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Horizontal information sharing or not? The choice in information leakage dilemma of the reverse supply chain

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ABSTRACT

Recyclers can derive benefits from horizontal demand information sharing with competitors under specific conditions. However, these advantages may be compromised by the actions of remanufacturers. Information leakage occurs when a remanufacturer selectively discloses information obtained from one recycler to another. This study aims to support recyclers within the reverse supply chain in effectively engaging in horizontal information sharing while mitigating the risk of remanufacturers disclosing proprietary information to competitors, thereby preventing the dissemination of information contrary to the recyclers' intentions for sharing. The research focuses on analyzing the impact of horizontal information sharing and information leakage on the profitability of both remanufacturers and recyclers. An analytical model has been developed based on partial and asymmetric signals of customer valuation. Three scenarios are explored: no information sharing and no leakage, information sharing only, and scenarios involving both sharing and leakage. The novelty of this study lies in its examination of a demand process characterized by distributional uncertainty, which mirrors the informational challenges faced by recyclers entering new markets or expanding into new recycling categories. Recyclers operate with incomplete information and cannot determine whether they possess superior information compared to their competitors. The findings suggest that information sharing among recyclers can enhance the profits of those experiencing high demand but may adversely affect those with lower demand levels. In the absence of horizontal information sharing between recyclers, remanufacturers tend to leak information about higher-demand recyclers to others. Ultimately, managers of competing firms who face uncertainty regarding their information standing should consider sharing information to gain improved demand forecasts or, at minimum, to prevent remanufacturers from exploiting information leakage for personal gain. This refined analysis provides critical insights for stakeholders in the reverse supply chain, highlighting the complex interplay between information sharing and competitive advantage, as well as the strategic importance of managing information flow to safeguard business interests.

1. Introduction

To address the increasingly diverse and sophisticated needs of consumers, the pace of product replacement has accelerated, leading to shortened product life cycles. As a result, there is a growing volume of obsolete products that no longer meet consumer expectations, necessitating their replacement. This trend has brought the recycling, processing, and reuse of waste products into the spotlight as a critical area of societal concern and academic research. The rapid turnover of products not only reflects evolving consumer preferences but also underscores the urgent need for sustainable practices in managing end-of-life products. Recycling and reusing waste products are essential strategies for reducing environmental impact, conserving resources, and supporting a circular economy. Consequently, these activities have garnered significant attention from policymakers, businesses, and researchers who are committed to developing innovative solutions for waste management and

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promoting sustainability. (Tansel, 2022). Due to the accelerated utilization of resources, which has resulted in a scarcity of some resources in recent decades, the recycling and remanufacturing supply chain has been shown to significantly reduce production costs(Kushwaha et al., 2022), which has gradually received more attention and exerted a wider influence in industry and academia (Abbey et al., 2019). The solution to discarded product recycling and remanufacturing can increase resource utilization efficiency, serving as a critical way to attaining green and sustainable development and cleaner production, as well as a major link in waste resource usage. The reverse supply chain, on which this study is based, often entails the recovery of abandoned products with remanufacturing value from customers, followed by operations such as sorting, testing, disassembly, and remanufacturing to meet the goal of resource reuse. The complexity of the supply chain process also makes the subject relationship more complicated and difficult to coordinate. Especially, at present, the challenge of managing supply chains is the inherent tension of coopetition: that is, to increase revenue through collaborative synergy while at the same time fighting with each other(Wilhelm, 2011). The coordination challenges are more challenging for organizations in closed-loop supply chains that incorporate recycling and remanufacturing than in typical supply chains. The reason is that ineffective recycling and reuse of waste products, as well as the uncertainty of consumers' demand for recycled and remanufactured products makes the process hazy, and it is difficult for enterprises to accurately measure their value in the operation decision-making process (Xavier et al., 2023).

In the reverse supply chain, recycling companies, remanufacturers, and recycling consumers often hold divergent views on market recycling needs and the intrinsic value of recyclable materials. This discrepancy is further intensified when one business entity possesses confidential information that remains inaccessible to other participants within the reverse supply chain. The resulting asymmetric information can undermine the profitability and inter-member relationships within these chains, impacting their overall stability. Information serves as a critical asset for effective business decision-making. In the context of the reverse supply chain, the gathering and judicious disclosure of information represent a collaborative strategy that enables swift exchange of market insights among participants. This approach fosters an environment conducive to achieving mutual benefits and "win-win" outcomes. By promoting transparency and cooperation in information sharing, members of the reverse supply chain can enhance operational efficiencies, improve decision-making processes, and ultimately bolster the sustainability and resilience of the entire system. Therefore, addressing the challenges posed by asymmetric information is crucial for maintaining healthy and productive relationships among reverse supply chain members. Encouraging open communication and cooperative practices can help align the interests of all parties involved, leading to more stable and profitable operations within the sector.(Cheng & Zheng, 2022). Those who lack access to vital information frequently suffer inevitable losses as a result of not having the relevant information needed to make wise decisions(D. Li et al., 2023). This cooperative approach based on information has attracted a lot of interest from businesses and academics in recent years (Wu et al., 2023). The act of sharing information voluntarily and mutually among competitive companies in production and operations management is referred to as horizontal information sharing (Raith, 1996; Vives, 1984). Numerous practices have recognized the potential benefits for both parties when exchanging information with competitors in a supply chain. For instance, in the airline service industry, airlines often enhance their operational performance by forming alliances with competitors and sharing demand information. The average annual revenue growth rate for both Star Alliance and SkyTeam Alliance has been 5.05% since they started horizontally sharing information in 2015. Similarly, in the field of energy efficiency and lighting, Phillips and LED Effect (LEI) were competitors, but in 2006, they shared confidential information and technology to collaborate on developing LED devices. This initiative expanded the influence of both brands and surpassed the competitor Color Kinetics. However, to avoid losing initiative, many information holders are reluctant to divulge their personal data to rivals (Hong et al., 2023). Members with access to market demand information have the ability to compromise profits of other participants by disclosing confidential information. When two companies are not engaged in horizontal information sharing and resources come from the same upstream supplier, there is a possibility that the upstream supplier may disclose information from one company to another for its own benefit, leading to incidents of information leakage.

In reverse supply chains, similar issues exist and merit further exploration. While solutions for product recovery and remanufacturing can enhance resource utilization efficiency and are crucial pathways to achieve green sustainable development, the lack of transparency in the recycling market leads to a scarcity of information exchange among recycling enterprises. This makes it challenging for them to accurately assess their value in operational decision-making processes. This asymmetry in information poses coordination challenges among enterprises and may disrupt the profitability and member relationships within the reverse supply chain, impacting the overall efficiency and stability of the reverse supply chain. When a recycler (downstream enterprise) sells recycled waste products to the same remanufacturer (upstream enterprise), the remanufacturer may engage in "information leakage" by sharing one downstream enterprise's private demand information with another downstream enterprise which provides informational advantage (Li et al., 2022; Yu et al., 2023). This phenomenon is derived from actual business activities, such as the well-known case of information leakage involving Vicor Corporation in the United States, which commissioned Bruno Corporation from Israel to provide electronic component services to Israeli manufacturers. Subsequently, Vicor expanded its electronic component services in Israel through another distributor, Migvan, and disclosed the strategic information managed by Bruno to Migvan. As a result, despite Bruno not obtaining information about the market entrant, Migvan gained access to advantageous information about Bruno, including business prices and customer lists, thus placing Bruno at a disadvantage situation. Consequently, Migvan, armed with information about their competitor, aggressively competed with Bruno for existing and potential customers in the Israeli market(Chang & Sanchez-Loor, 2020). The information leakage behavior of upstream enterprises has caused serious negative impact on the advantageous enterprises whose information has been leaked. Horizontal information sharing between enterprises of equal commercial standing is a form of cooperation and communication, whereas vertical information leakage represents a self-serving behavior by upstream enterprises for their own benefit. Therefore, compared with information leakage, whether actively sharing information horizontally with competitors can reduce the risk of revenue loss is a question worth discussing.

In other researches on information asymmetry: Firstly, most research focuses on traditional sales logistics, with relatively little attention given to reverse logistics and recycling. However, there are differences in demand-price functions and profit expressions between the two, warranting distinct research. Secondly, previous studies have mainly compared and optimized decisions related to vertical information sharing, with insufficient exploration of the interactive effects of horizontal information sharing between competing enterprises and the vertical information leakage between upstream and downstream enterprises. This study addresses this gap. Lastly, prior research has often assumed a sequential entry of competing firms into the market under information asymmetry, with one being a newcomer and the other an incumbent, assuming the latter possesses richer information. However, this assumption does not fully apply to reverse logistics, which this study challenges. Through market research and analysis, it is observed that the timing of electronic products becoming idle, and thus eligible for recycling, is closely linked to the introduction of new products. Consequently, the entry timing of recycling companies into specific segments of the recycling market for such products is similar. In reverse logistics, competing recyclers often lack clear knowledge of each other's market positions, resulting in neither having a clear advantage. Therefore, this study, premised on the mutual lack of clarity regarding each other's market positions among recyclers, examines whether they should horizontally exchange information to avoid unnecessary losses caused by upstream enterprise information leakage. Based on this, this study's model considers consumers' judgment of uncertain market demand signals, where each recycler possesses partial information and cannot determine their position in terms of information compared to similar enterprises. Further research explores the impact of horizontal information sharing and vertical information leakage on supply chain performance and finds that horizontal information sharing benefits recyclers with higher demand signals but harms those with lower demand signals. In the absence of horizontal information sharing, remanufacturers always leak information from recyclers with higher demand signals to those with lower demand signals.

Therefore, the conclusions of this study can provide management insights for waste recycling enterprises engaged in reverse logistics. As the research results indicate, when information positions are unclear, horizontal information sharing emerges as the most beneficial choice. Otherwise, there is a risk of upstream enterprises leaking market demand information to competitors, leading to significant losses due to passive information leakage. Thus, among recyclers in reverse logistics, there exists not merely a competitive relationship; rather, appropriate cooperation can yield unexpected gains. In enterprise management, if recyclers proactively engage in information exchange with competitors, they can better mitigate the risks of information leakage and revenue loss. These findings contribute to a better understanding of the impact of information asymmetry on reverse supply chain participants and help formulate more effective information sharing strategies. Additionally, this study provides important insights for achieving sustainable development goals.

The article is structured as follows: Section 2 reviews some related studies. Section 3 and 4 establish information analysis models for scenarios of no horizontal information sharing and no information leakage, horizontal information sharing, and information leakage. Section 5 dissects these models through simulation examples. Section 6 discusses the study's theoretical contributions and practical implications. Section 7 presents the main conclusions.

2. Literature Review

The article provides a comprehensive overview of three significant research areas within the literature: investigation of information leakage in the supply chain, exploration of horizontal and vertical information sharing, and analysis of information symmetry and asymmetry in reverse supply chain scenarios. Presently, a predominant focus exists on vertical information sharing within conventional supply chains, while inadequate attention has been given to studies pertaining to horizontal information sharing and information leakage. These inquiries typically operate under the assumption that the informational advantage lies with the incumbents as opposed to the new entrants, with minimal emphasis on research related to reverse supply chains. Prior studies have employed comparative signal models across various scenarios, including those involving strategies in downstream companies with either comparable or significantly disparate information states (incumbents and entrants), decisions regarding information sharing before or after the receipt of demand signals, contracts design to prevent information leakage, and assessment of information costs for the disadvantaged party.

2.1. Information leakage in the supply chain

Firstly, this research provided a comprehensive review of relevant research on information leakage, summarizing models describing demand information and manifestations of information leakage. The literature indicates that in the context of random market demand signals, the majority of studies are based on Li's demand signal analysis model, which assumes a random value for the demand signal with a mean of zero and a fixed variance (Li, 2002). However, subsequent research has indicated that a more realistic distribution for market demand signals should be symmetrical(Guo et al., 2014). Other studies mainly propose coordination contracts or specific decision-making strategies and countermeasures to mitigate supply chain risks caused by information leakage by comparing the supply chain conditions before and after information leakage(Y. Chen & Özer, 2019; D. Fang & Ren, 2019; Zhang et al., 2023). Furthermore, the issue of information leakage in specific supply chain compositions, such as those comprising manufacturers, dominant demand information-holding retailers, and capital-constrained new entrant retailers, has been investigated to address questions regarding the efficacy of trade credit in preventing information leakage (Yu et al., 2023). Research has also identified contract categories that promote vertical information sharing in the supply chain while preventing horizontal information leakage among competing suppliers (Chen & Özer, 2019). Another study assumed that two firms with private demand information placed orders with a common supplier, and further indicated whether the firm that acted first was willing to enter into a confidentiality agreement with the supplier(Jain & Sohoni, 2015). Moreover, some scholars have indicated the possibility of information leakage even in collaborative supply chains (Jung & Kouvelis, 2022).

The demand signal model used throughout this study aligns closely with the signal framework proposed by Jain et al. and Chang et al. (Chang & Sanchez-Loor, 2020; Jain et al., 2011). The current study extends the research model proposed by Chang et al. to the application scenario of reverse supply chains, making corresponding modifications better meet the real-life context of reverse supply chains. Notably, the model in this study assumes that the distribution of recycling demand is uncertain, and the recyclers cannot determine the average market demand or its comparative information position.

2.2. Information sharing in the supply chain

Secondly, a comprehensive analysis is conducted on the existing research regarding information sharing in traditional supply chains. A comprehensive review is presented on the practical issues related to information distortion, information costs, and the impact of comparative information positions of companies in the market on the forms and possibilities of information sharing within traditional supply chains. Based on different scenarios of information sharing, many scholars have compared the potential occurrence of information leakage and the impacts of different directions (top-down or bottom-up) and timing of information sharing (pre-share or post-share) on corporate profits and decision-making(Cai et al., 2023; Lv, 2023). Furthermore, some scholars have proposed information strategies and coordination contracts beneficial to all parties involved in the traditional supply chain (Chen et al., 2019; Fang et al., 2021; Hong et al., 2023; Li, 2020). There are studies that focus on green supply chain management under the context of information asymmetry (Sarkar & Guchhait, 2023; Xu et al., 2023). Additionally, the impact of horizontal information sharing on the expected profitability of supply chains is investigated. Notably, the study shows that horizontal information sharing has no significant impact on the vertical information sharing strategies of competitive supply chains. However, under conditions where competition between the chains is less intense, horizontal information sharing has been proven to enhance overall supply chain profitability (Chen et al., 2019). Prior studies primarily assumed a symmetrical scenario wherein retailers possess equal knowledge when receiving market information. It was also assumed that all signals were random and followed a standardized distribution. However, such assumptions fail to reflect real-world business practices, as information asymmetry is pervasive. While existing research on information asymmetry predominantly assumes that incumbent retailers possess superior demand information compared to new entrants, it is essential to acknowledge that this may not always hold true in practice (Shen et al., 2019). This study diverges from previous assumptions and presents a more realistic scenario that better captures the prevalent challenges faced by supply chains. This research contends that there is often a lack of mutual awareness of information positions among companies within the supply chain, leading to uncertainties regarding the extent of market information possessed by each party. This ambiguity surrounding market positions represents a common state among competitors and aligns more closely with the practical realities encountered in business settings.

2.3. Reverse supply chain management

Finally, focusing on the reverse supply chain that this study is based on, it is found that there is currently limited research on the reverse supply chain under conditions of information asymmetry, which warrants further exploration. Most previous studies have focused on traditional sales supply chains, with relatively few studies on reverse supply chains involving recycling and remanufacturing. Considering the scarcity of research on reverse supply chain management and operations under conditions of information asymmetry, there is a need for more investigation. In the context of information symmetry, the majority of research on reverse supply chains has primarily concentrated on topics such as coordinating and optimizing competition and cooperation among supply chain entities, investigating the influence of external factors on the operational efficiency of recycling supply chains and their mechanisms, and conducting comparative analyses of recycling structures within reverse supply chains. (Doan et al., 2021; Chen et al., 2018; Wang & Wang, 2022; Wu et al., 2020). However, in the real business situation of recycling supply chain, most enterprises have asymmetric information, so the research on reverse supply chain management under the situation of information asymmetry has practical significance (D. Li et al., 2023; Wu et al., 2023). Currently, limited research considers the impact of asymmetric information between enterprises in the recycling market on the profits of participants in the reverse supply chain and how to mitigate the risks brought about by asymmetric information. In the context of reverse supply chains, scholars have studied a closed-loop supply chain composed of original equipment manufacturers, retailers, and third-party suppliers, analyzing the impact of competition, collection efficiency, individual rationality, and asymmetric information on three different reverse channel structures (Suvadarshini et al., 2023).

Some studies have concentrated on the practical problems of information asymmetry, significant risks, recycling, traceability, etc., in the actual trading of retired power batteries (Yu et al., 2020). Another study focusing on the information asymmetry between internet recyclers and consumers in online transactions of second-hand products to avoid losses and additional recycling costs due to ethical risks associated with internet recyclers (Khan et al., 2023).

This research extends the investigation of information management and decision optimization for enterprises operating in reverse supply chains under conditions characterized by unclear information positions and uncertain demand. It's assumed that in reverse supply chains, recyclers lack clarity regarding their comparative understanding of market demand compared to their competitors. Consequently, competitive analysis and simultaneous decision-making are more appropriate approaches for analyzing this ambiguous information landscape. By conducting surveys and analyses of real-world practices in reverse supply chains, this study is intended to determine a more realistic distribution of information in the reverse supply chain. This research seeks to address the following question: When recyclers in the recycling market possess partially asymmetric demand information and cannot ascertain their information position relative to other recyclers, and how do decisions regarding horizontal information sharing among recyclers and information leaking by remanufacturers impact the profits of enterprises in the reverse supply chain?

3. Model

This study establishes a structural analysis model for a reverse supply chain, comprising one remanufacturer and two recyclers with different recycling demand information. This study is intended to examine the decision-making performance of two recyclers when setting appropriate pricing for the same type of waste with identical actual value during the recycling process. Remanufacturers obtain electronic wastes from recyclers. Recyclers gain electronic waste from the recycling market by paying specified compensation to customers. All parties share information truthfully in the process of information exchange, and there is no distortion or misrepresentation of information. The recyclers get the demand signal a_i from the recycling market, but they cannot determine if their information status is superior to others. The interrelationships among enterprises in this reverse supply chain are illustrated in Fig. 1.

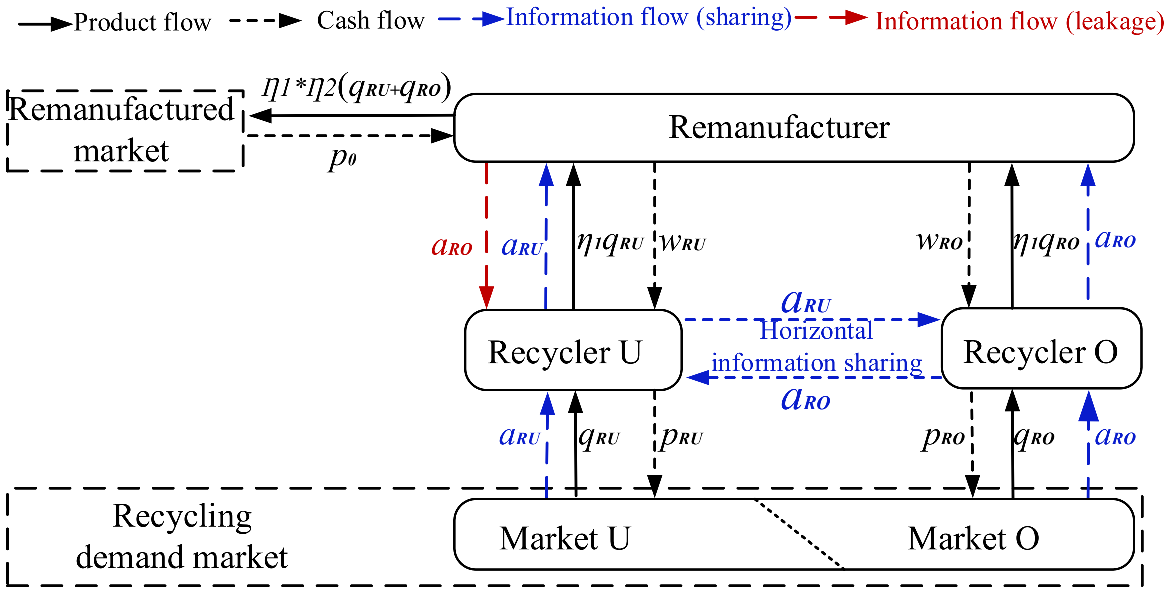

Fig. 1. Reverse Supply Chain Model under Information Asymmetry

This model simulates the scenario in which a recycler is collecting a new category of wastes or entering a new recycling market. Due to limited knowledge of the new market, the recycler cannot determine the demand distribution of wastes. This assumption aligns with scenarios in practice. In the presence of uncertain demand (a) in the recycling market, recyclers obtain a partial information signal a_i by estimating the payment price from customers for recycling. This reflects partial information about the recycling market demand ($a = \sum a_i$). In a new recycling market, when one recycler focuses on the specific reusable value of the waste to be collected, while another retailer focuses on the value of the remaining characteristics, partial information arises (Wu et al., 2018).

When customers estimate a lower benefit from delivering discarded electronic products to recyclers, they perceive a larger scale in the recycling market. The research referred to such recyclers as underestimating recyclers (recycler-U), while those with a lower demand signal are hereby designated as overestimating recyclers (recycler-O). As shown in Fig. 1, we assume that $a_{RU} > a_{RO}$. Without information sharing, recycler-U would make decisions to reduce recycling payment prices and exaggerate demand, assuming that other recyclers would take similar actions. This study is based on several assumptions:

(1) The recycled products are not stockpiled or subject to inventory costs and delayed delivery losses. All recyclers possess the necessary technology for recycling and primary processing, and the utilization rate η_1 $(0 < \eta_1 < 1)$ of recycled products is stable and uniform.
(2) Under the assumption of positive benefits, both recyclers and remanufacturers operate without fixed capacity or financial constraints.
(3) All companies are risk-neutral and economically rational, focusing solely on maximizing expected profit.
(4) Information conveyed by recyclers and remanufacturers is truthful, as disseminating false information would lead to significant additional loss of benefits.
(5) The manufacturer is uncertain about the true type of the market, but the retailer's selection of contracts is considered as a signal (Zhou et al., 2019) . That is, when the recycling company provides the remanufacturer with the actual number of recycled materials, the remanufacturer can deduce the demand information of the waste product market faced by the recycling company based on the number of orders placed. Both upstream and downstream enterprises have already shared demand information vertically when entering into cooperation (J. Li et al., 2019). Furthermore, it means that both recyclers have decided to share their private information vertically with remanufacturers, respectively. Previous literature has proved that sharing demand information between downstream enterprises and upstream enterprises can reduce their costs and bring greater benefits (Rached et al., 2016).

The game begins when each recycler decides whether to share information horizontally. Each recycler (O and U) receives the demand signal a_H and a_L from the market. By default, they engage in vertical information sharing with upstream remanufacturers and decide whether to engage in horizontal information sharing. Subsequently, if the recycler does not engage in horizontal information sharing, the remanufacturer will decide whether to disclose the information. The manufacturer then determines the price for bulk recycling w_{RU} and w_{RO}. Next, the recycler determines the amount of recycling and inventory surplus provided to the remanufacturer according to the Cournot competition principle, and sets the recycling price. Recyclers obtain the discarded electronic products held by customers at the recycling price, and then resell the recycled discarded products to remanufacturers at the bulk recycling price. Finally, the reverse supply chain can run smoothly. Remanufacturers then use the recycled waste products for processing, remanufacturing and resale. The average income p_0 per unit of product obtained by the remanufacturer through the treatment and remanufacturing and marketing of the product is an exogenous constant (assuming that each unit of second-hand product can produce η_2 $(0 < \eta_2 < 1)$ units of marketable re-product after treatment and remanufacturing), considering the cost of recovery, treatment and remanufacturing, etc., the unit cost is c $(c > 0)$ per unit.

The model of this study is a single-period model. According to the demand function of the forward supply chain $q = a - bp$ (Singh & Vives, 1984), where "b" represents the sensitivity coefficient of demand quantity to price, setting "b" as 1 in many previous studies has been found to facilitate the analysis and computation of the model without altering the core parameters' impact on the overall dependent variable and main conclusions (Desai, 2000; Fan et al., 2022). This simplifies the model. Therefore, this study also sets "b" as 1 in the demand function in the reverse supply chain. All the processes of model analysis are provided in the appendix to simplify the calculation. The inverse demand function that reflects the random basic demand of the recycling market is $p(q)$, $p(q) = -a + (q_{RU} + q_{RO})$. The objective function of this research model is to maximize the profit by optimizing the decision variables such as the payment price and the amount of recovery. $Q = q_{RU} + q_{RO}$. The basic demand of the recycling market a can reflect the customer's expected estimate of the recycling price, $a = a_{RU} + a_{RO}$.All the demand signals follow a uniform distribution, $a_i \sim U(a_{-} - x, a - x), x \sim U(0, a_{-})$. As the range of a_i changes, its average value also changes, so recyclers can't determine their own grasp of the market demand signal distribution and the average value of the relationship, this distribution relationship is also the core of recycling market demand information. The remanufacturer's income comes from selling remanufactured products to consumers.

$$\pi_M = \eta_1\eta_2(q_{RU} + q_{RO})p_0 - \eta_1(w_{RU}q_{RU} + w_{RO}q_{RO} + cq_{RU} + cq_{RO}) \tag{1}$$

The remanufacturer purchases waste from the recyclers at a price "w" in bulk, which is the primary source of income for the recyclers. The main expense of recyclers comes from the compensation they pay to customers when they recycle the waste held by customers. Since not all the components can be used when the recycled waste is resold to the remanufacturer, there will be losses, so the corresponding amount of recycling needs to be deducted from the loss in the calculation of profit, and only the value of the remaining part $\eta (0 < \eta < 1)$ is calculated.

$$\pi_{RU} = w_{RU} \cdot \eta_1 q_{RU} - p_{RU} q_{RU}$$
$$\pi_{RO} = w_{RO} \cdot \eta_1 q_{RO} - p_{RO} q_{RO}$$

By substituting the recycling price-demand function into the above two equations, the profit expressions of the two recyclers can be obtained as follows:

$$\pi_{RU} = w_{RU} \cdot \eta_1 q_{RU} + (a_{RU} + a_{RO})q_{RU} - q_{RU}^2 - q_{RU}q_{RO} \tag{2}$$
$$\pi_{RO} = w_{RO} \cdot \eta_1 q_{RO} + (a_{RU} + a_{RO})q_{RO} - q_{RO}^2 - q_{RU}q_{RO} \tag{3}$$

In the game model of this study, the remanufacturer is the leader of the game, and the two recyclers are the followers. The game process is shown in Figure 2. In model calculation and equilibrium solving, the method "Backward Induction" is adopted, and the specific calculation process is presented in the appendix.

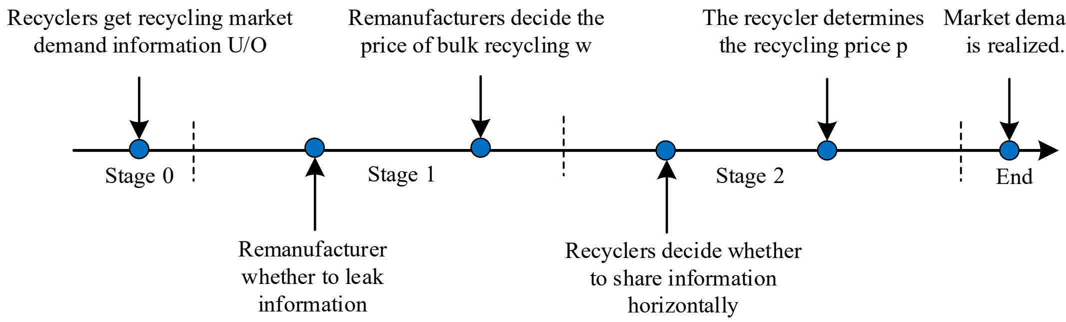

Fig. 2. The game sequence diagram.

4. Analysis

There are three basic scenarios in the model of this study, as shown in Fig. 3. Fig. 3 summarizes the information available to the two recyclers when making strategic decisions in three information scenarios. The upper part of the diagram is the recycling market where recycler-U operates, while the lower part represents the recycling market where recycler-O operates. The intersection between the two markets indicates that recycler can access information from both markets simultaneously. The square symbolizes the demand information accessible to recycler-U, while the circular symbol represents the demand information accessible to recycler-O. The distribution of different demand information in the diagram illustrates three information scenarios: "No Sharing & No Leaking," "Information Sharing," and "Information Leaking." Specifically, in the scenario of "No Sharing & No Leaking," each recycler can only obtain information from their respective market and cannot observe information from the other market. In the scenario of "Information Sharing," both parties can observe information from each other's market, as shown in Figure 3 where both recyclers can exchange information at the intersection of the two markets. In the scenario of "Information Leaking" (using the example of a remanufacturer leaking information from recycler-U to recycler-O), recycler-O can be at the intersection of the two markets and observe the market demand information of recycler-U, while recycler-U cannot observe the market demand information of recycler-O.

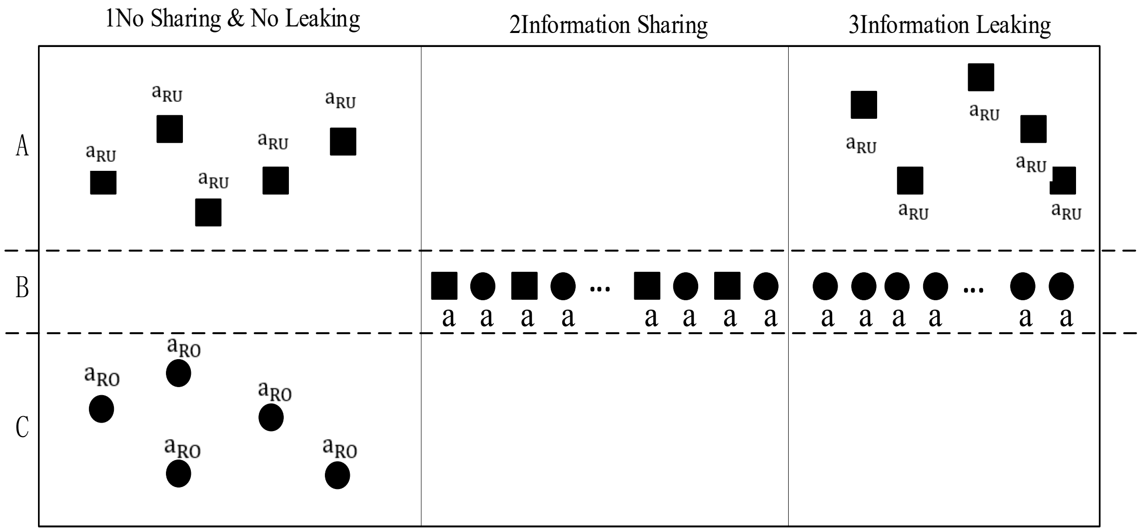

Fig. 3. Representation of information availability per scenario

The first scenario involves no information sharing among reverse supply chain members, and the remanufacturer will not disclose any information. In the second scenario, information is shared, with recyclers engaging in horizontal information sharing by exchanging their private demand information before confirming recycled orders with the remanufacturer. In this case, information leaking by the remanufacturer becomes meaningless since both recyclers have already shared information, and they possess each other's private information. The third scenario is information leakage, where if recyclers do not share information, the remanufacturer will disclose the private information of one recycler to another.

4.1. Scenario 1: No information sharing and no information leaking

In this scenario, where recyclers do not share information or have not reached a consensus on horizontal information sharing contracts, the remanufacturer is also unable to leak information to the other recycler. Due to the lack of information, each recycler can only rely on the limited information it possesses to make decisions. In the case of information ambiguity, each recycler's optimal estimate of the information held by the other recycler is based on its own exclusive demand information(Nickerson, 2001). The optimal solutions are as follows, and the specific calculation process is in the appendix.

$$w_{RU}{}^{*} = \frac{\eta_2\eta_1 p_0 - 2a_{RU} - c\eta_1}{2\eta_1};\ w_{RO}{}^{*} = \frac{\eta_1\eta_2 p_0 - 2a_{RO} - c\eta_1}{2\eta_1}.$$

$$q_{RU}{}^{*} = \frac{\eta_2\eta_1 p_0 - c\eta_1 + 2a_{RU}}{6};\ q_{RO}{}^{*} = \frac{\eta_1\eta_2 p_0 - c\eta_1 + 2a_{RO}}{6};\ p^{*} = \frac{\eta_2\eta_1 p_0 - c\eta_1 - 2(a_{RU} + a_{RO})}{3}.$$

Finally, the optimal profit for each recycler and the remanufacturer can be shown as follows.

$$\pi_M^{NS^*} = \frac{(\eta_2\eta_1 p_0 - c\eta_1)^2 + 2(\eta_2\eta_1 p_0 - c\eta_1)(a_{RU} + a_{RO}) + 2a_{RU}{}^2 + 2a_{RO}{}^2}{6};$$

$$\pi_{RU}^{NS^*} = \frac{((\eta_2\eta_1 p_0 - c\eta_1) - 2a_{RU} + 4a_{RO})((\eta_2\eta_1 p_0 - c\eta_1) + 2a_{RU})}{36};$$

$$\pi_{RO}^{NS^*} = \frac{((\eta_1\eta_2 p_0 - c\eta_1) - 2a_{RO} + 4a_{RU})((\eta_1\eta_2 p_0 - c\eta_1) + 2a_{RO})}{36}.$$

In the analysis of this model, it is assumed that there is no information sharing and information leakage. Both recyclers can earn positive profits from the beginning, and the recycling price as well as the recycling quantity remains greater than zero. When the profit of recyclers is greater than zero, they will recycle waste products, which is the basic condition for the model establishment and subsequent analysis, then Lemma 1 is obtained according to the profit function.

Lemma 1

$$\pi_{RU}^{NS^*} > 0\ and\ \pi_{RO}^{NS^*} > 0, if\ c < \eta_2 p_0 + \frac{4a_{RO} - 2a_{RU}}{\eta_1} < \eta_2 p_0 + \frac{2a_{RO}}{\eta_1} < \eta_2 p_0 + \frac{2a_{RU}}{\eta_1} < \eta_2 p_0 + \frac{4a_{Ru} - 2a_{RO}}{\eta_1}.$$

By comparing the profit of two recyclers, it is found that in the scenario of horizontal information sharing and information leakage, the profit of recycler-O is higher than that of recycler-U, as shown in Theorem 1.

Theorem 1 $\boldsymbol{\pi_{RU}^{NS^*} < \pi_{RO}^{NS^*}}$.

Based on the description of the model scenarios, if a company does not see the market distribution of another competitor, it will assume that the market status of the competitor is consistent with its own during the decision-making process. Compared to recycler-O, recycler-U possesses more market demand information, including estimates and forecasts of customer demand for waste recycling in the recycling market. This information is often used by customers to negotiate recycling prices with recyclers. Since recycler-U is not aware of recycler-O's market information, it will assume that its competitor has the same information as itself, i.e., a high demand state, and makes pricing and quantity decisions based on the higher market demand. As a result, after sending an excessive number of recyclables to upstream manufacturers, the upstream companies will make incorrect judgments based on the high amount of recycling, assuming the market is in high demand. In this scenario, the remanufacturer will employ price discrimination strategies based on supply and demand functions. It will make demand forecasts higher than the actual market demand based on the orders provided by the recyclers and offer lower recycling payment prices when purchasing waste products from the recyclers. Conversely, recycler-O believes that the recycling market where recycler-U operates is a low-demand market like its own. Consequently, when providing recycled materials to the remanufacturer, the signal captured by the remanufacturer is that this recycler is operating in a low-demand market. According to the demand-price function, the remanufacturer will offer higher recycling payment prices to recycler-O. Therefore, recyclers in high-demand markets may not achieve higher profits. This explanation and response provide insights into Theorem 1 in the context of real business scenarios.

4.2. Scenario 2: Information sharing

In the given scenario, the recyclers have reached an agreement to share their private demand information. Consequently, both recyclers possess complete knowledge of the estimates made by participating customers regarding current recycling prices before making any decisions. This information sharing arrangement enables them to make more informed and strategic choices. At this point, $q_{RO}{}^{*} = q_{RU}{}^{*}, w_{RU}{}^{*} = w_{RO}{}^{*}$. In the case of horizontal information sharing, the optimal solution can be obtained as follows:

$$w_{RU}{}^{*} = w_{RO}{}^{*} = \frac{\eta_1\eta_2 p_0 - \eta_1 c - (a_{RU} + a_{RO})}{2\eta_1}.$$

$$q_{RU}{}^{*} = q_{RO}{}^{*} = \frac{\eta_1\eta_2 p_0 - c\eta_1 + (a_{RU} + a_{RO})}{6}.$$

The optimal recycling price is:

$$p^{*} = -a + (q_{RU} + q_{RO}) = \frac{\eta_1\eta_2 p_0 - c\eta_1 - 2(a_{RU} + a_{RO})}{3}.$$

The optimal profit of each enterprise is as following.

$$\pi_M^{S\,*} = \frac{[(a_{RU} + a_{RO}) + (\eta_1\eta_2 p_0 - c\eta_1)]^2}{6}$$
$$\pi_{RU}^{S\;*} = \pi_{RO}^{S\;*} = \frac{[(\eta_1\eta_2 p_0 - \eta_1 c) + (a_{RU} + a_{RO})]^2}{36}$$

Under the premise of ensuring that the profits of recycling enterprises are positive (i.e., satisfying Lemma 1), the changes in profits of recycling enterprises under different information contexts can be compared, leading to Theorem 2. The results show that compared to the scenario without information sharing, horizontal information sharing reduces the profits of recycler-O and increases the profits of recycler-U. Based on this result analysis, horizontal information sharing is only beneficial to recycling companies that have an advantage in market demand and is not favorable for recycling companies in low-demand recycling markets.

Theorem 2 $\boldsymbol{\pi_{RO}^{S\;*} < \pi_{RO}^{NS^*}}$ **and** $\boldsymbol{\pi_{RU}^{NS^*} < \pi_{RU}^{S\;*}}$.

Based on the conclusion of Theorem 2, Proposition 1 can be derived. Besides showing that horizontal information sharing, compared to the scenario without information sharing, leads to increased profit for recycler-U and decreased profit for recycler-O, Proposition 1 also indicates that in the absence of information sharing, the profit of recycler-O in a low-demand market is higher than the profit of recycler-U in a high-demand market, consistent with the conclusion drawn in Theorem 1.

Proposition 1 $\boldsymbol{\pi_{RU}^{NS^*} < \pi_{RU}^{S\;*} = \pi_{RO}^{S\;*} < \pi_{RO}^{NS^*}}$.

If the model does not consider the risk of upstream companies leaking the information of one recycler to the other recycler, it can be seen from the model calculations and analysis results that horizontal information sharing alone cannot achieve a win-win situation for both recyclers. It seems that the decision of horizontal information sharing is not easily reached between the two recyclers because it does not appear to bring high profits to both sides simultaneously. Does this seemingly contradictory conclusion necessarily mean that horizontal information sharing is the worst choice for recyclers in low-demand markets? Not necessarily. Due to the possibility of upstream companies profiting from information leakage (Theorem 6, Theorem 7), more interesting conclusions will be drawn in Theorem 4 and Theorem 5 when comparing the profits of the two recyclers in horizontal information sharing with those in the vertical information leakage scenario involving remanufacturers.

4.3. Scenario 3: Information leakage

In this scenario, if recyclers don not share information horizontally, the remanufacturer will leak information from one recycler to the other. The remanufacturer, having acquired the private information of two recyclers through previous vertical information sharing, may disclose its demand information about one recycler to the other against their wishes.

This research compares the situation where the remanufacturer leaks information about recycler-U to recycler-O with the scenario where the remanufacturer leaks information about recycler-O to recycler-U.

(1) When information leaks from recycler-O to recycler-U,

$$\pi_M^{L\,O\to U*} = \frac{3(\eta_1\eta_2 p_0 - c\eta_1)^2 + 3(a_{RU} + 3a_{RO})(\eta_1\eta_2 p_0 - c\eta_1) + (a_{RU}^2 + 4a_{RU}a_{RO} + 7a_{RO}^2)}{18};$$
$$\pi_{RU}^{L\,O\to U*} = \frac{(\eta_1\eta_2 p_0 - c\eta_1 + 3a_{RU} - a_{RO})(\eta_1\eta_2 p_0 - c\eta_1 + a_{RU} + a_{RO})}{36};$$
$$\pi_{RO}^{L\,O\to U*} = \frac{(\eta_1\eta_2 p_0 - c\eta_1 + 4a_{RU} - 2a_{RO})(\eta_1\eta_2 p_0 - c\eta_1 + 2a_{RO})}{36}.$$

(2) When information leaks from recycler-U to recycler-O,

$$\pi_M^{L\,U\to O*} = \frac{3(\eta_1\eta_2 p_0 - \eta_1 c)(\eta_1\eta_2 p_0 - \eta_1 c + 3a_{RU} + a_{RO}) + (7a_{RU}a_{RU} + 4a_{RO}a_{RU} + a_{RO}a_{RO})}{18};$$
$$\pi_{RU}^{L\,U\to O*} = \frac{(\eta_1\eta_2 p_0 - \eta_1 c)(\eta_1\eta_2 p_0 - \eta_1 c + 4a_{RO}) - 4(a_{RU}^2 - 2a_{RU}a_{RO})}{36};$$
$$\pi_{RO}^{L\,U\to O*} = \frac{(\eta_1\eta_2 p_0 - \eta_1 c)(\eta_1\eta_2 p_0 - \eta_1 c + 4a_{RO}) + (3a_{RO} - a_{RU})(a_{RO} + a_{RU})}{36}.$$

The profit earned by the remanufacturer from leaking information from U to O is higher than that from leaking in the opposite direction. When information is leaked from U to O, recycler-O gains access to the entire market information, while U only has its information. Recycler-U must continue to speculate on the information of recycler-O, and the best guess for recycler-U is to assume that recycler-O possesses the same demand information as itself.

When the recycler-U is the information superior, $a_{RU} > a_{RO} > 0$.

$$\pi_M^{L\,O\to U*} - \pi_M^{L\,U\to O*} = \frac{(\eta_1\eta_2 p_0 - c\eta_1 + a_{RO} + a_{RU})(a_{RO} - a_{RU})}{3} < 0 \;\to\; \pi_M^{L\,O\to U*} < \pi_M^{L\,U\to O*}$$

Proposition 2 $\boldsymbol{\pi_M^{L\,O\to U^*} < \pi_M^{L\,U\to O^*}}$.

As shown in Proposition 2, the profit comparison results show the remanufacturer has no incentive to leak information from recycler-O to recycler-U, as the profit obtained from this direction is lower compared to leaking in the opposite direction. Therefore, in this study, the scenario of information leakage only considers the direction from recycler-U to recycler-O, as this decision is more favorable for the remanufacturer.

As shown in Theorem 3, after the information is leaked, the profit of the disclosed party is lower than that of the party who obtains the information of the other party.

Theorem 3 $\boldsymbol{\pi_{RU}^{L\,U\to O^*} < \pi_{RO}^{L\,U\to O^*}}$.

By analyzing the situations of recycler-O and recycler-U, we compare the profits of these two enterprises in different scenarios. Firstly, evaluate the profits of these two enterprises under the conditions of no information sharing and no information leakage, and information leakage.

Theorem 4 $\boldsymbol{\pi_{RU}^{L\,U\to O^*} = \pi_{RU}^{NS^*}, \pi_{RO}^{L\,U\to O^*} < \pi_{RO}^{NS^*}}$.

The results in Theorem 5 show that the decision of upstream companies to leak information has no impact on the profit of the recycler in high-demand markets, but it harms the interest of the recycler in low-demand markets. According to previous studies, this conclusion can be verified through the analysis of demand-price functions in the context of reverse supply chains. Looking back at the earlier conclusions, the direction of information leakage from upstream remanufacturers is only possible from recycler-U to O. Therefore, throughout the process, recycler-U will not receive any additional information outside its own market, and thus its decision-making remains unchanged. Conversely, after the upstream company leaks information from recycler-U to O, the demand assessment of the competitor by recycler-O changes from assuming the need is similar to its own to recognizing the actual high-demand market, leading to price discrimination by the remanufacturer, reducing the payment to recycler-O, which results in lower profits for recycler-O in the information leakage scenario compared to the scenario without information sharing.

Secondly, review the profits of recycler-O and recycler-U in the scenarios of information sharing and information leakage.

Theorem 6 $\boldsymbol{\pi_{RU}^{L\,U\to O^*} < \pi_{RU}^{S^*}, \pi_{RO}^{L\,U\to O^*} < \pi_{RO}^{S^*}}$.

As shown in Theorem 5, in the context of horizontal information sharing, the profits of both recyclers are higher than in the case of information being leaked by upstream companies vertically. Therefore, actively engaging in horizontal information sharing between recycling companies is beneficial in preventing the risk of profit reduction. Furthermore, considering the comparison of profits between "No Sharing & No Leaking" and "Information Sharing" mentioned earlier, does the inability of the two companies to achieve a win-win situation through horizontal information sharing imply that it is not an optimal decision? In this section, the answer to this question can be provided through the conclusion of Proposition 3.

Proposition 3 $\boldsymbol{\pi_{RU}^{L\,U\to O^*} = \pi_{RU}^{NS^*} < \pi_{RU}^{S^*}, \pi_{RO}^{L\,U\to O^*} < \pi_{RO}^{S^*} < \pi_{RO}^{NS^*}}$.

The Proposition 3 indicates that the dominant recycler should always lean towards horizontal information sharing. Without horizontal information sharing, recycler-U will obtain lower profits. Furthermore, compared to the scenario of horizontal information sharing, the leakage of information by the remanufacturer will reduce the profits of both recyclers.

The profit of the remanufacturer is also influenced by different information sharing scenarios. Next, the profits of the remanufacturer in three different information scenarios will be compared.

Theorem 7 $\boldsymbol{\pi_M^{L\,U\to O^*} > \pi_M^{NS^*}, \pi_M^{L\,U\to O^*} > \pi_M^{S^*}}$.

As shown in Proposition 3, information leakage will harm the profits of both recyclers. Unfortunately, as Theorem 6 demonstrates, remanufacturers achieve the highest profit in the scenario of information leakage. Therefore, if recyclers do not actively engage in horizontal information sharing, remanufacturers will inevitably leak the market information of the high-demand market recycler to the low-demand market recycler. While the low demand recycler gains insight into competitors' demand information through information leakage, their profit will be lower compared to the scenario of actively engaging in horizontal information sharing. At this point, active horizontal information sharing becomes the preferable option compared to information leakage for recyclers.

Subsequently, this study compares the profits of remanufacturers in the scenario where no information is shared and no information is leaked with those in the scenario where information is shared.

Theorem 8 $\boldsymbol{\pi_M^{NS^*} > \pi_M^{S^*}}$.

Based on the previous research findings, Proposition 4 can be deduced. Proposition 4 suggests that the remanufacturer is more inclined towards information leakage. If the recycler does not agree to share information horizontally, the remanufacturer will leak the information from the recycler with higher demand to the lower one.

Proposition 4 $\boldsymbol{\pi_M^{L\,U\rightarrow O^*} > \pi_M^{NS^*} > \pi_M^{S^*}}$.

According to Proposition 2, if two recyclers do not actively share information horizontally, remanufacturers will leak the market information of recycler-U to recycler-O. Thus, the three scenarios can be simplified to either sharing information horizontally or information leaked by upstream companies. Therefore, combining all the conclusions above, this study concludes that for two recyclers, actively sharing information horizontally is the best strategy to mitigate the risk of profit loss resulting from information leaking. This approach can yield the most favorable outcomes for both recyclers, considering that all parties are rational individuals.

5. Numerical Example

After solving the analytical model, the interaction of the reverse supply chain can be illustrated with a numerical example. The expression in Table 1 is used to calculate the decision variables and profit.

Table 1
Summary of optimal profit by subject and scenario

Scenario/Firm	Profit
NS/Recycler-U	$\frac{((\eta_2\eta_1p_0-c\eta_1)-2a_{RU}+4a_{RO})((\eta_2\eta_1p_0-c\eta_1)+2a_{RU})}{36}$
NS/Recycler-O	$\frac{((\eta_1\eta_2p_0-c\eta_1)-2a_{RO}+4a_{RU})((\eta_1\eta_2p_0-c\eta_1)+2a_{RO})}{36}$
NS/Remanufacturer	$\frac{(\eta_2\eta_1p_0-c\eta_1)^2+2(\eta_2\eta_1p_0-c\eta_1)(a_{RU}+a_{RO})+2a_{RU}{}^2+2a_{RO}{}^2}{6}$
S/Recycler-U	$\frac{[(\eta_1\eta_2p_0-\eta_1c)+(a_{RU}+a_{RO})]^2}{36}$
S/Recycler-O	$\frac{[(\eta_1\eta_2p_0-\eta_1c)+(a_{RU}+a_{RO})]^2}{36}$
S/ Remanufacturer	$\frac{[(a_{RU}+a_{RO})+(\eta_1\eta_2p_0-c\eta_1)]^2}{6}$
L/Recycler-U	$\frac{(\eta_1\eta_2p_0-\eta_1c)(\eta_1\eta_2p_0-\eta_1c+4a_{RO})-4(a_{RU}{}^2-2a_{RU}a_{RO})}{36}$
L/Recycler-O	$\frac{(\eta_1\eta_2p_0-\eta_1c)(\eta_1\eta_2p_0-\eta_1c+4a_{RO})+(3a_{RO}-a_{RU})(a_{RO}+a_{RU})}{36}$
L/Remanufacturer	$\frac{3(\eta_1\eta_2p_0-\eta_1c)(\eta_1\eta_2p_0-\eta_1c+3a_{RU}+a_{RO})+(7a_{RU}a_{RU}+4a_{RO}a_{RU}+a_{RO}a_{RO})}{18}$

According to the previous research and the actual situation, the parameter value of the test model is set as:
Demand uncertainty x=0. Demand distribution 1-2.
Demand signals $a_{RU} = 2, a_{RO} = 1$. Slope of inverse demand b=1;
Production cost c=1; p_0=10; $\eta_1 = 0.95; \eta_2 = 0.9$.

Table 2 presents results of numerical simulations for the three scenarios, including decision variables and optimal profits (rounded to three decimal places) for each scenario.

Table 2
Decision variables and profits by scenario in the numerical example

Variables	No sharing no leaking (NS)	Information sharing(S)	Information leaking(L)
π_{RU}	2.449	3.121	2.449
π_{RO}	3.627	3.121	2.532
π_M	18.893	18.727	20.549
π_{Total}	24.969	24.969	25.530
w_{RU}	1.895	2.421	2.070
w_{RO}	2.947	2.421	2.246
q_{RU}	1.933	1.767	1.933
q_{RO}	1.600	1.767	1.767
p	0.533	0.533	0.700

Fig. 4 shows the profits of each company.

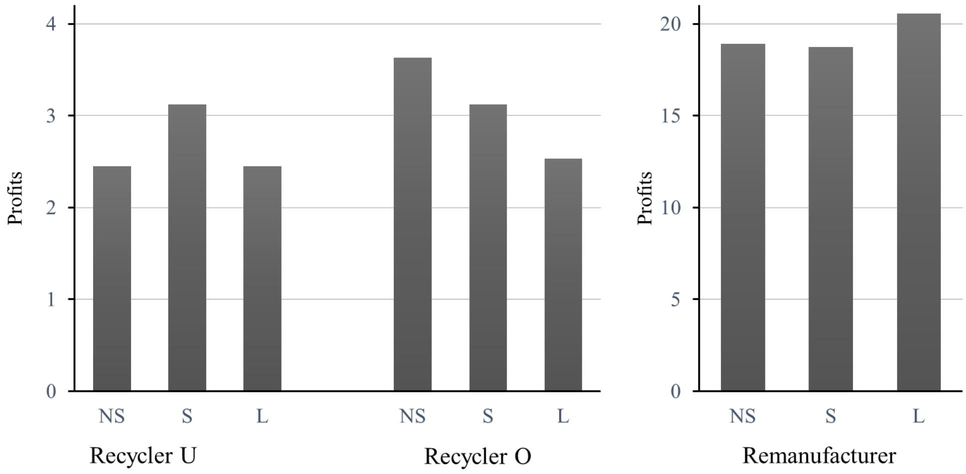

Fig. 4. Bar graphs of profits by scenario and firm in the numerical example

It conducted *a* sensitivity analysis study based on the demand uncertainty parameter x being between 0 and 1 and the demand signal following a uniform distribution, namely $a_i \sim U(1-\mathrm{x}, 2-\mathrm{x})$. Thus, the profit matrix is established with two axes, consisting of a numeric matrix $(0\sim 2.0, 0\sim 2.0)$ with possible values of 0.1 for a_{RO} and a_{RU}. The cells in the matrix represent the profits achieved by combining the demand signals a_{RO} and a_{RU}.

To find a conditional distribution of profits for a given x, the profit function needs to satisfy two conditions:

① $a_{RO} < a_{RU}$.
② Both signals' values a_{RO} and a_{RU} are in the interval $(1-\mathrm{x}, 2-\mathrm{x})$.

For each integer value of x, there are 55 possible profit combinations that satisfy these two conditions. Thus, given the value of x, the probability of observing a particular profit value is $\frac{1}{55}$. For any x, the following equation is satisfied.

$$Pr[(a_{RO} \cap a_{RU}) \cap x] = Pr[(a_{RO} \cap a_{RU})] * Pr(x) = \frac{1}{55} * \frac{1}{11} = \frac{1}{605}$$

Fig. 5 and Fig. 6 show the expected profit value of a given x value for different companies and different scenarios (Table in the appendix lists the values shown in the Fig. 5 and Fig. 6).

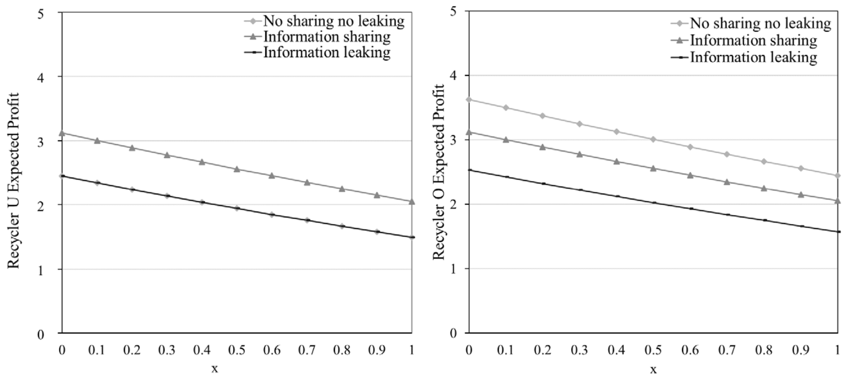

Fig. 5. Expected profit of recycler-U & O by scenario and demand uncertainty

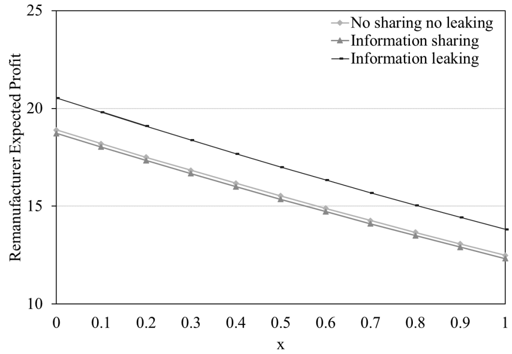

Fig. 6. Expected profit of remanufacturer by scenario and demand uncertainty

A lower x value in the study implies *a* higher demand signal value. With the increase of x value, the demand of recycling market decreases, and the profits of recyclers in all three cases show *a* downward trend. The difference between the recycler's profit in the information-sharing scenario and the profit in the other two scenarios will be reduced.

6. Discussion

By examining the conclusions of existing studies on supply chain information effects and reverse supply chains, this study builds an analytical model that includes cases where recyclers cannot determine their information status. This model describes the profits of recyclers with partial or no information when they enter a new recycling market or enter a new business category in the context of ambiguous recycling demand information. The key findings of this study are as follows. First, if there is no agreement among recyclers to share information horizontally, remanufacturers will always leak information. Second, in the recycling market, recyclers with ambiguous information status should support information sharing to prevent the negative effects of information leakage. Third, the benefits of horizontal information sharing among recyclers are inconsistent, as it favors recyclers who have a greater signal of demand valuation in the recycling market.

(1) Remanufacturers are always prone to information leakage, because information leakage can always bring higher profits to remanufacturers (Proposition 4). This is in line with the research in the traditional supply chain. The conclusion of this study shows that remanufacturer leakage from recycler-U to recycler-O will bring better returns (Proposition 2), while leakage in reverse will bring lower profits.

(2) Under the condition of horizontal information sharing, the profits of the two recyclers are equal (Proposition 1). However, horizontal information sharing has different effects on the two recyclers. Sharing information horizontally increases the profits of the information dominant recycler while decreasing the profits of the information disadvantage recycler. Among the three scenarios of information sharing, the recycler with information advantage often prefers horizontal information sharing because the profits gained from information sharing are always higher than those without information sharing. Since information leakage will occur if information is not shared horizontally, for recyclers with inferior information, the profit obtained by information leakage is lower than that that from horizontal information sharing. This is a noteworthy conclusion that contradicts previous findings and common knowledge regarding supply chain information management. Horizontal information sharing between recyclers, whether it is Recycler-O or Recycler-U, is an effective choice, at least better than the scenario of information leakage (Proposition 3).

(3) Recycler-U with high demand signal gets higher benefits in horizontal information sharing than without information sharing, while the Recycler-O is contrary (Proposition 1). This is inconformity to the conclusion of information sharing in traditional supply chains, because enterprises with information advantages (incumbents) are often unwilling to share information with other enterprises (entrants). This conflict may be explained by the fact that previous studies have always assumed that the incumbent has more information than the entrant, so that the incumbent can make better decisions based on their observed market state. Based on the premise that both companies in the recycling market do not know their personal information status, this study is more in line with reality. The findings of this study will offer valuable insights for the management decisions of incumbent firms in reverse supply chains.

This study offers a novel approach for analyzing the competitive interactions between uncertain information-sharing recyclers in a reverse supply chain. The assumption of mutual ignorance among competing firms regarding each other's information and the fuzzy hypothesis about relative information positions in the market are realistic as they accurately reflect the situation where firms lack control over prior demand information when expanding into new recycling markets or introducing new recycling categories. Following information leakage, recycler-U continues to pass on the waste it has collected to the remanufacturer, resulting in an expected increase in total demand. Both recycler-O and recycler-U will then lower their recycling payment prices to recycle waste. Consequently, the remanufacturer's bulk recycling payment price will also decrease, leading to an increase in total recycling quantity and the remanufacturer's profit.

Without horizontal information sharing, the remanufacturer is bound to disclose the recycler's information. Therefore, horizontal information sharing becomes the optimal choice for both recyclers. An increase in x signifies a reduction in demand in the recycling market, leading recyclers to incur higher costs to acquire discarded products, resulting in decreased profits. Consequently, the remanufacturer's profit is also adversely affected.

7. Conclusion

7.1 Main findings

This study analyzes the reverse supply chain model involving one remanufacturer and two recyclers competing in the waste recycling market. The demand signals received by the recyclers are partial and asymmetric, leading to their inability to accurately assess their information positions in the recycling market. Considering this real-world scenario, we examine three common information states for analysis: no information sharing and information leakage, information sharing, and information leakage. Through model analysis and numerical examples, it's demonstrated that due to the risk of profit erosion associated with information leakage, competitive recyclers tend to refrain from leaking information. Recycler-U achieves higher profits through information sharing, while Recycler-O, considering the potential profit loss from remanufacturer information leakage, is compelled to opt for horizontal information sharing. Therefore, horizontal information sharing proves consistently beneficial. Conversely, if recyclers fail to reach a mutually acceptable agreement on information sharing, the remanufacturer consistently resorts to leaking the high-signal recycler's information to other recyclers, thereby enhancing its own profits. The conclusion also demonstrates that, under the assumption of the remanufacturer's rationality, scenarios devoid of information sharing and information leakage do not exist in practice, as information leakage consistently results in higher returns for the remanufacturer. Furthermore, it can be deduced that both recyclers will invariably choose to proactively engage in horizontal information sharing to safeguard their interests.

7.2 Managerial insights

The findings of this study provide valuable decision guidance for recyclers facing horizontal information sharing decisions in the context of information asymmetry. By reasonably sharing market information with competitors, recyclers can avoid losses caused by information leakage without the consent of downstream enterprises, thereby improving the efficiency of reverse supply chains. Ultimately, this research can promote the circular economy and sustainable development process through optimizing supply chain decisions and improving supply chain efficiency. By investigating reverse supply chain management, this study provides a more realistic understanding of information sharing in reverse supply chains. This research emphasizes the importance of horizontal information sharing with competitors and proposes strategies to avoid risks of information leakage, providing a new perspective to fill the research gap in the field of information asymmetry in reverse supply chains.

For downstream recyclers in the recycling supply chain, according to Proposition 1 and Proposition 3, horizontal information sharing increases the profits of information-advantaged recyclers while reducing the benefits of information-disadvantaged ones. Therefore, recyclers with information advantages often prefer horizontal information sharing. However, without horizontal information sharing, information leakage occurs, which leads to greater profit loss for information-disadvantaged recyclers compared to horizontal information sharing. Moreover, according to Proposition 4, in the absence of horizontal information sharing among downstream recyclers, upstream manufacturers will inevitably leak their information, causing profit loss for downstream enterprises. Therefore, downstream recyclers, whether information-advantaged or information-disadvantaged, should actively adopt appropriate approaches to exchange information with competing enterprises to mitigate the risk of profit loss. For example, when a new electronic waste enters the recycling market, recycling companies can exchange customer demand information, such as demand for new products through trade-in programs and expectations for the remaining value of old products. Based on this information, recycling companies can make decisions that are more optimized than having only their own information or when information leakage occurs. Through model calculations and analysis, this study provides theoretical guidance and directional guidance for decision-making of enterprises in reverse logistics when facing information dilemmas.

These insights provide practical significance for optimizing management decisions when competing recyclers are uncertain about their demand information. By considering the potential information leakage behavior of upstream enterprises and then coordinating with other enterprises in competition and cooperation, better management of recycling reverse logistics is achieved, and risks of profit loss due to information leakage are mitigated.

7.3 Limitations and Future research

The limitation of this study resides in the lack of consideration for decision changes of supply chain enterprises in long-term collaboration. In actual business scenarios, collaborations between enterprises are typically not short-term but rather aimed at seeking long-term stable partners. Therefore, future research could explore the impact of demand information asymmetry phenomena with market information updates over multiple periods on reverse supply chain management, and derive optimal solutions based on this consideration. Furthermore, this study assumes that all enterprises are in a profitable state (Lemma 1). However, in actual business scenarios, there may be instances where some companies experience losses. These aspects can be addressed more comprehensively in future research.

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Appendix

Scenario 1: No information sharing and no information leaking：

$$\pi_{RU} = \eta_1 w_{RU} q_{RU} - p_{RU} q_{RU} = \eta_1 w_{RU} q_{RU} + (a_{RU} + a_{RO}) q_{RU} - {q_{RU}}^2 - q_{RU} q_{RO}$$
$$\pi_{RO} = \eta_1 w_{RO} q_{RO} - p_{RO} q_{RO} = \eta_1 w_{RO} q_{RO} + (a_{RU} + a_{RO}) q_{RO} - {q_{RO}}^2 - q_{RU} q_{RO}$$
$$\frac{\partial \pi_{RU}}{\partial q_{RU}} = \eta_1 w_{RU} + (a_{RU} + a_{RO}) - 2q_{RU} - q_{RO} = 0$$
$$\frac{\partial \pi_{RO}}{\partial q_{RO}} = \eta_1 w_{RO} + (a_{RU} + a_{RO}) - 2q_{RO} - q_{RU} = 0$$
$$q_{RU} = \frac{2\eta_1 w_{RU} - \eta_1 w_{RO} + (a_{RU} + a_{RO})}{3}; q_{RO} = \frac{2\eta_1 w_{RO} - \eta_1 w_{RU} + (a_{RU} + a_{RO})}{3}$$

In the case of ambiguous information, each recycler's best estimate of the information that other recyclers have is the private demand information that he has.

$$q_{RU} = \frac{\eta_1 w_{RU} + 2a_{RU}}{3}; q_{RO} = \frac{\eta_1 w_{RO} + 2a_{RO}}{3}; p(q) = \frac{\eta_1 w_{RU} + \eta_1 w_{RO} - a_{RU} - a_{RO}}{3}$$
$$\frac{\partial \pi_M}{\partial w_{RU}} = \frac{\eta_1 \eta_1 \eta_2 p_0 - 2\eta_1 \eta_1 w_{RU} - \eta_1 \eta_1 c - 2\eta_1 a_{RU}}{3} = 0$$
$$\frac{\partial \pi_M}{\partial w_{RO}} = \frac{\eta_1 \eta_1 \eta_2 p_0 - \eta_1 \eta_1 c - \eta_1 2\eta_1 w_{RO} - \eta_1 2a_{RO}}{3} = 0$$
$${w_{RU}}^* = \frac{\eta_1 \eta_2 p_0 - \eta_1 c - 2a_{RU}}{2\eta_1}; {w_{RO}}^* = \frac{\eta_1 \eta_2 p_0 - \eta_1 c - 2a_{RO}}{2\eta_1}$$
$${q_{RU}}^* = \frac{\eta_1 \eta_2 p_0 - \eta_1 c + 2a_{RU}}{6}; {q_{RO}}^* = \frac{\eta_1 \eta_2 p_0 - \eta_1 c + 2a_{RO}}{6}; p^* = \frac{\eta_1 \eta_2 p_0 - \eta_1 c - 2a_{RU} - 2a_{RO}}{3}$$
$$\pi_M^{NS^*} = \frac{(\eta_2 \eta_1 p_0 - c\eta_1)^2 + 2(\eta_2 \eta_1 p_0 - c\eta_1)(a_{RU} + a_{RO}) + 2{a_{RU}}^2 + 2{a_{RO}}^2}{6}$$
$$\pi_{RU}^{NS^*} = \frac{((\eta_2 \eta_1 p_0 - c\eta_1) - 2a_{RU} + 4a_{RO})((\eta_2 \eta_1 p_0 - c\eta_1) + 2a_{RU})}{36}$$
$$\pi_{RO}^{NS^*} = \frac{((\eta_1 \eta_2 p_0 - c\eta_1) - 2a_{RO} + 4a_{RU})((\eta_1 \eta_2 p_0 - c\eta_1) + 2a_{RO})}{36}$$

Proof of Lemma 1

In the no sharing no leaking scenario, we focus on the profit of recycler U to find the solutions of the inequality:
$$\pi_{RU}^{NS^*} = \frac{((\eta_2 \eta_1 p_0 - c\eta_1) - 2a_{RU} + 4a_{RO})((\eta_2 \eta_1 p_0 - c\eta_1) + 2a_{RU})}{36} > 0$$
We factorize the expression (${q_{RU}}^* > 0, {q_{RO}}^* > 0$),

$$\begin{cases} \eta_2\eta_1p_0 - c\eta_1 + 2a_{RU} > 0 \\ \eta_2\eta_1p_0 - c\eta_1 - 2a_{RU} + 4a_{RO} > 0 \end{cases} \rightarrow c < \eta_2p_0 + \frac{4a_{RO}-2a_{RU}}{\eta_1} < \eta_2p_0 + \frac{2a_{RU}}{\eta_1}$$

For the profit of recycler O, $c < \eta_2p_0 + \frac{4a_{Ru}-2a_{RO}}{\eta_1} < \eta_2p_0 + \frac{2a_{RO}}{\eta_1}$

Assuming that recycler O is the overestimating recycler $a_{RU} > a_{RO} > 0$, when $c < \eta_2p_0 + \frac{4a_{RO}-2a_{RU}}{\eta_1} < \eta_2p_0 + \frac{2a_{RO}}{\eta_1} < \eta_2p_0 + \frac{2a_{RU}}{\eta_1} < \eta_2p_0 + \frac{4a_{Ru}-2a_{RO}}{\eta_1}, \pi_{RU}^{NS^*} > 0 \; and \; \pi_{RO}^{NS^*} > 0.$

Proof of Theorem 1

We compare the two profits of recyclers：

$$\pi_{RU}^{NS^*} - \pi_{RO}^{NS^*} = \frac{(a_{RO}-a_{RU})(\eta_2\eta_1p_0-c\eta_1+a_{RO}+a_{RU})}{9} < 0, \; if \; Lemma \; 1.$$

Therefore, $\pi_{RU}^{NS^*} < \pi_{RO}^{NS^*}$, if a_{RO}<a_{RU}.

Proof of Theorem 2

Scenario 2: Information sharing:

$$\pi_M = \eta_1\eta_2(q_{RU} + q_{RO})p_0 - \eta_1(w_{RU}q_{RU} + w_{RO}q_{RO} + cq_{RU} + cq_{RO})$$
$$\pi_{RU} = \eta_1w_{RU}q_{RU} - p_{RU}q_{RU} = \eta_1w_{RU}q_{RU} + (a_{RU} + a_{RO})q_{RU} - {q_{RU}}^2 - q_{RU}q_{RO}$$
$$\pi_{RO} = \eta_1w_{RO}q_{RO} - p_{RO}q_{RO} = \eta_1w_{RO}q_{RO} + (a_{RU} + a_{RO})q_{RO} - {q_{RO}}^2 - q_{RU}q_{RO}$$

When information is symmetrical:

$$q_{RU} = \frac{2\eta_1w_{RU}-\eta_1w_{RO}+(a_{RU}+a_{RO})}{3}; q_{RO} = \frac{2\eta_1w_{RO}-\eta_1w_{RU}+(a_{RU}+a_{RO})}{3}.$$

Assuming that recycler O is the overestimating recycler, we compare the profit of recycler O in the no sharing no leaking and the information sharing scenario.

$$\pi_{RO}^{S\;*} - \pi_{RO}^{NS^*} = \frac{(a_{RO}-a_{RU})(2(\eta_1\eta_2p_0-\eta_1c)+5a_{RO}-a_{RU})}{36} < 0 \text{ using Lemma1.}$$
$$\pi_{RU}^{S\;*} - \pi_{RU}^{NS^*} = \frac{(2(\eta_1\eta_2p_0-\eta_1c)+5a_{RU}-a_{RO})(a_{RU}-a_{RO})}{36} > 0$$

When a_{RO}<a_{RU}, $\pi_{RO}^{S\;*} < \pi_{RO}^{NS^*}$; $\pi_{RU}^{S\;*} > \pi_{RU}^{NS^*}$.

Consequently, the overestimating recycler earns lower profit in the information sharing scenario than in the no sharing no leaking scenario. The underestimating recycler earns higher profit in the information sharing scenario than in the no sharing no leaking scenario.

Scenario 3: Information leakage:

When the information leak from $O \; to \; U$:

Assuming that the information is leaked from the overestimating recycler O to underestimating recycler U ($O \rightarrow U$), we compare the profits of both recyclers in the information leaking scenario.

$${q_{RU}}^{O\rightarrow U} = \frac{2\eta_1w_{RU}-\eta_1w_{RO}+(a_{RU}+a_{RO})}{3}; {q_{RO}}^{O\rightarrow U} = \frac{2\eta_1w_{RO}-\eta_1w_{RU}+2a_{RO}}{3}$$
$${w_{RU}}^{O\rightarrow U*} = \frac{3\eta_1\eta_2p_0-3c\eta_1-2a_{RU}-4a_{RO}}{6\eta_1}; {w_{RO}}^{O\rightarrow U*} = \frac{3\eta_1\eta_2p_0-3c\eta_1-a_{RU}-5a_{RO}}{6\eta_1}$$
$${q_{RU}}^{O\rightarrow U*} = \frac{\eta_1\eta_2p_0-c\eta_1+a_{RU}+a_{RO}}{6}; {q_{RO}}^{O\rightarrow U*} = \frac{\eta_1\eta_2p_0-c\eta_1+2a_{RO}}{6}$$
$$p^{O\rightarrow U*} = \frac{2\eta_1\eta_2p_0-2c\eta_1-5a_{RU}-3a_{RO}}{6}$$
$$\pi_M^{L\;O\rightarrow U*} = \frac{6(\eta_1\eta_2p_0-c\eta_1)^2+6(a_{RU}+3a_{RO})(\eta_1\eta_2p_0-c\eta_1)+2(a_{RU}a_{RU}+4a_{RO}a_{RU}+7a_{RO}a_{RO})}{36}$$
$$\pi_{RU}^{L\;O\rightarrow U*} = \frac{(\eta_1\eta_2p_0-c\eta_1+3a_{RU}-a_{RO})(\eta_1\eta_2p_0-c\eta_1+a_{RU}+a_{RO})}{36}$$
$$\pi_{RO}^{L\;O\rightarrow U*} = \frac{(\eta_1\eta_2p_0-c\eta_1+4a_{RU}-2a_{RO})(\eta_1\eta_2p_0-c\eta_1+2a_{RO})}{36}$$

When the information leak from $O \; to \; U$:

$q_{RU}{}^{U\to O} = \frac{2\eta_1 w_{RU} - \eta_1 w_{RO} + 2a_{RU}}{3}$; $q_{RO}{}^{U\to O} = \frac{2\eta_1 w_{RO} - \eta_1 w_{RU} + (a_{RU} + a_{RO})}{3}$

$w_{RU}{}^{U\to O*} = \frac{3\eta_1(\eta_2 p_0 - c) - 5a_{RU} - a_{RO}}{6\eta_1}$; $w_{RO}{}^{U\to O*} = \frac{3\eta_1(\eta_2 p_0 - c) - 4a_{RU} - 2a_{RO}}{6\eta_1}$

$q_{RU}{}^{U\to O*} = \frac{\eta_1(\eta_2 p_0 - c) + 2a_{RU}}{6}$; $q_{RO}{}^{U\to O*} = \frac{\eta_1(\eta_2 p_0 - c) + a_{RU} + a_{RO}}{6}$

$p^* = \frac{2\eta_1(\eta_2 p_0 - c) - 3a_{RU} - 5a_{RO}}{6}$

$\pi_M^{L\,U\to O*} = \frac{3(\eta_1\eta_2 p_0 - \eta_1 c)(\eta_1\eta_2 p_0 - \eta_1 c + 3a_{RU} + a_{RO}) + (7a_{RU}a_{RU} + 4a_{RO}a_{RU} + a_{RO}a_{RO})}{18}$

$\pi_{RU}^{L\,U\to O*} = \frac{(\eta_1\eta_2 p_0 - \eta_1 c)^2 + 4(\eta_1\eta_2 p_0 - \eta_1 c)a_{RO} + 4a_{RU}(2a_{RO} - a_{RU})}{36}$

$\pi_{RO}^{L\,U\to O*} = \frac{(\eta_1(\eta_2 p_0 - c) - a_{RU} + 3a_{RO})(\eta_1(\eta_2 p_0 - c) + a_{RU} + a_{RO})}{36}$

$\pi_M^{L\,O\to U*} - \pi_M^{L\,U\to O*} = \frac{(\eta_1\eta_2 p_0 - c\eta_1 + a_{RO} + a_{RU})(a_{RO} - a_{RU})}{3} < 0$

$\pi_M^{L\,O\to U*} < \pi_M^{L\,U\to O*}$

Proof of Theorem 3

$$\pi_{RU}^{L\,U\to O*} - \pi_{RO}^{L\,U\to O*} = -\frac{(a_{RU} - a_{RO})^2}{12} < 0$$

$\pi_{RU}^{L\,U\to O*} < \pi_{RO}^{L\,U\to O*}$

Proof of Theorem 4

Assuming information leaks from recycler U to recycler O, we compare the profits of recycler U and recycler O in the no-share & no-leak scenario and the information leak scenario, respectively.

$\pi_{RO}^{L\,U\to O*} - \pi_{RO}^{NS*} = \frac{(a_{RO} - a_{RU})(4\eta_1\eta_2 p_0 - 4c\eta_1 + 7a_{RO} + a_{RU})}{36} < 0 \to \pi_{RO}^{L\,U\to O*} < \pi_{RO}^{NS*}$

$\pi_{RU}^{L\,U\to O*} - \pi_{RU}^{NS*} = 0 \to \pi_{RU}^{L\,U\to O*} = \pi_{RU}^{NS*}$

Proof of Theorem 5

Compare the profit of recycler U and recycler O under information sharing and information leakage scenarios.

$\pi_{RU}^{L\,U\to O*} - \pi_{RU}^{S*} = \frac{(2\eta_1\eta_2 p_0 - 2\eta_1 c + 5a_{RU} - a_{RO})(a_{RO} - a_{RU})}{36} < 0 \to \pi_{RU}^{L\,U\to O*} < \pi_{RU}^{S*}$

$\pi_{RO}^{L\,U\to O*} - \pi_{RO}^{S*} = \frac{2(\eta_1(\eta_2 p_0 - c) + a_{RU} + a_{RO})(a_{RO} - a_{RU})}{36} < 0 \to \pi_{RO}^{L\,U\to O*} < \pi_{RO}^{S*}$

$If\ Lemma\ 1, \pi_{RU}^{L\,U\to O*} < \pi_{RU}^{S*}, \pi_{RO}^{L\,U\to O*} < \pi_{RO}^{S*}.$

Proof of Theorem 6

Assuming that information leaks from overestimating recycler O to underestimating recycler U, we compare the profits of remanufacturers in the case of information leakage and the case of no sharing & no leakage.

$\pi_M^{L\,U\to O*} = \frac{3(\eta_1\eta_2 p_0 - \eta_1 c)(\eta_1\eta_2 p_0 - \eta_1 c + 3a_{RU} + a_{RO}) + (7a_{RU}a_{RU} + 4a_{RO}a_{RU} + a_{RO}a_{RO})}{18}$

$\pi_M^{NS*} = \frac{(\eta_2\eta_1 p_0 - c\eta_1)^2 + 2(\eta_2\eta_1 p_0 - c\eta_1)(a_{RU} + a_{RO}) + 2a_{RU}{}^2 + 2a_{RO}{}^2}{6}$

$\pi_M^{L\,U\to O*} - \pi_M^{NS*} = \frac{(3\eta_1\eta_2 p_0 - 3\eta_1 c + a_{RU} + 5a_{RO})(a_{RU} - a_{RO})}{18} > 0$

$\pi_M^{L\,U\to O*} > \pi_M^{NS*}$, if lemma 1.

$\pi_M^{S\,*} = \frac{[(a_{RU} + a_{RO}) + (\eta_1\eta_2 p_0 - c\eta_1)]^2}{6}$

$\pi_M^{L\,U\to O*} = \frac{3(\eta_1\eta_2 p_0 - \eta_1 c)(\eta_1\eta_2 p_0 - \eta_1 c + 3a_{RU} + a_{RO}) + (7a_{RU}a_{RU} + 4a_{RO}a_{RU} + a_{RO}a_{RO})}{18}$

$\pi_M^{S\,*} - \pi_M^{L\,U\to O*} = \frac{(3\eta_1\eta_2 p_0 - 3\eta_1 c + 2a_{RO} + 4a_{RU})(a_{RO} - a_{RU})}{18} < 0$

Proof of Theorem 7

Compare the profit of remanufacturers under the two conditions of no sharing& no leakage, and information sharing

$$\pi_M^{NS*} = \frac{(\eta_2\eta_1 p_0 - c\eta_1)^2 + 2(\eta_2\eta_1 p_0 - c\eta_1)(a_{RU} + a_{RO}) + 2a_{RU}{}^2 + 2a_{RO}{}^2}{6}$$

$\pi_M^{S\,*} = \frac{[(a_{RU} + a_{RO}) + (\eta_1\eta_2 p_0 - c\eta_1)]^2}{6}$

$\pi_M^{NS*} - \pi_M^{S\,*} = \frac{a_{RU}{}^2 + a_{RO}{}^2}{6} > 0$, $\pi_M^{NS*} > \pi_M^{S\,*}$, if lemma 1.

Sensibility Analysis Appendix

$$\pi_M^{L\,U\to O*} = \frac{3(\eta_1\eta_2 p_0-\eta_1 c)(\eta_1\eta_2 p_0-\eta_1 c+3a_{RU}+a_{RO})+(7a_{RU}a_{RU}+4a_{RO}a_{RU}+a_{RO}a_{RO})}{18}$$

$$\pi_{RU}^{L\,U\to O*} = \frac{(\eta_1\eta_2 p_0-\eta_1 c)(\eta_1\eta_2 p_0-\eta_1 c+4a_{RO})-4({a_{RU}}^2-2a_{RU}a_{RO})}{36}$$

$$\pi_{RO}^{L\,U\to O*} = \frac{(\eta_1\eta_2 p_0-\eta_1 c)(\eta_1\eta_2 p_0-\eta_1 c+4a_{RO})+(3a_{RO}-a_{RU})(a_{RO}+a_{RU})}{36}$$

Table A.1
Results of sensibility analysis changing uncertainty

x	No sharing no leaking			Information sharing			Information leaking		
	E(π_{RU})	E(π_{RO})	E (π_M)	E(π_{RU})	E(π_{RO})	E (π_M)	E(π_{RU})	E(π_{RO})	E (π_M)
0	2.449	3.627	18.893	3.121	3.121	18.727	2.449	2.532	20.549
0.1	2.343	3.499	18.193	3.004	3.004	18.027	2.343	2.427	19.816
0.2	2.240	3.373	17.507	2.890	2.890	17.340	2.240	2.323	19.096
0.3	2.139	3.250	16.833	2.778	2.778	16.667	2.139	2.222	18.389
0.4	2.040	3.129	16.173	2.668	2.668	16.007	2.040	2.123	17.696
0.5	1.943	3.010	15.527	2.560	2.560	15.360	1.943	2.027	17.016
0.6	1.849	2.893	14.893	2.454	2.454	14.727	1.849	1.932	16.349
0.7	1.757	2.779	14.273	2.351	2.351	14.107	1.757	1.840	15.696
0.8	1.667	2.667	13.667	2.250	2.250	13.500	1.667	1.750	15.056
0.9	1.579	2.557	13.073	2.151	2.151	12.907	1.579	1.662	14.429
1	1.493	2.449	12.493	2.054	2.054	12.327	1.493	1.577	13.816