufacturer with acquiring quality information is as follow:

$$\tilde{\Pi}^a = \frac{1}{8} \left(\frac{2}{3} \theta^2 q_{nd}^3 - c_m \theta q_{nd}^2 + \frac{1}{3} \theta^2 - c_m \theta + c_m^2 + \frac{\Delta^2}{\alpha} \right) - z, \quad (A4)$$

The profit of the green manufacturer without acquiring the quality information is $\tilde{\Pi}^{na} = \int_0^1 \tilde{\Pi}^{nd} dF(q)$.

Where, $F(q) = q$ and $\tilde{\Pi}^{nd} = \frac{(\theta q_{nd} - c_m)^2}{8} + \frac{\Delta^2}{8\alpha}$. The profit functions of the green manufacturer without acquiring quality information is as follow:

$$\tilde{\Pi}^{na} = \frac{1}{8} \left[(\theta q_{nd} - c_m)^2 + \frac{\Delta^2}{\alpha} \right]. \quad (A5)$$

From Eqs. (A4) and (A5), the study has $\tilde{\Pi}^a - \tilde{\Pi}^{na} = \frac{1}{24} (2\theta^2 q_{nd}^3 - 3c_m \theta q_{nd}^2 - 3\theta^2 q_{nd}^2 + 6c_m \theta q_{nd} + \theta^2 - 3c_m \theta) - z$. The green manufacturer acquires quality information only when $\tilde{\Pi}^a - \tilde{\Pi}^{na} \geq 0$. The green manufacturer's information acquisition cost range for acquiring quality information is as follow:

$$z \leq \tilde{z} = \frac{1}{24} (2\theta^2 q_{nd}^3 - 3c_m \theta q_{nd}^2 - 3\theta^2 q_{nd}^2 + 6c_m \theta q_{nd} + \theta^2 - 3c_m \theta). \quad (A6)$$

The proof of Theorem 3

With the mandatory quality information disclosure for green products, the retailer updates quality information as q with acquiring quality information. The retailer's profit is $\hat{\pi} = (p - w)(\theta q - p) + b\tau(\theta q - p) - \alpha\tau^2(\theta q - p)^2$.

The first order condition of $\hat{\pi}$ describes that the retail price and recycling rate are $p = \frac{\theta q + w}{2}$ and $\tau = \frac{b}{\alpha(\theta q - w)}$ respectively based on π is jointly concave in p and τ .

$\hat{\Pi} = (w - c_m + \Delta\tau)(\theta q - p) - b\tau(\theta q - p)$. The study substitutes p and τ into $\hat{\Pi}$, $\hat{\Pi} = \frac{1}{2}(w - c_m)(\theta q - w) - \frac{b\Delta - b^2}{2\alpha}$. The first order condition of $\hat{\Pi}$ describes that the optimal $\hat{w}^d = \frac{\theta q + c_m}{2}$ and $\hat{b}^d = \frac{\Delta}{2}$. The study gets the optimal $\hat{p}^d = \frac{3\theta q + c_m}{4}$ and the optimal $\hat{\tau}^d = \frac{\Delta}{\alpha(\theta q - c_m)}$ by substituting \hat{w}^d and \hat{b}^d into p and τ .

With the mandatory quality information disclosure for green products, the profit of the green manufacturer with disclosing quality information is $\hat{\Pi}^d = \frac{(\theta q - c_m)^2}{8} + \frac{\Delta^2}{8\alpha}$. The profit of the retailer with disclosing quality information is $\hat{\pi}^d = \frac{(\theta q - c_m)^2}{16} + \frac{\Delta^2}{16\alpha}$.

The proof of Theorem 4

With the mandatory quality information disclosure for green products, the retailer updates quality

information as \bar{q} without acquiring quality information, and $\bar{q} = E(q) = \frac{1}{2}$. $\hat{\pi} = (p - w)(\theta\bar{q} - p) + b\tau(\theta\bar{q} - p) - \alpha\tau^2(\theta\bar{q} - p)^2$.

The first order condition of $\hat{\pi}$ describes that the retail price and recycling rate are $p = \frac{\theta\bar{q} + w}{2}$ and $\tau = \frac{b}{\alpha(\theta\bar{q} - w)}$ respectively based on π is jointly concave in τ and p .

$\hat{\Pi} = (w - c_m + \Delta\tau)(\theta\bar{q} - p) - b\tau(\theta\bar{q} - p)$. The study substitutes p and τ into $\hat{\Pi}$, $\hat{\Pi} = \frac{1}{2}(w - c_m)(\theta\bar{q} - w) - \frac{b\Delta - b^2}{2\alpha}$. The first order condition of $\hat{\Pi}$ describes that the optimal $\hat{w}^{nd} = \frac{\theta\bar{q} + c_m}{2}$ and $\hat{b}^{nd} = \frac{\Delta}{2}$. The study gets the optimal $\hat{p}^{nd} = \frac{3\theta\bar{q} + c_m}{4}$ and the optimal $\hat{\tau}^{nd} = \frac{\Delta}{\alpha(\bar{q} - c_m)}$ by substituting \hat{w}^{nd} and \hat{b}^{nd} into p and τ .

With the mandatory quality information disclosure for green products, the profit of the green manufacturer without disclosing quality information is $\hat{\Pi}^{nd} = \frac{(\theta\bar{q} - c_m)^2}{8} + \frac{\Delta^2}{8\alpha}$. The profit of the retailer without disclosing quality information is $\hat{\pi}^{nd} = \frac{(\theta\bar{q} - c_m)^2}{16} + \frac{\Delta^2}{16\alpha}$.

The proof of Proposition 4

The profit of the green manufacturer with acquiring the quality information is $\hat{\Pi}^a = \int_0^1 \hat{\Pi}^d dF(q) - z$ with the mandatory quality information disclosure for green products. Where, $F(q) = q$, $\hat{\Pi}^d = \frac{(\theta q - c_m)^2}{8} + \frac{\Delta^2}{8\alpha}$. The profit functions of the green manufacturer with acquiring quality information is as follow:

$$\hat{\Pi}^a = \frac{1}{8} \left(\frac{1}{3} \theta^2 - c_m \theta + c_m^2 + \frac{\Delta^2}{\alpha} \right) - z, \quad (\text{A7})$$

The profit of the green manufacturer without acquiring the quality information is $\hat{\Pi}^{na} = \int_0^1 \hat{\Pi}^{nd} dF(q)$. Where, $F(q) = q$ and $\hat{\Pi}^{nd} = \frac{(\theta\bar{q} - c_m)^2}{8} + \frac{\Delta^2}{8\alpha}$. The profit functions of the green manufacturer without acquiring quality information is as follow:

$$\hat{\Pi}^{na} = \frac{1}{8} \left(\frac{1}{4} \theta^2 - c_m \theta + c_m^2 + \frac{\Delta^2}{\alpha} \right). \quad (\text{A8})$$

From Eqs. (A7) and (A8), the study has $\hat{\Pi}^a - \hat{\Pi}^{na} = \frac{\theta^2}{96} - z$. Quality information acquisition occurs only when $\hat{\Pi}^a - \hat{\Pi}^{na} \geq 0$. Hence, the study derives that the green manufacturer's information acquisition cost range for acquiring quality information is as follow:

$$z \leq \hat{z} = \frac{\theta^2}{96}. \quad (\text{A9})$$

The proof of Proposition 5 and 6

The green manufacturer acquires quality information when the information acquisition cost $z \in (0, \bar{z})$ with the voluntary quality information disclosure for green products. The green manufacturer's profit function

$$\text{is } \tilde{\Pi} = \underbrace{\int_0^{q_{nd}} \left[\frac{(\theta q_{nd} - c_m)^2}{8} + \frac{\Delta^2}{8\alpha} \right] dF(q)}_{\text{Non-disclosure}} + \underbrace{\int_{q_{nd}}^1 \left[\frac{(\theta q - c_m)^2}{8} + \frac{\Delta^2}{8\alpha} \right] dF(q)}_{\text{disclosure}} - z, \text{ where } F(q) = q. \text{ By integrating, the}$$

study gets the green manufacturer's profit function is $\tilde{\Pi} = \frac{1}{24}(2\theta^2 q_{nd}^3 - 3c_m \theta q_{nd}^2 + \theta^2 - 3c_m \theta + 3c_m^2 +$

$$3\frac{\Delta^2}{\alpha}) - z. \text{ The retailer's profit is } \tilde{\pi} = \underbrace{\int_0^{q_{nd}} \left[\frac{(\theta q_{nd} - c_m)^2}{16} + \frac{\Delta^2}{16\alpha} \right] dF(q)}_{\text{Non-disclosure}} + \underbrace{\int_{q_{nd}}^1 \left[\frac{(\theta q - c_m)^2}{16} + \frac{\Delta^2}{16\alpha} \right] dF(q)}_{\text{disclosure}}, \text{ where}$$

$F(q) = q$. By integrating, the study gets the retailer's profit function is $\tilde{\pi} = \frac{1}{48}(2\theta^2 q_{nd}^3 - 3c_m \theta q_{nd}^2 +$

$$\theta^2 - 3c_m \theta + 3c_m^2 + 3\frac{\Delta^2}{\alpha}).$$

The green manufacturer refuses to acquire quality information when the information acquisition cost $z \in (\bar{z}, Z)$ with the voluntary quality information disclosure for green products. His profit is $\tilde{\Pi} = \frac{(\theta q_{nd} - c_m)^2}{8} + \frac{\Delta^2}{8\alpha}$.

$$\text{And the retailer's profit is } \tilde{\pi} = \frac{(\theta q_{nd} - c_m)^2}{16} + \frac{\Delta^2}{16\alpha}.$$

The green manufacturer acquires quality information when the information acquisition cost $z \in (0, \bar{z})$ with the mandatory quality information disclosure for green products. His profit is $\hat{\Pi} = \int_0^1 \left[\frac{(\theta q - c_m)^2}{8} + \frac{\Delta^2}{8\alpha} \right] dF(q) - z$, where $F(q) = q$. By integrating, the study gets the green manufacturer's profit function is

$$\hat{\Pi} = \frac{1}{24}(\theta^2 - 3c_m \theta + 3c_m^2 + 3\frac{\Delta^2}{\alpha}) - z. \text{ The retailer's profit is } \hat{\pi} = \int_0^1 \left[\frac{(\theta q - c_m)^2}{16} + \frac{\Delta^2}{16\alpha} \right] dF(q), \text{ where}$$

$$F(q) = q. \text{ By integrating, the study gets the retailer's profit function is } \hat{\pi} = \frac{1}{48}(\theta^2 - 3c_m \theta + 3c_m^2 + 3\frac{\Delta^2}{\alpha}).$$

The green manufacturer refuses to acquire quality information when the information acquisition cost $z \in (\bar{z}, Z)$. His profit is $\hat{\Pi} = \frac{(\theta \bar{q} - c_m)^2}{8} + \frac{\Delta^2}{8\alpha}$. And the retailer's profit is $\hat{\pi} = \frac{(\theta \bar{q} - c_m)^2}{16} + \frac{\Delta^2}{16\alpha}$.

When the green manufacturer acquires quality information, the green manufacturer's profit difference between the two disclosure mechanisms is $\tilde{\Pi} - \hat{\Pi} = \frac{1}{24}\theta q_{nd}^2(2\theta q_{nd} - 3c_m)$. When $\theta q_{nd} < \frac{3}{2}c_m$, $\tilde{\Pi} - \hat{\Pi} <$

0. According to Proposition 2, the study knows $\theta q_{nd} > c_m$. Hence, the profit of the green manufacturer is

higher with the mandatory quality information disclosure for green products when $c_m < \theta q_{nd} < \frac{3}{2}c_m$. When

$\theta q_{nd} > \frac{3}{2}c_m$, $\tilde{\Pi} - \hat{\Pi} > 0$. Hence, the profit of the green manufacturer is higher with the voluntary quality

information disclosure for green products when $\theta q_{nd} > \frac{3}{2}c_m$.

When the green manufacturer refuses to acquire the quality information, $\tilde{\Pi} - \hat{\Pi} = \frac{(\theta q_{nd} - c_m)^2}{8} - \frac{(\theta \bar{q} - c_m)^2}{8}$, where $q_{nd} \leq \bar{q}$ and $\theta q > c_m$. Hence, $\tilde{\Pi} - \hat{\Pi} < 0$.

When quality information acquisition occurs, the retailer's profit difference between the two disclosure mechanisms is $\tilde{\pi} - \hat{\pi} = \frac{1}{48}\theta q_{nd}^2(2\theta q_{nd} - 3c_m)$. When $c_m < \theta q_{nd} < \frac{3}{2}c_m$, $\tilde{\pi} - \hat{\pi} < 0$. The profit of the retailer is higher with the mandatory quality information disclosure for green products when $c_m < \theta q_{nd} < \frac{3}{2}c_m$. When $\theta q_{nd} > \frac{3}{2}c_m$, $\tilde{\pi} - \hat{\pi} > 0$. The profit of the retailer is higher with the voluntary quality information disclosure for green products when $\theta q_{nd} > \frac{3}{2}c_m$.

When the green manufacturer refuses to acquire the quality information, $\tilde{\pi} - \hat{\pi} = \frac{(\theta q_{nd} - c_m)^2}{16} - \frac{(\theta \bar{q} - c_m)^2}{16}$, where $q_{nd} \leq \bar{q}$ and $\theta q > c_m$. Hence, $\tilde{\pi} - \hat{\pi} < 0$.

The proof of Proposition 7

If the green manufacturer discloses product quality information (the green manufacturer acquires quality information), the consumer surplus is $\widehat{CS}^d = (\theta q - p)\widehat{D}^d - \frac{1}{2}\widehat{D}^{d2} = \frac{(\theta q - c_m)^2}{32}$. Conversely, if quality information disclosure does not occur, the consumer surplus is $\widehat{CS}^{nd} = (\theta q_{nd} - p_{nd})\widehat{D}^{nd} - \frac{1}{2}\widehat{D}^{nd2} = \frac{(\theta q_{nd} - c_m)^2}{32}$.

Thus, with the voluntary quality information disclosure for green products $\widehat{ECS} = G(\hat{z}) \left\{ \int_0^{q_{nd}} \left[\frac{(\theta q_{nd} - c_m)^2}{32} \right] dF(q) \right\} + G(\hat{z}) \left\{ \int_{q_{nd}}^1 \left[\frac{(\theta q - c_m)^2}{32} \right] dF(q) \right\} + [1 - G(\hat{z})] \frac{(\theta q_{nd} - c_m)^2}{32}$, where $F(q) = q$. By integrating, the study gets the consumer surplus is $\widehat{ECS} = \frac{\hat{z}^2}{4Z} + \frac{(\theta q_{nd} - c_m)^2}{32}$.

With the mandatory quality information disclosure for green products, the consumer surplus is $\widehat{CS}^d = (\theta q - p)\widehat{D}^d - \frac{1}{2}\widehat{D}^{d2} = \frac{(\theta q - c_m)^2}{32}$ with disclosing quality information. Conversely, the consumer surplus is $\widehat{CS}^{nd} = (\theta \bar{q} - p_{nd})\widehat{D}^{nd} - \frac{1}{2}\widehat{D}^{nd2} = \frac{(\theta \bar{q} - c_m)^2}{32}$ without disclosing quality information

Thus, the expected consumer surplus is $\widehat{ECS} = G(\hat{z}) \left\{ \int_0^1 \left[\frac{(\theta q - c_m)^2}{32} \right] dF(q) \right\} + [1 - G(\hat{z})] \frac{(\theta \bar{q} - c_m)^2}{32}$, where $F(q) = q$. By integrating, the study gets the consumer surplus is $\widehat{ECS} = \frac{\hat{z}^2}{4Z} + \frac{(\theta \bar{q} - c_m)^2}{32}$.

The difference between the voluntary and mandatory quality information disclosure for green products of

the consumer surplus is $\widetilde{ECS} - ECS = \frac{\bar{z}^2 - \hat{z}^2}{4Z} + \frac{(\widehat{\theta q_{nd} - c_m})^2 - (\theta \bar{q} - c_m)^2}{32} < 0$. Hence, the consumer surplus is higher with the mandatory quality information disclosure for green products.