

Article

Sustainable Supply Chain Management: Optimal Entry Strategies for Marine Plastic Recycling

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Abstract

The market for remanufactured products made from marine plastic waste is expanding rapidly, but the recycling rate of this waste remains strikingly low. This disconnect forces conventional plastic recycling firms to make a consequential strategic choice: enter the marine plastic recycling supply segment by expanding to build market power or enter by competing as a specialized supplier. To examine this trade-off, this paper develops a two-period game-theoretic model that contrasts entry strategies and performance under monopolistic and competitive market structures. We derive and compare equilibrium pricing, quantities, and profits for the relevant supply chain participants in both settings and then characterize the conditions under which one entry mode dominates the other. The results indicate that neither the preferred entry strategy nor the profitability that follows is driven by a single parameter. Instead, outcomes are shaped by the joint effects of consumer tastes, remanufacturing costs, and the scale of capacity investment cost required for entry. When consumers show a stronger preference for conventional remanufactured products, a supplier pursuing monopolistic expansion can earn higher profits by offering a more flexible product portfolio. By contrast, when the cost of remanufacturing marine plastics and the associated capacity investment cost are relatively low, the environment favors a specialized, competitively oriented entry strategy. Profit allocation within the supply chain is also closely tied to remanufacturer costs: as these costs fall, suppliers are able to appropriate a larger share of total profits. Overall, the analysis provides a theoretical basis for entry decisions in the emerging marine plastic recycling industry and offers actionable guidance for firms facing different demand and cost conditions across market structures.

Keywords: remanufacturing; entry strategy; marine plastic waste; supply chain management



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1. Introduction

Plastic waste is accumulating in marine environments at a pace that has made the problem both highly visible and difficult to ignore [1]. Current estimates suggest that roughly 8–12 million metric tons of plastic enter the oceans each year, with consequences that extend beyond ecological damage to include economic losses and wider social costs. Against this backdrop, the circular economy has gained traction in plastics policy and corporate practice, shifting attention from end-of-pipe cleanup toward keeping plastic materials in use through closed-loop recovery and reuse.

Regulatory and market forces are jointly reshaping the value proposition of marine plastics. Policy actions at multiple levels are reframing them from an environmental liability

into a potential secondary raw material. Concurrently, growing consumer awareness of plastic pollution, corporate sustainability commitments, and brand differentiation strategies have spurred demand for products made with “ocean-bound” or recycled marine plastics. This demand is often associated with a green premium, reflecting consumers’ willingness to pay a higher price compared to conventional recycled plastics, which signals the emergence of this market segment. This brand-driven demand has sent clear market signals: for instance, Adidas partners with the environmental organization Parley to transform plastics collected from coastal areas into premium sportswear; fast-moving consumer goods giants like Procter & Gamble have also pledged to scale up the use of marine plastics in their packaging. On the industry side, as a specialized processor, Veolia Huafei Polymer Technology (Zhejiang in China) Co., Ltd. (Huzhou, China) joined Zhejiang Province’s “Blue Cycle” project in 2021. Its recycled marine plastic can command a price about four times that of conventional recycled plastic, with profits significantly surpassing those of traditional recyclers. These cases collectively validate the existence of differentiated market valuation and the green premium for marine plastics.

However, upstream supply has not kept pace with this demand growth. It is important to clarify that the marine plastic waste examined in this study specifically refers to plastic waste that has already entered the marine environment or, due to its disposal location and management practices [2], is at high risk of directly entering waterways and reaching the ocean, thus requiring complex preprocessing steps such as collection, desalination, and quality screening. The dispersed sources and difficulties in retrieval and transport, coupled with these necessary preprocessing steps, result in significantly higher collection and preprocessing costs compared to terrestrial plastics, keeping recovery volumes at a low level. This supply bottleneck manifests in reality as two distinct challenges: on one hand, technology-driven projects like “The Ocean Cleanup” highlight the extreme logistical and cost challenges of large-scale recovery in the open ocean; on the other hand, practices like “Plastic Bank” in the Philippines innovate collection networks through community empowerment models, partially alleviating difficulties in source collection, yet they still face the severe technical challenge of upgrading low-quality, mixed waste into standardized industrial feedstock. This elevated and complex cost structure, combined with the dedicated capacity investments required downstream for remanufacturing, creates a critical bottleneck hindering market development.

The resulting supply–demand gap presents a fundamental strategic choice for incumbent recycling suppliers (the upstream actors) regarding market structure: should they leverage their scale and network advantages for monopolistic expansion, integrating control over this new, differentiated material stream, or should they remain focused on terrestrial plastics, leaving the marine segment to specialized competitive entrants? This choice hinges on how different upstream market structures (monopoly vs. competition) affect equilibrium pricing, quantities, and profit distribution—a question not adequately addressed in the existing literature.

Research on closed-loop supply chains has predominantly focused on downstream remanufacturers’ decisions, while analytical attention to upstream suppliers’ entry strategies and pricing behavior for differentiated recycled feedstocks has been limited. This omission is significant, because marine plastics differ from conventional recycled inputs in ways that are central to strategic interaction: their recovery is costlier, their preprocessing is more demanding, and their demand stems from consumers’ heterogeneous preference for their green attributes.

To address this gap, we develop a two-period game-theoretic model of a two-echelon supply chain to compare two second-period market structures: (i) monopolistic expansion, where the incumbent supplier provides both terrestrial and marine plastic waste, and

(ii) specialized competition, where an entrant supplies marine plastics while the incumbent remains focused on terrestrial waste. This framework allows us to isolate how market structure shapes outcomes. We focus on three questions:

- (1) What features of the marine plastic segment materially affect supplier decision-making?
- (2) How do consumer preference θ , the marine remanufacturing cost c_S , and the scale of capacity investment cost A jointly determine whether entry is profitable under monopoly versus competition?
- (3) How does profit sharing between suppliers and the remanufacturer change across these structures, and through what mechanisms?

This study contributes by shifting analytical attention upstream, providing a unified comparison of monopoly and competitive equilibria in this setting, and offering practical implications for firms and policymakers regarding when integrated expansion or specialized competition is preferable and how cost reductions reshape bargaining power.

2. Literature Review

In what follows, we organize the literature around three strands that are most relevant to our setting: (1) coordination and decision-making in CLSCs under different channel structures; (2) competitive and cooperative interactions among remanufacturing-related actors; and (3) the role of external drivers such as consumer preferences and regulation. We then highlight the remaining gap for marine plastic waste recycling and use it to motivate the present study.

2.1. Foundational Models: Coordination, Pricing, and Power Structures

Early studies on CLSCs developed the basic analytical tools for coordination and pricing in reverse channels. A widely cited example is Savaskan, et al. [3], who studied reverse-channel design in the presence of competing retailers and provided a benchmark framework for evaluating collection performance. Subsequent research broadened this framework by bringing channel power and incentive design into the model. Heese et al. [4], for example, showed how alternative power allocations between manufacturers and retailers change both profitability and collection efficiency. Related work also examined how competition among manufacturers affects equilibrium outcomes and how coordinating contracts can be designed when governments apply combined incentives and penalties [5,6]. A common message across these papers is that who moves first, who sets which prices, and how incentives are structured can materially shape both economic results and environmental performance—an insight that motivates our use of supplier-led (Stackelberg) decision-making and explicit cost asymmetries in the model.

These literature sources provide the basic two-echelon, Stackelberg-game framework we adopt. However, crucially, we relax the homogeneous-cost assumption common in foundational models by introducing a positive collection cost for marine plastics (c_O) and a convex capacity investment (Aq_O^2). These modifications are essential to capture the high specialized costs of marine plastic recovery and processing, which are central to its economics.

2.2. Dynamics of Competition and Cooperation

A second major strand focuses on strategic interaction among original equipment manufacturers (OEMs), independent remanufacturers, and third-party collectors. The report by Ferrer and Swaminathan [7] is often cited as an early analytical treatment of how an OEM should respond when independent remanufacturers enter and compete, which is closely related to questions of entry and product differentiation. Another set of studies examines governance choices in the reverse channel, in particular the trade-off between

vertical integration and outsourcing. Örsdemir, et al. [8], for instance, compare an OEM's remanufacturing decisions under direct competition with an independent remanufacturer versus a setting where the OEM authorizes that remanufacturer. In addition, both dynamic game formulations and empirical evidence have been used to identify when cooperation can be sustained and how channel power affects remanufacturing performance [9,10]. Taken together, these literature sources highlight two points that are central to our setup: market structure matters, and the roles assigned to upstream and downstream players (integrated versus specialized, leader versus follower) can change equilibrium decisions and profit outcomes—motivating our comparison of monopolistic expansion and specialized competition on the supplier side.

From the literature in this section, we transpose the classic “integration vs. specialization” lens upstream to the supplier tier. Our core dichotomy between monopoly (Model M) and competition (Model C) directly operationalizes this strategic choice. This focus is justified, because the initial bottleneck and key strategic decisions in the nascent marine plastic chain lie at the feedstock supply level.

2.3. Incorporation of External Factors

As CLSC research developed, many models were extended to account for external conditions that firms face in practice. One prominent direction concerns regulation, particularly extended producer responsibility (EPR). Corsini, et al. [11] seek to bridge this gap by making use of quantitative analyses to investigate how key issues related to WEEE directive transposition and organizational settings adopted by each member state influenced the results achieved in those member states in terms of collection from households. In parallel, a large body of literature examines demand-side heterogeneity associated with environmental preferences. Debo, et al. [12] for example, assessed model market segmentation based on willingness to pay for “green” attributes and analyzed how it shapes technology adoption and remanufacturing decisions under regulation. Related work has incorporated operational and financial considerations, including investment in green R&D [13], the joint role of subsidies and cost-sharing in improving collection outcomes [14], and financing arrangements for sustainable operations under capital constraints [15,16]. More recent studies refine these themes with greater empirical and behavioral detail. Khyzhniakova [17] proposes a model of internal and external communications for a manufacturing enterprise. Furthermore, he identifies analytical indicators that allow for assessment of the growth level in environmental responsibility at these listed stages. He, et al. [18] investigate the economic and environmental implications of OEMs' strategic desired quality level choices under remanufacturing outsourcing. This study investigates the threshold for environmental impact for different lifecycle phases. Overall, these extensions reinforce a general point: remanufacturing outcomes are shaped not only by operational costs and channel structure, but also by the broader regulatory environment and by how consumers interpret and value “green” attributes.

Following the tradition of modeling green segmentation [12], we internalize consumer preference via parameter θ , which governs both the willingness-to-pay difference and competitive substitution between terrestrial and marine products. This captures the “green premium” as an endogenous market outcome, central to the marine plastic value proposition.

2.4. Focus on Specific Product and Industry Contexts

Because remanufacturing settings differ widely across products and industries, a growing set of studies has moved from generic CLSC structures to more context-specific analyses. For capital-intensive durable goods (e.g., heavy machinery), researchers have

emphasized issues such as quality uncertainty and the strategic interaction between OEMs and independent remanufacturers [19]. In the context of the energy transition, another active stream focuses on electric vehicle (EV) batteries, where pricing, take-back/return policies, and network design are studied under policy instruments such as subsidies and carbon trading [20].

Marine and ocean-bound plastics have also started to receive focused attention, with research expanding beyond initial technical assessments. Nagy, et al. [21] propose a methodology to estimate plastic release to the ocean, considering a more detailed characterization of each river basin, including natural attributes and manmade constructions that may act as barriers or boosters for this release. Heath, et al. [22] assess the lifecycle environmental and economic trade-offs of alternative chemical recycling routes for mixed ocean-bound plastics, highlighting how technology choice maps to a cost frontier. Complementing these studies, a growing body of work examines the distinctive institutional dimensions of this market. Izadi, et al. [23] investigate the solution of an ocean waste plastic management system model. The model is represented by a nonlinear system which is divided into three compartments. Moreover, it gives the basic reproduction number and discusses the existence of equilibria, and the local stability of equilibria are investigated. Parsamanesh, et al. [24] investigate a mathematical model in the form of a system of ordinary differential equations, consisting of three compartments: plastic waste, marine debris, and recycled material. This study first describes the model formulation and presents some of its fundamental properties. Then, it derives the model's equilibria and its basic reproduction number using the next generation matrix method. Additionally, this study proves the global stability of the model at these equilibria. Tehrani and Cui [25] investigate plastic waste management, focusing on Japan. The volume of plastic waste in Japan is more than 8 million tons, and less than a quarter of the plastic waste is subjected to recycling. This research explores the underlying factors that have made Japan one of the highest users of plastic. In addition, this study evaluates different strategies that are utilized in Japan to deal with the reduction in plastic utilization and plastic waste.

This section notes that research on closed-loop supply chains has gradually shifted from generic models toward contextualized analyses of specific fields. Particularly regarding marine plastics, existing literature has largely focused on technical assessments, environmental lifecycle analyses, methods for estimating plastic flux into the oceans, and regional governance practices—primarily empirical and technical issues. However, there remains a lack of in-depth theoretical modeling and comparative research on the systematic strategic behaviors and operational coordination mechanisms within the supply chain for this material stream. The key decision-making structures and dynamic impacts that distinguish marine plastic wastes from conventional recycled materials have yet to be fully elucidated.

2.5. Identified Research Gap and This Study's Position

To systematically clarify the position of this study within the existing literature, key literature sources spanning foundational models of closed-loop supply chains, competition and cooperation, external factors, and specific contexts (e.g., marine plastics) are compared in Table 1.

It is evident that, although the CLSC and remanufacturing literature is extensive, two gaps remain salient for the marine plastics setting considered here. First, despite the fact that feedstock suppliers constitute the first bottleneck in any closed-loop system, most analytical work has concentrated on downstream decisions—those of OEMs/independent remanufacturers and, in some cases, retailers. By contrast, upstream suppliers' strategic choices, especially the entry decision into a new and differentiated recycling stream and

the associated pricing behavior, have received limited treatment in formal models. Second, while recent empirical and technical studies (e.g., [21]) have started to document the realities of marine plastic recovery, comparatively few papers develop analytical frameworks that capture supplier-level strategic interaction and competition in this setting.

Table 1. Literature comparison: focus on upstream supplier strategies.

Reference	Primary Focus	Supplier Entry Modeled?	Feedstock Differentiated?	Market Structure Compared?
Savaskan, et al. [1]	Reverse channel design	No	No	No
Ferrer and Swaminathan [5]	Downstream remanufacturer competition	No	No	No
Örşdemir, et al. [6]	OEM remanufacturing strategy	No	No	No
Atasu, et al. [9]	EPR policy analysis	No	No	No
Debo, et al. [12]	Green consumer preference	No	No	No
Zhu and He [15]	Material-specific EPR effects	No	Yes (Material type)	No
Rahman and Lee [19]	Marine plastic supply chains (empirical)	Addressed (Descriptive)	Yes	No
This Study	Supplier entry into marine plastic recycling	Yes	Yes (Marine vs. Terrestrial)	Yes (Monopoly vs. Competition)

This omission is consequential, because marine plastics differ from conventional recycled inputs along several dimensions that are central to equilibrium behavior: recovery is costly and logistically difficult, preprocessing and quality control are more demanding, and demand is often shaped by a “green” attribute whose valuation varies across consumers. These features jointly generate a strategic environment that is not well represented by models that treat recycled feedstock as a homogeneous input or abstract away from upstream competition.

Therefore, this study directly bridges these gaps. By drawing upon classic channel structure analysis [26] to construct a game-theoretic model, we provide formal analytical rigor that complements recent empirical work. We focus explicitly on the upstream supplier’s strategic entry decision into the marine plastic waste recycling sector, systematically comparing outcomes under monopolistic expansion and specialized competition. In doing so, we integrate and extend insights from the foundational work on channel power and competitive interactions, as well as the latest understanding of material-specific contexts, to offer a novel theoretical framework for understanding the profitability drivers and supply chain implications of this critical strategic choice.

3. Model Preparation

3.1. Problem Description

We consider a two-period game within a two-echelon supply chain consisting of a single supplier (*S*) and a single remanufacturer (*R*). The core strategic dilemma revolves around the supplier’s decision to enter the nascent but promising market for marine plastic waste recycling in the second period and how this choice is shaped by the resulting market structure.

Period 1 (Baseline): The supplier collects only terrestrial (conventional) plastic waste and sells it to the remanufacturer at a wholesale price. Using this input, the remanufacturer

produces and sells remanufactured products based on terrestrial plastics. This baseline therefore involves a single feedstock stream (Figure 1).

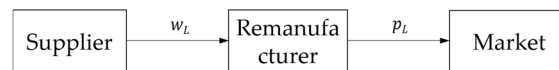


Figure 1. Baseline in period 1.

Period 2 (Strategic Expansion): Market conditions change in the second period: the remanufacturer introduces a marine-plastic product line in response to rising demand and regulatory pressure. This expansion creates a new business opportunity upstream, as the supplier may now consider supplying marine plastic waste in addition to its existing terrestrial stream.

Option A (Monopolistic Expansion): The incumbent supplier (*S*), as the expanding entity, must bear most or all of the upfront investments required to enter the marine plastic recycling market. These investments include specialized vessels, port preprocessing equipment, and new collection and sorting centers. The remanufacturer (*R*) is responsible for its own backend production investment (represented in the model as Aq_O^2), which is used for the remanufacturing of marine plastics. Leveraging its existing network and capital, supplier *S* integrates and controls the entire chain from collection to preprocessing. It is responsible for establishing a unified collection system and implementing quality control and may lead or exclusively hold related traceability systems and environmental certifications (such as marine plastic content certification), thereby strengthening its market power and product premium capability. As the sole upstream node, supplier *S* simultaneously supplies both terrestrial and marine plastics to *R*. This bundled supply relationship grants *S* strong bargaining power, enabling it to achieve overall profit maximization by adjusting the wholesale prices of the two materials (w_L and w_O), as illustrated in the “internal subsidization” strategy analyzed in this paper. This creates a monopolistic supplier market in the second period, denoted as Model M (see Figure 2). In this sequential game, the monopolistic supplier acts as the Stackelberg leader.

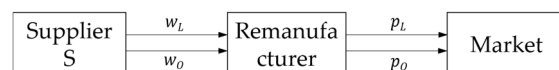


Figure 2. Option A for period 2.

Option B (Specialized Competition): The new specialized entrant supplier (*O*) must independently bear all the upfront investments required to establish its marine plastic recycling business. The remanufacturer (*R*) similarly bears its own backend production investment. This reflects the dispersion of capital investment under specialized division of labor. Specialized supplier *O* controls the collection network and primary preprocessing of marine plastics and may develop its own independent certification or traceability schemes. The remanufacturer *R* or third-party certification bodies may become more deeply involved in supervision to ensure the authenticity of the “marine-origin” feedstock and meet brand customer requirements. This reflects the division of labor and checks and balances inherent in specialization. The remanufacturer *R* needs to negotiate and transact separately with supplier *L*, who focuses on terrestrial plastics, and supplier *O*, who specializes in marine plastics. The competition between *L* and *O* at the input level weakens their respective bargaining power (particularly manifested as Nash competition in Model C), allowing *R* to obtain lower input costs but potentially facing more complex supply chain coordination challenges. Thus, in period 2, two suppliers engage in Nash competition: the incumbent (supplier *L*, for terrestrial) and the new entrant (supplier *O*, for marine). The remanufacturer remains the single downstream player. This scenario is denoted as Model C (see Figure 3).

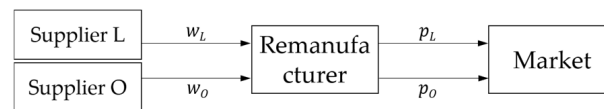


Figure 3. Option B for period 2.

This modeling framework allows us to isolate and compare the economic and strategic consequences of the supplier's fundamental choice: to leverage its incumbent position for monopolistic expansion into a new green market or to stay specialized and face market competition. The comparison between Model M and Model C directly addresses our core research questions regarding optimal entry strategy and profit distribution under different market structures.

3.2. Basic Assumptions

To formalize the game-theoretic models (M and C), we establish the following assumptions, which capture the key economic and operational distinctions between terrestrial and marine plastic waste recycling.

Assumption 1 (Pricing and Product Flow). *The supplier (S) collects terrestrial waste and marine plastic waste, selling them as raw materials to the remanufacturer at wholesale prices w_L and w_O , respectively. The remanufacturer then produces and sells two types of remanufactured products to the market at retail prices p_L (terrestrial-based) and p_O (marine-based).*

Assumption 2 (Collection Cost Structure). *Following the analytical convention in the closed-loop supply chain literature that often normalizes the baseline cost of established operations to zero to sharpen the focus on the incremental cost of new system components (see Savaskan, et al. [27], who normalize the collection cost for conventional channels in their benchmark model), we normalize the unit collection cost for terrestrial plastic waste to zero. By contrast, marine plastic waste is costly to recover, because it must be retrieved from dispersed sources and typically requires transport and pre-treatment (e.g., cleaning/desalination) before it can be used. The unit collection cost for marine plastic waste is denoted as $c_O > 0$.*

Assumption 3 (Remanufacturer's Capacity Investment Cost). *Producing remanufactured products from marine plastic waste requires dedicated equipment and process upgrades, so the remanufacturer must incur an additional capacity investment cost. Consistent with standard quadratic investment specifications in the operations literature [28], we model this cost as $C = Aq_O^2$, where $A > 0$ measures the scale (or intensity) of capital investment needed to establish the marine-plastic line. This formulation captures the idea that expanding capacity becomes increasingly costly as the marine output level increases.*

Assumption 4 (Material Intensity and Production Cost). *Marine plastic remanufactured products are entirely sourced from marine plastic waste [29]. To maintain analytical tractability and focus on the primary cost differentials, we assume a constant input–output coefficient, a common simplification in supply chain models dealing with material transformation (e.g., standard Leontief production function representations). The parameter $n > 1$ denotes the units of marine plastic waste required to produce one unit of final product [30], reflecting material loss during the intensive cleaning and processing.*

Assumption 5 (Demand Substitution). *The terrestrial and marine plastic remanufactured products are imperfect substitutes. Following Ferguson and Toktay [5], their inverse demand functions are given by*

$$p_O = Q - q_O - \theta q_L, \quad (1)$$

$$p_L = \theta(Q - q_O - q_L), \quad (2)$$

where Q is the potential market size, normalized to 1 [1].

Economic Interpretation: This system captures two essential features of the market. First, the parameter $\theta \in (0, 1)$ synthesizes the relative market positioning of the terrestrial product. It simultaneously scales the base willingness- to pay for the terrestrial product (intercept) and governs the substitution intensity between the two products (cross-effect). A lower θ implies that consumers perceive the terrestrial product as less valuable relative to the marine alternative; this not only directly lowers the price they are willing to pay for the terrestrial product p_L , but also weakens the competitive pressure (cross-price effect) that terrestrial product quantity exerts on the marine product's price p_O . This is a parsimonious way to model a market where the “green” attribute of marine plastics both creates a vertical differentiation (value difference) and influences the horizontal competition pattern. We assume $p_O > p_L$ in equilibrium, which requires θ to be sufficiently less than 1, consistent with the presence of a green premium for marine plastics.

Assumption 6 (Market Expansion Effect of Competition). *Under the competitive scenario, the potential market demand is assumed to be 1, whereas under the monopoly scenario, it is assumed to be $Q = 1 - q_1^*$. This assumption is grounded in the market diffusion theory proposed by [31,32]: the entry of competitors typically brings about advertising effects, media exposure, and increased consumer awareness, thereby activating a portion of previously untapped market demand. In this paper, the monopolist in the first period has already satisfied part of the market q_1^* , leaving a residual potential demand of $1 - q_1^*$. Entering the second period, if the monopoly remains, market awareness does not change significantly, and the potential demand stays at $1 - q_1^*$; if a new competitor enters, its market activities (such as environmental promotion and new product launches) will awaken some dormant demand, restoring the total potential demand to the initial market capacity of 1. This assumption reflects the positive externality of competition on market size, aligning with the typical diffusion patterns observed in emerging industries.*

Assumption 7 (Game Sequence and Structure). *The supplier (S), as the upstream party, hold the first-mover advantage as a Stackelberg leader. The remanufacturer acts as the follower. In Model C, the two suppliers (L and O) engage in Nash competition simultaneously, deciding their respective wholesale prices [26].*

The assumption that the supplier acts as the Stackelberg leader in setting wholesale prices reflects a commonly adopted power structure in the closed-loop supply chain literature, particularly in settings where upstream participants control scarce or differentiated input flows [26,27]. In the context of marine plastic recycling, several industry characteristics reinforce the plausibility of this assumption:

- (1) **Entry barriers and resource scarcity:** Marine plastic collection involves high logistical costs and specialized equipment and often operates in geographically dispersed or legally complex environments. These factors create natural entry barriers and can confer first-mover advantages to established or early-entrant suppliers.
- (2) **Material differentiation and “green” premium:** Marine plastics carry a distinct environmental attribute that is valued by downstream consumers and brands. Suppliers who secure access to or control over this differentiated feedstock can exert pricing influence, especially when certification and traceability are required.
- (3) **Upstream consolidation trends:** In practice, many recycling markets show tendencies toward consolidation at the collection and preprocessing stages, which can strengthen the bargaining position of larger suppliers relative to downstream manufacturers.

Key notations are summarized in Table 2.

Table 2. Symbol descriptions.

Symbol	Description
w_O	Wholesale price of marine plastic waste
w_L	Wholesale price of terrestrial plastic waste
p_O	Selling price of remanufactured products from marine plastic waste
p_L	Selling price of remanufactured products from terrestrial plastic waste
q_O	Demand quantity for remanufactured products from marine plastic waste
q_L	Demand quantity for remanufactured products from terrestrial plastic waste
c_s	Unit remanufacturing cost of marine plastic products (hereafter referred to as marine plastic waste remanufacturing cost)
c_O	Unit collection cost of marine plastic waste (hereafter referred to as marine plastic waste collection cost)
θ	Consumers' willingness to pay for remanufactured products from terrestrial plastic waste
A	Capital input coefficient for manufacturers engaging in marine plastic waste remanufacturing
n	Number of units of marine plastic waste required to produce one unit of remanufactured marine plastic product
Q	Potential market demand quantity

4. Model Construction and Optimization Analysis

4.1. First Period

The profit function for the remanufacturer is

$$\Pi_{1R} = (p_{1L} - w_{1L})q_{1L} \quad (3)$$

The supplier's profit function is

$$\Pi_{1S} = w_{1L}q_{1L} \quad (4)$$

The market demand function is

$$q_{1L} = 1 - p_{1L} \quad (5)$$

The optimal solution for the first period is obtained as $w_{1L}^* = \frac{1}{2}$, $p_{1L}^* = \frac{3}{4}$, $q_{1L}^* = \frac{1}{4}$. The market residual potential demand is $\frac{3}{4}$. Here, the subscript $j = \{1\}$ denotes the first period.

4.2. Second Period

The second period is divided into two scenarios: if suppliers recycle marine waste plastic from the first period, Model M applies; otherwise, Model C applies.

In both models, the remanufacturer's profit is

$$\Pi_R = (p_O - c_s - nw_O)q_O - Aq_O^2 + (p_L - w_L)q_L \quad (6)$$

In Model M, the supplier's profit function is

$$\Pi_S = (w_O - c_O)nq_O + w_Lq_L \quad (7)$$

In Model C, the supplier's profit function is

$$\Pi_L = w_Lq_L \quad (8)$$

In Model C, the competitor's (hereafter also referred to as the competing supplier's) profit function is

$$\Pi_O = (w_O - c_O)nq_O \quad (9)$$

Using reverse induction, the equilibrium solutions for both models are obtained, as shown in Table 3. All proofs can be found at Appendix A.

Table 3. Comparison of optimal decisions across the two models.

Variable	Model M	Model C
w_O^*	$\frac{4c_O n - 4c_S + 3}{8n}$	$\frac{2A - 2c_S - 2\theta - 2Ac_S - A\theta + 2c_O n + c_S\theta + 2Ac_O n + 2}{n(4A - \theta + 4)}$
w_L^*	$\frac{3\theta}{8}$	$\frac{\theta(2A + c_S - \theta + c_O n + 1)}{4A - \theta + 4}$
p_O^*	$\frac{12A + 4c_S - 9\theta - 3A\theta + 4c_O n - 4c_S\theta - 4c_O n\theta + 9}{16(A - \theta + 1)}$	$\frac{14A + 2c_S - 9\theta + 2Ac_S - 12A\theta + 2c_O n - 2c_S\theta + A\theta^2 - 2A^2\theta + 8A^2 + 3\theta^2 + 2Ac_O n - Ac_S\theta - 2c_O n\theta - Ac_O n\theta + 6}{2(4A^2 - 5A\theta + 8A + \theta^2 - 5\theta + 4)}$
p_L^*	$\frac{9\theta}{16}$	$\frac{\theta(6A + c_S - 2\theta + c_O n + 5)}{8A - 2\theta + 8}$
q_O^*	$-\frac{4c_S + 3\theta + 4c_O n - 3}{16(A - \theta + 1)}$	$-\frac{2c_S - 2A + 2\theta + 2Ac_S + A\theta + 2c_O n - c_S\theta + 2Ac_O n - c_O n\theta - 2}{2(4A^2 - 5A\theta + 8A + \theta^2 - 5\theta + 4)}$
q_L^*	$\frac{3A + 4c_S + 4c_O n}{16(A - \theta + 1)}$	$\frac{(A+1)(2A + c_S - \theta + c_O n + 1)}{2(4A^2 - 5A\theta + 8A + \theta^2 - 5\theta + 4)}$
Π_R^*	$\frac{9A\theta - 9\theta - 24c_S - 24c_O n + 24c_S\theta + 16c_S^2 + 16c_O^2 n^2 + 32c_O c_S n + 24c_O n\theta + 9}{256(A - \theta + 1)}$	$(A+1) \left(\frac{4A^2\theta + 4Ac_O^2 n^2 + 8Ac_O c_S n - 8Ac_O n + 4Ac_S^2 - 8Ac_S - 3A\theta^2 + 8A\theta + 4A - 3c_O^2 n^2 + 4c_O^2 n^2}{-6c_O c_S n\theta + 8c_O c_S n + 2c_O n\theta^2 + 6c_O n\theta - 8c_O n - 3c_S^2\theta + 4c_S^2 + 2c_S\theta^2 + 6c_S\theta - 8c_S - 5\theta^2 + \theta + 4} \right)$
Π_S^*	$\frac{3\theta(3A + 4c_S + 4c_O n)}{128(A - \theta + 1)} + \frac{n(c_O - \frac{4c_O n - 4c_S + 3}{8n})(4c_S + 3\theta + 4c_O n - 3)}{16(A - \theta + 1)}$	—
Π_O^*	—	$\frac{\left(\frac{2c_S - 2A + 2\theta + 2Ac_S + A\theta + 2c_O n - c_S\theta + 2Ac_O n - c_O n\theta - 2}{2(4A - \theta + 4)(4A^2 - 5A\theta + 8A + \theta^2 - 5\theta + 4)} \right)^2}{\frac{\theta(A+1)(2A + c_S - \theta + c_O n + 1)^2}{2(4A - \theta + 4)(4A^2 - 5A\theta + 8A + \theta^2 - 5\theta + 4)}}$
Π_L^*	—	$\frac{\theta(A+1)(2A + c_S - \theta + c_O n + 1)^2}{2(4A - \theta + 4)(4A^2 - 5A\theta + 8A + \theta^2 - 5\theta + 4)}$

4.2.1. Equilibrium Analysis Under Model M

Proposition 1. Under conditions $0 < c_O < \frac{3(1-\theta)}{4n}$ and $0 < \theta < \frac{1}{n}$, if $nc_O + \frac{3(1-n\theta)}{4} < c_S < \frac{3(1-\theta)}{4} - nc_O$, $w_O^* < w_L^*$; if $0 < c_S < nc_O + \frac{3(1-n\theta)}{4}$, $w_O^* > w_L^*$.

The proof of Proposition 1 can be found at Appendix B. Proposition 1 reveals the fundamental impact of downstream remanufacturing costs (c_S) on the pricing strategy of a monopolistic supplier: when downstream costs are high, the supplier lowers the wholesale price of marine plastics; when downstream costs are low, the supplier raises it. The underlying logic reflects the supplier's dynamic game-theoretic strategy as a market leader: its pricing decision aims to balance short-term profit with long-term supply chain collaboration. When downstream costs are high, the supplier actively reduces the wholesale price to share cost pressure and sustain production scale, constituting a market cultivation strategy of “trading price for volume.” Conversely, when downstream costs fall, the supplier raises prices to capture a share of the green premium and efficiency gains, shifting toward “value appropriation.” This means that, before entering the market, suppliers should carefully assess the manufacturing cost level of downstream partners—if downstream costs are high, a low-price penetration strategy is advisable; if downstream efficiency is high, higher premiums can be secured. At the same time, downstream firms should recognize that their own cost-control capability directly determines their bargaining power in profit distribution.

Proposition 2. Under the conditions $0 < c_O < \frac{3(1-A-\theta)}{8n}$ and $0 < A < 1 - \theta$, if $\frac{3(1-A-\theta)}{8} - nc_O < c_S < \frac{3(1-\theta)}{4} - nc_O$, $q_O^* < q_L^*$; if $0 < c_S < \frac{3(1-A-\theta)}{8} - nc_O$, $q_O^* > q_L^*$.

The proof of Proposition 2 can be found at Appendix C. Proposition 2 shows that a monopolistic supplier's supply structure for marine versus terrestrial plastics dynamically

adjusts with the downstream remanufacturing cost (c_S): when downstream costs are high, marine plastic output is lower than terrestrial plastic output; when downstream costs are low, marine plastic output surpasses terrestrial plastic output.

This reflects the supplier's "proactive capacity-matching" strategy as a supply chain coordinator. Its supply decisions are not made independently, but closely follow the profit orientation and production choices of the downstream firm. When downstream production of marine plastics contracts due to high costs, the supplier reduces its supply accordingly to avoid inventory buildup and resource misallocation. Conversely, when downstream expands marine plastic production due to lower costs, the supplier actively shifts its supply structure, directing resources toward the higher-value segment to jointly maximize chain-wide profits. The supplier's capacity allocation must focus on tracking downstream technological cost changes. The downstream technological maturity (reflected in c_S) is a key signal for upstream adjustments in recycling structure and capacity investment. When downstream costs remain high, investment in marine plastic recycling capacity should be cautious; when there are significant downstream cost reductions, resources should be swiftly reallocated toward the marine plastic recycling system to capture the green premium and market growth opportunities.

Proposition 3. When $0 < c_S < \frac{3}{4} - \frac{3\sqrt{(1+A)\theta}}{4n} - nc_O$, both monopolistic suppliers and recyclers derive greater profits from marine waste plastics ($\Pi_{SO}^* > \Pi_{SL}^*$ and $\Pi_{RO}^* > \Pi_{RL}^*$). When $\frac{3}{4} - \frac{3\sqrt{(1+A)\theta}}{4n} - nc_O < c_S < \frac{3(1-\theta)}{4} - nc_O$ and $0 < c_O < \frac{3(1-\sqrt{(1+A)\theta})}{4n}$, or when $\frac{3(1-\sqrt{(1+A)\theta})}{4n} < c_O < \frac{3(1-\theta)}{4n}$, both the monopoly supplier and the recycler derive greater profits from land-based plastic waste ($\Pi_{SO}^* < \Pi_{SL}^*$, $\Pi_{RO}^* < \Pi_{RL}^*$).

The proof of Proposition 3 can be found at Appendix D. Proposition 3 indicates that the profit comparison for both the supplier and remanufacturer, between marine and terrestrial plastics, is jointly determined by downstream remanufacturing cost (c_S) and upstream recycling cost (c_O). Only when both costs are sufficiently low will the profits from marine plastics surpass those from terrestrial plastics. This reveals that a shift in the entire supply chain's profit model depends on system-wide cost breakthroughs. Cost reduction in a single segment is insufficient to alter the profit structure. Only when the entire "recycling–remanufacturing" chain achieves low costs will the commercial potential of marine plastics be fully unlocked, shifting the chain's profit center. Until then, terrestrial plastics remain the more stable profit source. This tells us that, when deciding whether to strategically pivot toward marine plastics, firms (whether supplier or remanufacturer) must conduct a full-chain cost audit. Optimizing only their own segment is insufficient; they must also assess their partner's cost position. Before costs are collaboratively reduced across the industry, maintaining flexibility in the business portfolio (i.e., not abandoning terrestrial plastics) is a more robust strategy.

Proposition 4. Monopoly suppliers earn higher profits than remanufacturers, $\Pi_R^* < \Pi_S^*$.

The proof of Proposition 4 can be found at Appendix E. Proposition 4 reveals that, under a monopoly structure, the supplier consistently earns higher profits than the remanufacturer. This indicates that profits are structurally concentrated upstream in this emerging market. This outcome stems from the supplier's control over the scarce "green" feedstock and its ability to capture the associated premium. The remanufacturer, despite bearing production risks, depends on this bottleneck resource, limiting its bargaining power. This finding suggests that suppliers hold a dominant position in this nascent industry. For a sustainable chain, downstream firms may need to seek alternative inputs or collaborative

agreements, while suppliers should avoid excessive pricing that could stifle long-term market growth.

4.2.2. Equilibrium Analysis Under Model C

Proposition 5. When $0 < c_S < \frac{3Anc_O - n\theta c_O + 2A^2 + 3nc_O + A + \theta - 1}{3A - \theta + 3}$, $0 < c_O < -\frac{2A^2 + A + \theta - 1}{3A - \theta + 3}$, $\theta < 1 - 2A^2 - A$, and $A < \frac{1}{2}$, then $q_O^* > q_L^*$; when $\frac{3Anc_O - n\theta c_O + 2A^2 + 3nc_O + A + \theta - 1}{3A - \theta + 3} < c_S < -\frac{2Anc_O - n\theta c_O + A\theta + 2nc_O - 2A + 2\theta - 2}{2A - \theta + 2}$, $0 < c_O < -\frac{2A^2 + A + \theta - 1}{3A - \theta + 3}$, $\theta < 1 - 2A^2 - A$, and $A < \frac{1}{2}$ or $-\frac{2A^2 + A + \theta - 1}{3A - \theta + 3} < c_O < -\frac{A\theta - 2A + 2\theta - 2}{n(2A - \theta + 2)}$, then $q_O^* < q_L^*$.

The proof of Proposition 5 can be found at Appendix F. Proposition 5 shows that, in a competitive market, whether marine plastics can achieve output superiority depends on dual cost constraints both upstream and downstream. Output surpasses that of terrestrial plastics only when both the recycling cost (c_O) and the remanufacturing cost (c_S) are sufficiently low; otherwise, terrestrial plastics remain dominant. This reveals the “cost linkage effect” in a specialized competitive market: a cost advantage in any single segment is insufficient to shift the product structure; it requires cost competitiveness across the entire chain to change the market landscape. As a specialized entrant, the decision must be based on a two-way cost assessment—being efficient alone is not enough; it also requires downstream partners to have low-cost remanufacturing capabilities. The optimal entry timing should prioritize identifying or creating a market window where both the upstream and downstream components have achieved low costs.

Proposition 6. Under the conditions $1 < n < -\frac{A\theta + 2\theta - 2A - 2}{\theta(1 + A - \theta)}$, $\frac{-n\theta^2 + 2n\theta A + n\theta + A\theta + 2\theta - 2A - 2}{n(2 + 2A - n\theta)} < c_O < \frac{\theta(A - \theta + 1)}{2A - \theta + 2}$, or $n > \frac{2A + 2}{\theta}$, $0 < c_O < \frac{-n\theta^2 + 2n\theta A + n\theta + A\theta + 2\theta - 2A - 2}{n(2 + 2A - n\theta)}$, when $\frac{n(-n\theta c_O + 2Ac_O - 2A\theta + \theta^2 + 2c_O - \theta) + A(2 - \theta) - 2\theta + 2}{2A - \theta + n\theta + 2} < c_S < \frac{-(2Anc_O - n\theta c_O + A\theta + 2nc_O - 2A + 2\theta - 2)}{2A - \theta + 2}$, $w_O^* < w_L^*$; when $0 < c_S < \frac{n(-n\theta c_O + 2Ac_O - 2A\theta + \theta^2 + 2c_O - \theta) + A(2 - \theta) - 2\theta + 2}{2A - \theta + n\theta + 2}$, $w_O^* > w_L^*$.

The proof of Proposition 6 can be found at Appendix G. Proposition 6 reveals that, in a specialized competitive structure, whether the wholesale price of marine plastics exceeds that of terrestrial plastics fundamentally depends on the profit margin of downstream remanufacturers: when downstream manufacturing costs (c_S) are low, remanufacturers exhibit strong demand for marine plastic feedstock, granting specialized suppliers greater bargaining power and enabling them to capture part of the green premium through higher wholesale prices; conversely, if downstream costs are high, weak demand forces suppliers to lower wholesale prices to sustain supply chain cooperation. This mechanism illustrates that the pricing power of upstream suppliers essentially mirrors the profitability and cost efficiency of the downstream segment. Therefore, specialized recycling firms should treat the cost structure of downstream partners as a core determinant of pricing and aim to enter the market during periods when downstream technology matures and costs decline, in order to achieve better profit capture.

Proposition 7. Under the conditions $0 < c_O < \frac{1 - \sqrt{(1 + A)\theta}}{n}$ and $0 < \theta < \frac{1}{A + 1}$, when $0 < c_S < 1 - \sqrt{(1 + A)\theta} - nc_O$, $\Pi_{RO}^* > \Pi_{RL}^*$ and $\Pi_O^* > \Pi_L^*$; when $1 - \sqrt{(1 + A)\theta} - nc_O < c_S < -\frac{n(2Ac_O - \theta c_O + 2c_O) - 2A + A\theta + 2\theta - 2}{2A - \theta + 2}$ or $\frac{1 - \sqrt{(1 + A)\theta}}{n} < c_O < -\frac{A\theta - 2A + 2\theta - 2}{n(2A - \theta + 2)}$, $\Pi_{RO}^* < \Pi_{RL}^*$ and $\Pi_O^* < \Pi_L^*$.

The proof of Proposition 7 can be found at Appendix H. Proposition 7 shows that, in a competitive structure, whether the marine plastic stream becomes more profitable than the terrestrial one for both the specialized supplier and the remanufacturer depends on

a concurrent reduction in costs across the supply chain. Only when both the upstream recovery cost (c_O) and the downstream remanufacturing cost (c_S) are sufficiently low does the total surplus generated by the marine segment become large enough to dominate profits. This highlights a critical system-level cost threshold for green materials: isolated cost advantages are insufficient to shift profit centers. Therefore, specialized suppliers and remanufacturers must coordinate their efforts to reduce systemic costs or carefully time their strategic focus on the marine business until such alignment is achieved.

4.2.3. Model Comparison

Proposition 8. *Under all conditions, both marine and land-based plastic waste output are lower under monopoly than under competition, $q_O^{M*} < q_O^{C*}$ and $q_L^{M*} < q_L^{C*}$.*

The proof of Proposition 8 can be found at Appendix I. Proposition 8 demonstrates that a monopolistic supplier structure consistently leads to lower output for both marine and terrestrial plastics compared to a competitive supplier market. This occurs because a monopolist, facing no upstream rivalry, exerts stronger bargaining power and sets higher wholesale prices, which increases costs for the downstream remanufacturer and ultimately suppresses production volumes. In contrast, competition between specialized suppliers weakens their individual pricing power, leading to lower input costs for the remanufacturer, higher output that better matches market demand, and greater overall supply chain efficiency. This finding underscores a fundamental trade-off: while monopoly may benefit the incumbent supplier, it constrains total market output and consumer access to remanufactured products.

Proposition 9. *When $0 < c_S < \frac{8A\theta+13\theta-4n\theta c_O-4A-4}{4\theta}$, $0 < c_O < -\frac{8A\theta+13\theta-4A-4}{4n\theta}$, $A < \frac{4-13\theta}{4(2\theta-1)}$, $\frac{4}{13} < \theta < \frac{1}{2}$, or $A < \frac{4-10\theta-3\theta^2}{8\theta-4}$, $\theta < \frac{1}{2}$, then $w_O^{M*} > w_O^{C*}$; when $\frac{8A\theta+13\theta-4n\theta c_O-4A-4}{4\theta} < c_S < \frac{3(1-\theta)}{4} - nc_O$, $0 < c_O < -\frac{8A\theta+13\theta-4A-4}{4n\theta}$, $A < \frac{4-13\theta}{4(2\theta-1)}$, $\frac{4}{13} < \theta < \frac{1}{2}$, or $-\frac{8A\theta+13\theta-4A-4}{4n\theta} < c_O < \frac{3(1-\theta)}{4n}$, then $w_O^{M*} < w_O^{C*}$.*

The proof of Proposition 9 can be found at Appendix J. Proposition 9 reveals that whether the wholesale price of marine plastics is higher under monopoly (w_O^{M*}) or competition (w_O^{C*}) is determined by a cost-driven threshold: when downstream remanufacturing costs (c_S) and capacity investment scale (A) are sufficiently low, the monopolist raises w_O^{M*} above w_O^{C*} to capture the enhanced green premium enabled by efficient downstream production. However, if downstream costs remain high, the monopolist lowers w_O^{M*} below the competitive level to sustain minimal downstream participation, whereas competition can still support a modest price due to specialization. This underscores that a supplier's pricing strategy under different market structures is not static, but adapts strategically to the efficiency and scale of downstream operations.

Proposition 10. *When $0 < c_S < \frac{1-A}{2} + \frac{5\theta}{8} - nc_O$, $0 < c_O < \frac{5\theta-4A+4}{8n}$, $\frac{11\theta-2}{4} < A < \frac{4+5\theta}{4}$, or $0 < A < \frac{11\theta-2}{4}$, $\frac{2}{11} < \theta < 1$, then $w_L^{M*} > w_L^{C*}$; when $\frac{1-A}{2} + \frac{5\theta}{8} - nc_O < c_S < \frac{3(1-\theta)}{4} - nc_O$, $0 < c_O < \frac{5\theta-4A+4}{8n}$, $\frac{11\theta-2}{4} < A < \frac{4+5\theta}{4}$, or $\frac{5\theta-4A+4}{8n} < c_O < \frac{3(1-\theta)}{4n}$, $A > \frac{11\theta-2}{4}$, then $w_L^{M*} < w_L^{C*}$.*

The proof of Proposition 10 can be found at Appendix K. Proposition 10 examines how the wholesale price of terrestrial plastics compares under monopoly versus competition. It finds that a monopolistic supplier can charge a higher price for terrestrial waste ($w_L^{M*} > w_L^{C*}$) primarily when downstream production of marine plastics is efficient (low c_S and manageable A) and consumer preference for terrestrial products is sufficiently strong

(high θ). In this scenario, the monopolist leverages its control over both material streams to elevate prices across the board. Conversely, if marine plastic recovery or remanufacturing is costly, the weakened demand for the entire system limits the monopolist's ability to sustain high terrestrial prices, often making them lower than in a competitive market ($w_L^{M*} < w_L^{C*}$). This indicates that the pricing power of a monopolist over a mature product line is contingent on the health and profitability of the new, differentiated segment it aims to control.

Proposition 11. When $0 < c_S < \frac{7\theta}{8} - \frac{1+3A}{2} - nc_O$, $0 < c_O < \frac{7\theta-12A-4}{8n}$, $\frac{13\theta-10}{12} < A < \frac{7\theta-4}{12}$, or $0 < A < \frac{13\theta-10}{12}$, $\frac{10}{13} < \theta < 1$, then $p_L^{M*} > p_L^{C*}$; when $\frac{7\theta}{8} - \frac{1+3A}{2} - nc_O < c_S < \frac{3(1-\theta)}{4} - nc_O$, $0 < c_O < \frac{7\theta-12A-4}{8n}$, $\frac{13\theta-10}{12} < A < \frac{7\theta-4}{12}$, or $\frac{7\theta-12A-4}{8n} < c_O < \frac{3(1-\theta)}{4n}$, then $p_L^{M*} < p_L^{C*}$.

The proof of Proposition 11 can be found at Appendix L. Proposition 11 compares the retail price of terrestrial remanufactured products across market structures. It finds that this price can be higher under monopoly ($p_L^{M*} > p_L^{C*}$) only when downstream marine remanufacturing is sufficiently efficient (low c_S and A). In such cases, the monopolist's strategy of raising wholesale prices for both material streams (as shown in Propositions 9 and 10) transmits these higher input costs downstream, forcing the remanufacturer to increase the final retail price p_L . Conversely, when downstream efficiency is low, the monopolist's weakened position leads to lower wholesale prices, which can result in a lower retail price under monopoly than under competition ($p_L^{M*} < p_L^{C*}$). This result highlights that the retail price of a mature product is not determined in isolation, but is critically influenced by the cost dynamics and pricing strategies applied to a new, co-existing green product line within the same supply chain.

Conclusion 1. In the marine plastic waste remanufacturing market, the sales price of marine plastic waste remanufactured products is lower under supplier monopoly conditions than under supplier competition conditions. This contradicts the traditional economic intuition that “competition drives prices down.”

As shown in Figure 4, regardless of the scenario, the price of marine plastic recycled products decreases as c_S and A decrease, with prices being higher under competitive conditions.

Figure 5 demonstrates the same trend. This occurs because reductions in production costs and investment scale lower the unit cost of recycled marine plastic products, thereby decreasing their price. Simultaneously, in competitive scenarios, suppliers focus on their own product lines; as investment increases, costs inevitably rise, ultimately leading to higher prices. This counterintuitive conclusion is primarily driven by the interplay of two key mechanisms within the model.

Pressure to allocate downstream investment costs: In the competitive model (C), the remanufacturer exclusively bears the full convex capacity investment cost Aq_O^2 required to establish the marine plastic production line. To cover this rapidly increasing cost and maintain profitability, the remanufacturer has a stronger incentive to set a higher retail price p_O , thereby transferring part of the investment burden to consumers.

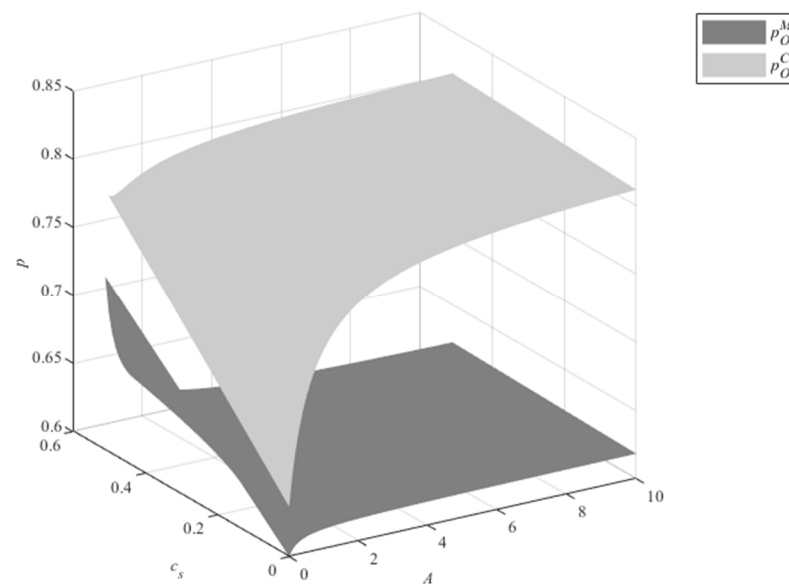


Figure 4. Comparison of marine plastic recycled product prices when $\theta = 0.7$.

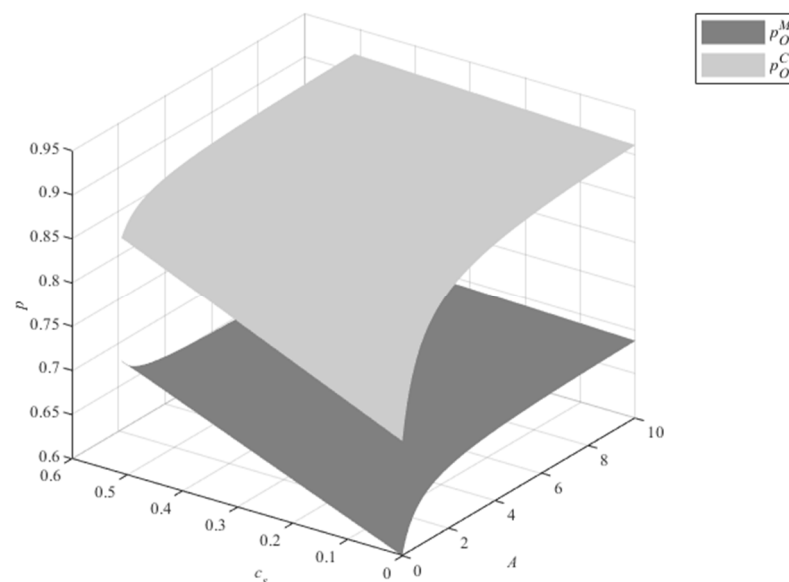


Figure 5. Comparison of marine plastic recycled product prices when $\theta = 0.3$.

Strategic price-reduction incentive for the upstream monopolist: In the monopoly model (M), the monopolistic supplier provides both material streams. When the profit from terrestrial products is substantial (i.e., θ is relatively high), the supplier has an incentive to strategically lower the wholesale price of marine plastics w_O to stimulate greater downstream production of marine products. This not only expands sales of marine feedstock, but, more importantly, allows the supplier to enhance overall brand value or market share through the “green” product line, thereby indirectly supporting profits from its terrestrial business. This move essentially represents the monopolist leveraging its integrated position to engage in internal subsidization or cross-coordination, which mitigates the double marginalization effect in the supply chain and ultimately leads to a lower retail price.

5. Numerical Analysis

Following Wang, et al. [33], we set $n = 1.5$ and $c_O = 0.1$. To represent contrasting market perceptions of the “green” attribute, we assign $\theta = 0.3$ and $\theta = 0.7$. These values reflect a high green-premium scenario (where consumers strongly value marine plastics)

and a low green-premium scenario (where they are seen as closer substitutes), respectively. The choice is informed by empirical ranges of environmental premiums and provides clear comparative insights. Sensitivity analysis confirms that our key insights are qualitatively robust within a reasonable range of θ .

5.1. Comparison of Remanufacturer Profits Under Monopoly and Competition Conditions

Conclusion 2. When θ is high, as c_s and A decrease, remanufacturer profits in the competitive model increase significantly, while profits in the monopoly scenario decline (as shown in Figure 6). However, when θ is low, as c_s and A decrease, remanufacturer profits in both models increase (as shown in Figure 7). Simultaneously, remanufacturer profits in the competitive model are consistently higher.

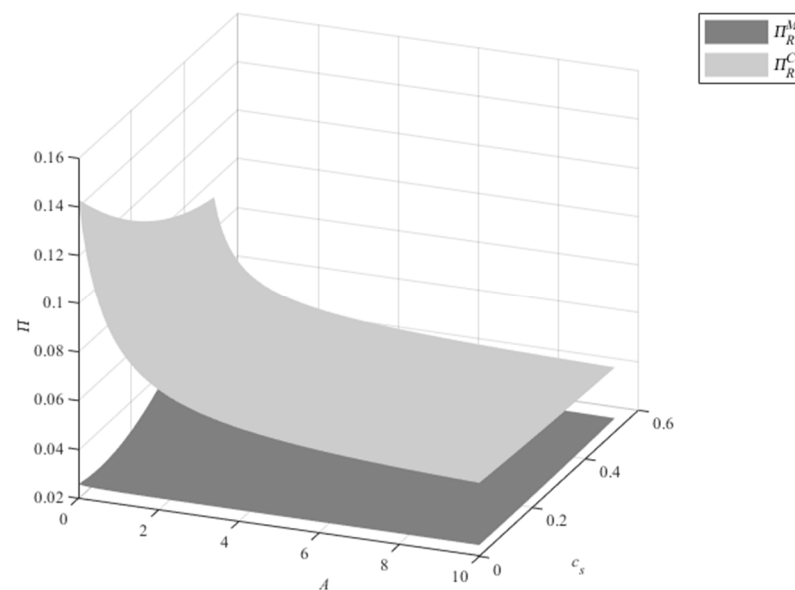


Figure 6. Comparison of remanufacturer profits under monopoly and competition conditions when $\theta = 0.7$.

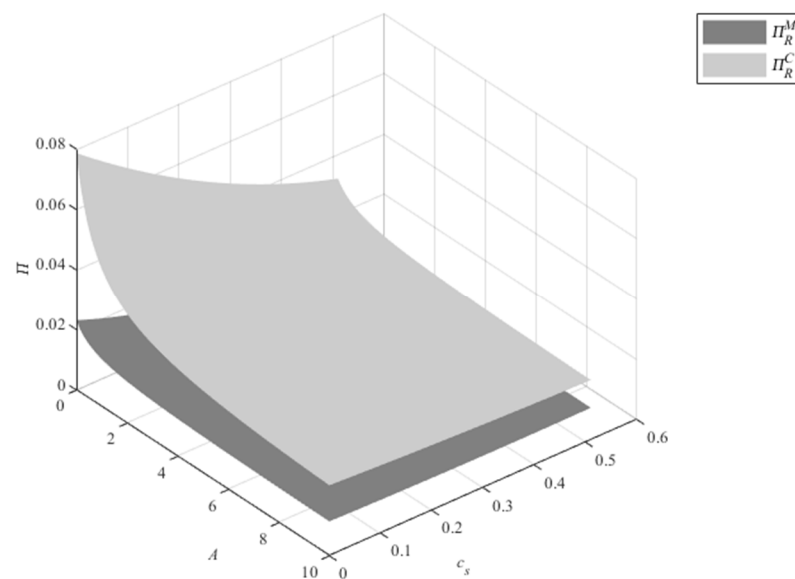


Figure 7. Supplier profit comparison under monopoly and competition conditions when $\theta = 0.3$.

The fundamental reason lies in the competitive model's greater effectiveness at lowering wholesale prices for waste plastic, reducing remanufacturers' costs, and achieving higher sales volumes, thereby consistently yielding higher profits. Specifically, reduced production costs and investment scale better enable remanufacturers to control expenses. Counterintuitively, however, monopoly-mode remanufacturers experience declining profits alongside falling c_s when θ is high. This occurs because higher θ leads to reduced production of marine plastic remanufactured goods. Although remanufacturers produce more land-based plastic goods, the market is already saturated with these homogeneous products, yielding significantly lower profits than marine plastic remanufactured goods. Simultaneously, lower production costs imply lower entry barriers, which conversely means remanufacturers lack pricing power.

5.2. Supplier Profit Comparison Under Monopoly and Competition Conditions

Conclusion 3. As shown in Figure 8, when θ is high, as investment scale decreases, competitive suppliers' profits decline while monopoly suppliers' profits rise, achieving higher profits within a certain range. The same holds when θ is low (Figure 9). However, when c_s is high, monopoly suppliers' profits do not necessarily increase.

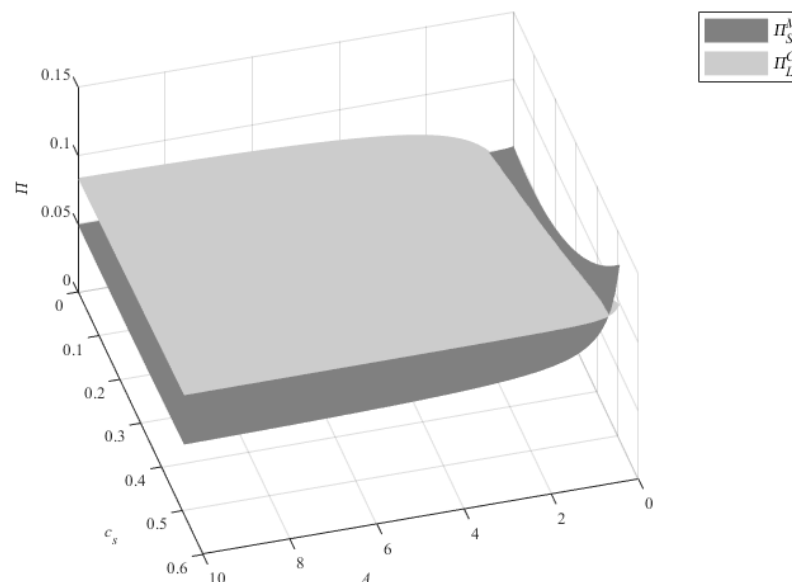


Figure 8. Profit comparison between monopoly suppliers and competitive scenarios for land-based plastic waste suppliers when $\theta = 0.7$.

This occurs because reduced investment costs lower the unit cost of marine plastic recycled products, ultimately decreasing their price and increasing demand. This, in turn, partially impacts demand for land-based plastic recycled products, leading to the observed phenomenon. Furthermore, when consumer preference for land-based recycled products is low, excessive consumer demand for marine recycled products coupled with higher production costs for recyclers enables recyclers to dominate the industry. This allows them to suppress marine waste plastic prices, capturing substantial profits. This also indicates that, when downstream players excessively control industry discourse, suppliers entering new industries may not necessarily secure higher profits.

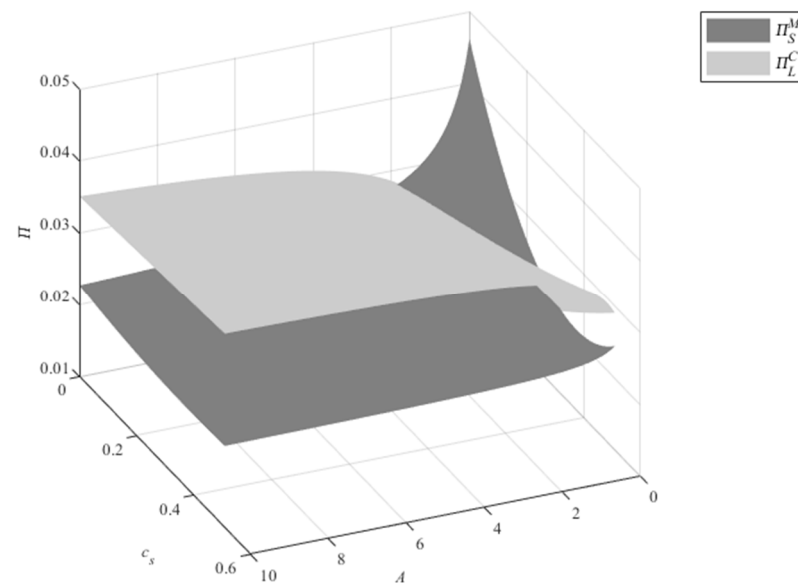


Figure 9. Profit comparison between monopoly suppliers and competitive scenarios for land-based waste plastic suppliers when $\theta = 0.3$.

Conclusion 4. As shown in Figure 10, when θ is high, supplier profits under monopoly conditions consistently exceed those of competitive suppliers. Conversely, when θ is low (Figure 11), competitive suppliers only achieve higher profits when both production costs and investment costs remain at low levels.

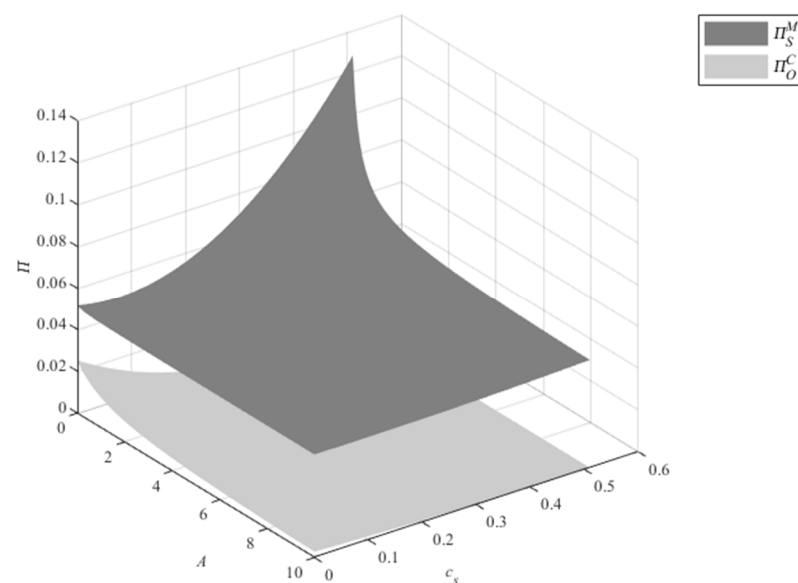


Figure 10. Profit comparison between monopoly suppliers and competitive scenarios for marine waste plastic suppliers when $\theta = 0.7$.

The reason lies in the fact that, under the monopoly model, suppliers additionally recycle terrestrial plastic products, enabling them to achieve higher profits in most scenarios. However, if consumer acceptance of terrestrial plastics is low, suppliers' profits from this segment become extremely minimal. Consequently, when marine plastic recycled products gain market traction, profit growth remains sluggish. Recycling enterprises should enter this new industry with limitless potential based on end-market preferences and abandon outdated industries when necessary.

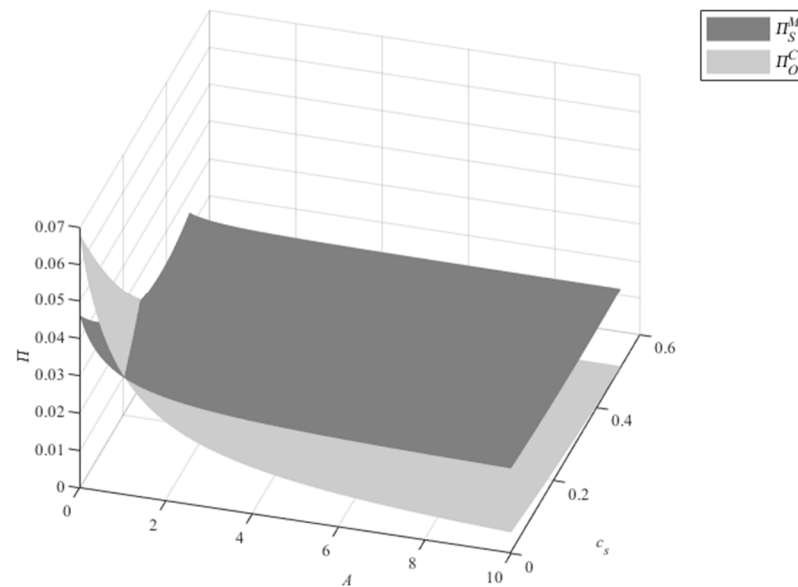


Figure 11. Comparison of supplier profits for marine plastic waste under monopoly and competitive scenarios when $\theta = 0.3$.

6. Conclusions

This study reveals that recycling suppliers' decisions to enter marine plastic waste remanufacturing fundamentally depend on consumer preferences and the costs borne by downstream remanufacturers. When the market favors marine plastic remanufactured products and remanufacturers' production costs are low, suppliers benefit from specializing in recycling, potentially even abandoning terrestrial plastic waste recycling in certain scenarios. When consumers place limited value on marine plastic products and remanufacturers face high production costs, entering marine plastic recycling is unlikely to be profitable for suppliers. In such cases, suppliers may be better served by maintaining a diversified recycling portfolio to manage risk or by postponing entry until costs fall or demand conditions improve.

For a monopolistic supplier, the analysis also suggests a contingent pricing policy. When the remanufacturer's costs are high, lowering wholesale prices for marine feedstock can help sustain downstream participation and support the diffusion of marine plastic products. When the remanufacturer's costs are low, the supplier can raise wholesale prices and capture a larger share of the surplus associated with the marine "green" attribute. Under supplier competition, the implication is different: entry is most attractive when cost conditions allow the marine stream to scale, and competitive pricing can help avoid upstream shortages that would otherwise compress remanufacturers' margins and slow market development.

This study has several limitations, most of which stem from the stylized structure needed for tractability. First, we assume a single remanufacturer and complete information; this abstracts from downstream competition and from information frictions such as verification and certification of "ocean plastic." Second, the two-period setting does not capture longer-run dynamics, including learning-by-doing, path dependence, or behavioral concerns such as perceived fairness, and it does not explicitly incorporate policy tools (e.g., subsidies, take-back mandates, or penalties). Third, the objective is restricted to firms' economic profits, leaving aside other welfare criteria such as consumer surplus and environmental or social benefits. Extending the framework to multi-period, multi-agent, and multi-objective settings would be a natural direction for future research and could provide a broader basis for both managerial decisions and policy design.

This study provides a theoretical lens for analyzing entry strategies in the emerging marine plastic recycling market. While the stylized model offers generalizable insights into the strategic trade-offs shaped by consumer preferences and cost structures, we acknowledge that its conclusions are derived under specific, simplified assumptions. The absence of empirical case studies limits the direct mapping of results to any particular firm or region. However, the analytical framework and the derived conditions (e.g., the roles of θ , c_S , and A) establish a foundational logic and a diagnostic tool for practitioners. Future research that tests and refines these propositions through case-based or empirical analysis would be a valuable complement, further bridging theory with the complex realities of this evolving industry.

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Appendix A. Analysis of Two Models

Analysis of Model C: Substituting the price functions $p_O = \frac{3}{4} - q_O - \theta q_L$ and $p_L = \theta(\frac{3}{4} - q_O - q_L)$ into Π_R yields

$$\Pi_R = -Aq_O^2 - q_O \left(c_S + q_O + nw_O + \theta q_L - \frac{3}{4} \right) - q_L [w_L + \theta(q_L + q_O - 3/4)] \quad (A1)$$

Thus, the Hessian matrix for Manufacturer R’s profit function is

$$\begin{bmatrix} -2A - 2 & -2\theta \\ -2\theta & -2\theta \end{bmatrix} \quad (A2)$$

From $A > 0$ and $0 < \theta < 1$, we obtain $-2A - 2 < 0$ and $4\theta(1 + A - \theta) > 0$. Therefore, this Hessian matrix is negative definite, indicating that manufacturer R’s profit function is concave and has an optimal solution. Differentiating q_O and q_L from Π_R and solving the simultaneous equations yields

$$q_O = -\frac{4c_S + 3\theta - 4w_L + 4nw_O - 3}{8(A - \theta + 1)} \quad (A3)$$

$$q_L = \frac{4\theta c_S + 3A\theta - 4w_L - 4Aw_L + 4n\theta w_O}{8\theta(A - \theta + 1)} \quad (A4)$$

Substituting these into the supplier’s profit function gives

$$\Pi_S = \frac{n(4c_S + 3\theta - 4w_L + 4nw_O - 3)(c_O - w_O)}{8(A - \theta + 1)} + \frac{w_L(4\theta c_S + 3A\theta - 4w_L - 4Aw_L + 4n\theta w_O)}{8\theta(A - \theta + 1)} \quad (A5)$$

Thus, the Hessian matrix for supplier S's profit function is

$$\begin{bmatrix} \frac{n^2}{\theta-A-1} & \frac{n}{1+A-\theta} \\ \frac{n}{1+A-\theta} & \frac{4A+4}{4\theta(\theta-A-1)} \end{bmatrix} \quad (\text{A6})$$

From $n > 1$, we obtain $\frac{n^2}{\theta-A-1} < 0$ and $\frac{n^2}{\theta(1+A-\theta)} > 0$. Therefore, the Hessian matrix of supplier S's profit function is negative definite, indicating that the profit function is concave and has an optimal solution. Differentiating Π_S with respect to w_O and w_L , then solving the simultaneous equations, yields $w_O = \frac{4nc_O - 4c_S + 3}{8n}$ and $w_L = 3/8\theta$. Substituting w_O and w_L into q_O and q_L , as well as p_O and p_L , we obtain

$$q_O = -\frac{4c_S + 3\theta + 4nc_O - 3}{16(1 + A - \theta)} \quad (\text{A7})$$

$$q_L = \frac{3A + 4c_S + 4nc_O}{16(1 + A - \theta)} \quad (\text{A8})$$

$$p_L = 9\theta/16 \quad (\text{A9})$$

$$p_O = \frac{12A + 4c_S - 9\theta - 3A\theta + 4nc_O - 4\theta c_S - 4n\theta c_O + 9}{16(1 + A - \theta)} \quad (\text{A10})$$

Parameter range of Model M: From $\begin{cases} 0 < q_O < 1 \\ 0 < q_L < 1 \end{cases}$, we obtain $0 < c_S < \frac{3(1-\theta)}{4} - nc_O$.

Furthermore, since $\frac{3(1-\theta)}{4} - nc_O > 0$, we obtain $0 < c_O < \frac{3(1-\theta)}{4n}$.

Analysis of Model C: Substituting the price functions $p_O = 1 - q_O - \theta q_L$ and $p_L = \theta(1 - q_O - q_L)$ into Π_R yields

$$\Pi_R = -Aq_O^2 - q_O(c_S + q_O + nw_O + \theta q_L - 1) - q_L[w_L + \theta(q_L + q_O - 1)] \quad (\text{A11})$$

Thus, the Hessian matrix for manufacturer R's profit function is

$$\begin{bmatrix} -2A - 2 & -2\theta \\ -2\theta & -2\theta \end{bmatrix} \quad (\text{A12})$$

Since this Hessian matrix is negative definite, manufacturer R's profit function is concave, and an optimal solution exists. Differentiating q_O and q_L from Π_R and solving the simultaneous equations yields

$$q_O = -\frac{c_S + \theta - w_L + nw_O - 1}{2(A - \theta + 1)} \quad (\text{A13})$$

$$q_L = \frac{\theta c_S + A\theta - w_L - Aw_L + n\theta w_O}{2\theta(A - \theta + 1)} \quad (\text{A14})$$

Substituting these into the profit functions of both suppliers yields

$$\Pi_O = \frac{n(c_S + \theta - w_L + nw_O - 1)(c_O - w_O)}{2(A - \theta + 1)} \quad (\text{A15})$$

$$\Pi_L = \frac{w_L(\theta c_S + A\theta - w_L - Aw_L + n\theta w_O)}{2\theta(A - \theta + 1)} \quad (\text{A16})$$

Taking the second partial derivatives of w_O in Π_O and w_L in Π_L yields $-\frac{n^2}{A-\theta+1} < 0$ and $-\frac{A+1}{\theta(A-\theta+1)} < 0$, respectively, indicating the existence of an optimal solution. Next, taking the first partial derivatives of w_O in Π_O and w_L in Π_L and solving the simultaneous equa-

tions, we obtain $w_O = \frac{2A-2\theta-2Ac_S-A\theta+2nc_O+\theta c_S+2Anc_O-2c_S+2}{n(4A-\theta+4)}$ and $w_L = \frac{\theta(2A-\theta+nc_O+c_S+1)}{4A-\theta+4}$. Substituting w_O and w_L into q_O and q_L , and into p_O and p_L , respectively, we obtain

$$q_O = -\frac{2c_S - 2A + 2\theta + 2Ac_S + A\theta + 2nc_O - \theta c_S + (2A - \theta)nc_O - 2}{2(4A^2 - 5A\theta + 8A + \theta^2 - 5\theta + 4)} \quad (A17)$$

$$q_L = \frac{(A + 1)(2A + c_S - \theta + nc_O + 1)}{2(4 + 4A^2 - 5A\theta + 8A - 5\theta)} \quad (A18)$$

$$p_L = \frac{\theta(6A + c_S - 2\theta + nc_O + 5)}{8A - 2\theta + 8} \quad (A19)$$

$$p_O = \frac{14A + 2c_S - 9\theta + 2Ac_S - 12A\theta + 2nc_O - 2\theta c_S + A\theta^2 - 2A^2\theta + 8A^2 + 3\theta^2 + 2Anc_O - A\theta c_S - 2n\theta c_O - An\theta c_O + 6}{2(4 + 4A^2 - 5A\theta + 8A - 5\theta)} \quad (A20)$$

Appendix B

Proof of Proposition 1. Let $w_O^M - w_L^M = 0$, yielding $c_S = nc_O + \frac{3(1-\theta)}{4}$. When $c_S < 0$, we have $c_O < \frac{3(n\theta-1)}{4n}$. To satisfy $c_O > 0$, we must also satisfy $\theta > \frac{1}{n}$. When $0 < c_S < \frac{3(1-\theta)}{4} - nc_O$, we have $\frac{3(n\theta-1)}{4n} < c_O < \frac{3\theta(n-1)}{8n}$. To satisfy $c_O < \frac{3(1-\theta)}{4n}$, we must also satisfy $\frac{1}{n} < \theta < \frac{2}{n+1}$. When $c_S > \frac{3(1-\theta)}{4n} - nc_O$, to satisfy $c_O > \frac{3\theta(n-1)}{8n}$, we must also satisfy $\frac{2}{n+1} < \theta < 1$. Q.E.D. $\square$

Appendix C

Proof of Proposition 2. Let $q_O^M - q_L^M = 0$, yielding $c_S = \frac{3(1-A-\theta)}{3} - nc_O$. When $c_S < 0$, then $c_O > \frac{3(1-A-\theta)}{8n}$; when $c_S > 0$, then $c_O < \frac{3(1-A-\theta)}{8n}$. To satisfy the condition $0 < c_O < \frac{3(1-\theta)}{4n}$, it must also satisfy $A < 1 - \theta$, thus proving the proposition. $\square$

Appendix D

Proof of Proposition 3. Let $\Pi_{SO}^M - \Pi_{SL}^M = 0$ and $\Pi_{RO}^M - \Pi_{RL}^M = 0$. Solving yields two roots: $c_{S1} = \frac{3(1-\sqrt{(A+1)\theta})}{4} - nc_O$ and $c_{S2} = \frac{3(1+\sqrt{(A+1)\theta})}{4} - nc_O$. When $c_{S1} < 0$, we have $c_O > \frac{3(1-\sqrt{(A+1)\theta})}{4n}$. To satisfy $c_O < \frac{3(1-\theta)}{4n}$, we must also satisfy $\frac{3(1-\sqrt{(A+1)\theta})}{4n} - \frac{3(1-\theta)}{4n} < 0$. Since $\frac{3(1-\sqrt{(A+1)\theta})}{4n} - \frac{3(1-\theta)}{4n} < 0$ holds for all cases, no additional conditions need be met. When $c_{S1} > 0$, we have $c_O < \frac{3(1-\sqrt{(A+1)\theta})}{4n}$. To satisfy $c_O > 0$, we must also satisfy $\theta < \frac{1}{A+1}$. Since $c_{S1} - \left(\frac{3(1-\theta)}{4n} - nc_O\right) = \frac{3(\theta-\sqrt{(A+1)\theta})}{4} < 0$, the case $c_{S1} > \frac{3(1-\theta)}{4n} - nc_O$ need not be considered. Furthermore, since $c_{S2} - \left(\frac{3(1-\theta)}{4n} - nc_O\right) = \frac{3(\theta+\sqrt{(A+1)\theta})}{4} > 0$, we only need to examine the sign of c_{S1} . Q.E.D. $\square$

Appendix E

Proof of Proposition 4. Let $\Pi_S^M - \Pi_R^M = 0$. Solving yields two roots: $-nc_O + \frac{3(1-\theta)}{4} \pm \frac{3(1-\sqrt{(\theta-A-1)\theta})}{4}$. Since $(\theta - A - 1)\theta < 0$, this equation has no real solutions. Furthermore, since the coefficient of c_S^2 is $\frac{16}{256(A+1-\theta)} > 0$, we have $\Pi_S^M > \Pi_R^M$. Q.E.D. $\square$

Parameter Range of Model C: From $\begin{cases} 0 < q_O < 1 \\ 0 < q_L < 1 \end{cases}$, we obtain $0 < c_{SC} < -\frac{2Anc_O - n\theta c_O + A\theta + 2nc_O - 2(1+A-\theta)}{2A-\theta+2}$. Furthermore, from $-\frac{2Anc_O - n\theta c_O + A\theta + 2nc_O - 2(1+A-\theta)}{2A-\theta+2} > 0$, we obtain $0 < c_O < -\frac{A\theta - 2(1+A-\theta)}{n(2A-\theta+2)}$. (c_{SC} is the upper bound for this model.)

Appendix F

Proof of Proposition 5. Let $q_O^C - q_L^C = 0$. Its solution c_{S2} is less than $-\frac{2Anc_O - n\theta c_O + A\theta + 2nc_O - 2(1+A-\theta)}{2A-\theta+2}$. When $c_{S2} < 0$, $-\frac{2A^2+A+\theta-1}{n(3A-\theta+3)} < c_O < -\frac{A\theta-2(1+A-\theta)}{n(2A-\theta+2)}$; when $c_{S2} > 0$, $c_O < -\frac{2A^2+A+\theta-1}{n(3A-\theta+3)}$, and satisfying $-\frac{2A^2+A+\theta-1}{n(3A-\theta+3)} > 0$, we obtain $\theta < 1 - 2A^2 - A$ and $A < \frac{1}{2}$. $\square$

Appendix G

Proof of Proposition 6. Let $w_O^C - w_L^C = 0$. Its solution is $c_{S3} = \frac{-n^2\theta c_O + 2Anc_O - 2An\theta + n\theta^2 - A\theta + 2nc_O - n\theta + 2(A-\theta+1)}{n\theta + 2A - \theta + 2}$. When $0 < c_{S3} < c_{SC}$, the following condition must also hold:
$$\begin{cases} \frac{2A+2}{\theta} < n \\ 0 < c_O < \frac{-n\theta^2 + 2n\theta A + n\theta + A\theta + 2\theta - 2A - 2}{n(2+2A-n\theta)} \end{cases} \text{ or } \begin{cases} \frac{-n\theta^2 + 2n\theta A + n\theta + A\theta + 2\theta - 2A - 2}{n(2+2A-n\theta)} < n < \frac{\theta(A-\theta+1)}{2A-\theta+2} \\ \frac{-n\theta^2 + 2n\theta A + n\theta + A\theta + 2\theta - 2A - 2}{n(2+2A-n\theta)} < c_O < \frac{\theta(A-\theta+1)}{2A-\theta+2} \end{cases} \text{ Q.E.D. } \square$$

Appendix H

Proof of Proposition 7. Let $\Pi_O^C - \Pi_L^C = 0$ and $\Pi_{RO}^C - \Pi_{RL}^C = 0$. Solving yields two identical roots: $c_{S4} = 1 - nc_O + \sqrt{\theta(A+1)}$ and $c_{S5} = 1 - nc_O - \sqrt{\theta(A+1)}$. Since $c_{S4} - c_{SC} = \frac{(2A-\theta+2)\sqrt{\theta(A+1)} + \theta(A+1)}{2A-\theta+2}$ is always greater than 0, only the magnitude of c_{S5} needs consideration. Moreover, $c_{S5} - c_{SC} = \frac{(-2A+\theta-2)\sqrt{\theta(A+1)} + \theta(A+1)}{2A-\theta+2}$ is always less than 0. When $c_{S5} < 0$, we obtain $\frac{1-\sqrt{\theta(A+1)}}{n} < c_O < -\frac{A\theta-2(1+A-\theta)}{n(2A-\theta+2)}$; when $c_{S5} > 0$, we obtain $0 < c_O < \frac{1-\sqrt{\theta(A+1)}}{n}$. To satisfy $\frac{1-\sqrt{\theta(A+1)}}{n} > 0$, the condition $\theta < \frac{1}{A+1}$ must also hold. Q.E.D. $\square$

From $c_{SC} - \left[\frac{3(1-\theta)}{4} - nc_O\right] = \frac{(2A+1)\theta + 2A + 2 - 3\theta^2}{8A - 4\theta + 8} > 0$, we know that the common interval of model M and model C coincides with that of model M.

Appendix I

Proof of Proposition 8. Let $q_O^M - q_L^C = 0$, yielding $c_S = -\frac{4n\theta c_O + 4A\theta - 3\theta^2 + 4A - \theta + 4}{4\theta} < 0$; let $q_L^M - q_L^C = 0$, yielding $c_S = \frac{4A^2 + (12-8nc_O-5\theta)A + 4n\theta c_O - 8nc_O - 8\theta + 8}{8A - 4\theta + 8}$. Then subtract c_{SM} from this, resulting in $\frac{4A^2 + (6+\theta)A - 3\theta^2 + \theta + 2}{8A - 4\theta + 8} > 0$. Q.E.D. (c_{SM} is the upper bound of c_S in model M). $\square$

Appendix J

Proof of Proposition 9. Let $w_O^M - w_O^C = 0$. Solving yields $c_{S6} = \frac{8A\theta - 4A - 4 + 13\theta - 4n\theta c_O}{4\theta}$. When $c_{S6} < 0$, we obtain $c_O > \frac{8A\theta - 4A - 4 + 13\theta}{4n\theta}$; when $c_{S6} > c_{SM}$, we obtain $A < \frac{4-3\theta^2-10\theta}{8\theta-4}$. Since $A > 0$, we must also satisfy: $\theta < \frac{1}{2}$. When $0 < c_{S6} < c_{SM}$, we obtain $c_O < \frac{8A\theta - 4A - 4 + 13\theta}{4n\theta}$. Since $c_O > 0$, we must additionally satisfy: $A < \frac{4-13\theta}{4(2\theta-1)}$ and $\frac{4}{13} < \theta < \frac{1}{2}$. Q.E.D. $\square$

Appendix K

Proof of Proposition 10. Let $w_L^M - w_L^C = 0$, yielding $c_{S7} = \frac{1-A}{2} - \frac{5\theta}{8} - nc_O$. When $c_{S7} < 0$, we obtain $\frac{5\theta+4-4A}{8n} < c_O < \frac{3(1-\theta)}{4n}$. For the inequality to hold, we must also satisfy $A > \frac{11\theta}{4} - \frac{1}{2}$. When $c_{S7} > c_{SM}$, we obtain $A < \frac{11\theta}{4} - \frac{1}{2}$. Since $A > 0$, we must additionally satisfy $\theta < \frac{2}{11}$. When $0 < c_{S7} < c_{SM}$, we obtain $c_O < \frac{5\theta+4-4A}{8n}$. Since $c_O > 0$, we must additionally satisfy $\frac{11\theta}{4} - \frac{1}{2} < A < \frac{5\theta}{4} + 1$. Q.E.D. $\square$

Appendix L

Proof of Proposition 11. Let $p_L^M - p_L^C = 0$, yielding $c_{S8} = \frac{7\theta}{8} - \frac{1+3A}{2} - nc_O$. When $c_{S8} < 0$, we obtain $\frac{5\theta-4-12A}{8n} < c_O < \frac{3(1-\theta)}{4n}$; when $c_{S8} > c_{SM}$, we obtain $A < \frac{13\theta}{12} - \frac{5}{6}$. Since $A > 0$, we further require: $\theta > \frac{10}{13}$. When $0 < c_{S7} < c_{SM}$, we obtain $c_O < \frac{7\theta-4-12A}{8n}$. Since $c_O > 0$, we further require: $\frac{13\theta}{12} - \frac{5}{6} < A < \frac{7\theta}{12} - \frac{1}{3}$. Q.E.D. $\square$

References

- Gemechu, A.; Abebe, A.; Anna, D.; Csaba, B.I. Role of Reverse Logistics Activities in the Recycling of Used Plastic Bottled Water Waste Management. *Sustainability* **2022**, *14*, 7650. [\[CrossRef\]](#)
- Belioka, M.P.; Achilias, D.S. Microplastic Pollution and Monitoring in Seawater and Harbor Environments: A Meta-Analysis and Review. *Sustainability* **2023**, *15*, 9079. [\[CrossRef\]](#)
- Savaskan, R.C.; Wassenhove, L.N. Reverse channel design: The case of competing retailers. *Manag. Sci.* **2006**, *52*, 1–14. [\[CrossRef\]](#)
- Heese, H.S.; Cattani, K.; Ferrer, G.; Gilland, W.; Roth, A.V. Competitive advantage through take-back of used products. *Eur. J. Oper. Res.* **2005**, *164*, 143–157. [\[CrossRef\]](#)
- Ferguson, M.E.; Toktay, L.B. The effect of competition on recovery strategies. *Prod. Oper. Manag.* **2006**, *15*, 351–368. [\[CrossRef\]](#)
- Atasu, A.; Wassenhove, L.N.V. An operations perspective on product take-back legislation for e-waste: Theory, practice, and research needs. *Prod. Oper. Manag.* **2012**, *21*, 407–422. [\[CrossRef\]](#)
- Ferrer, G.; Swaminathan, J.M. Managing new and differentiated remanufactured products. *Eur. J. Oper. Res.* **2010**, *203*, 370–379. [\[CrossRef\]](#)
- Örşdemir, A.; Kemahloğlu-Ziya, E.; Parlaktürk, A.K. Competitive quality choice and remanufacturing. *Prod. Oper. Manag.* **2014**, *23*, 48–64. [\[CrossRef\]](#)
- Abbey, J.D.; Blackburn, J.D.; Guide, V.D.R. Optimal pricing for new and remanufactured products. *J. Oper. Manag.* **2015**, *36*, 130–146. [\[CrossRef\]](#)
- Wei, J.; Zhao, J. Pricing and remanufacturing decisions in two competing supply chains. *Int. J. Prod. Res.* **2015**, *53*, 258–278. [\[CrossRef\]](#)
- Corsini, F.; Rizzi, F.; Frey, M. Extended producer responsibility: The impact of organizational dimensions on WEEE collection from households. *Waste Manag.* **2017**, *59*, 23–29. [\[CrossRef\]](#)
- Debo, L.G.; Toktay, L.B.; Van Wassenhove, L.N. Market segmentation and product technology selection for remanufacturable products. *Manag. Sci.* **2005**, *51*, 1193–1205. [\[CrossRef\]](#)
- Wang, J.; Chen, X. Pricing, greening, and recycling decisions of capital-constrained closed-loop supply chain with government subsidies under financing strategies. *J. Clean. Prod.* **2024**, *434*, 140089.
- Huang, Y.; Wang, Z.; Wang, Z. Coordination of a closed-loop supply chain with strategic consumer behavior under financial incentives. *Int. J. Prod. Econ.* **2019**, *217*, 246–258.
- Zhu, W.; He, Y. Green product design in supply chains under competition. *Eur. J. Oper. Res.* **2017**, *258*, 165–180. [\[CrossRef\]](#)
- Cao, E.; Yu, M. Trade credit financing and coordination for an emission-dependent supply chain. *Comput. Ind. Eng.* **2018**, *119*, 50–62. [\[CrossRef\]](#)
- Khyzhniakova, N.O. Analysis of the possibilities for the growth of social and environmental responsibility of enterprises. *Econ. Time Realities* **2024**, *75*, 68–76. [\[CrossRef\]](#)
- He, W.; Liang, L.; Wang, K. Economic and environmental implications of quality choice under remanufacturing outsourcing. *Sustainability* **2020**, *12*, 874. [\[CrossRef\]](#)
- Guide, V.D.R.; Li, J. The potential for cannibalization of new products sales by remanufactured products. *Decis. Sci.* **2010**, *41*, 547–572. [\[CrossRef\]](#)
- Liu, X.; Wang, K.; Lu, H. Research on supply chain decisions for production waste recovery and reuse based on a recycler focus. *Sustainability* **2023**, *15*, 3320. [\[CrossRef\]](#)
- Ita-Nagy, D.; Vázquez-Rowe, I.; Kahhat, R. Developing a methodology to quantify mismanaged plastic waste entering the ocean in coastal countries. *J. Ind. Ecol.* **2022**, *26*, 2108–2122. [\[CrossRef\]](#)
- Heath, A.; Cotton, M. Responsibility, engagement, and policy strategy for ocean plastic waste management: A Q-method study of stakeholder perspectives. *J. Environ. Plan. Manag.* **2022**, *65*, 2412–2435. [\[CrossRef\]](#)
- Izadi, M.; Parsamanesh, M.; Adel, W. Numerical and stability investigations of the waste plastic management model in the ocean system. *Mathematics* **2022**, *10*, 4601. [\[CrossRef\]](#)
- Parsamanesh, M.; Izadi, M. Global stability and bifurcations in a mathematical model for the waste plastic management in the ocean. *Sci. Rep.* **2024**, *14*, 19532. [\[CrossRef\]](#)
- Tehrani, M.; Cui, Y. Governance and innovation in plastic waste management: The case of Japan. *Sustainability* **2025**, *17*, 9387. [\[CrossRef\]](#)

26. Choi, S.C. Price competition in a channel structure with a common retailer. *Mark. Sci.* **1991**, *10*, 271–296. [[CrossRef](#)]
27. Savaskan, R.C.; Bhattacharya, S.; Van Wassenhove, L.N. Closed-loop supply chain models with product remanufacturing. *Manag. Sci.* **2006**, *52*, 238–252. [[CrossRef](#)]
28. Pindyck, R.S. A note on competitive investment under uncertainty. *Am. Econ. Rev.* **1993**, *83*, 273–277.
29. China Environment Network. The “Green Rebirth” of Marine Debris: Wenzhou’s “Blue Ocean Station” Unlocks the Code of Plastic Circular Economy [EB/OL]. Available online: <https://res.cenews.com.cn/hjw/news.html?aid=1231695> (accessed on 29 December 2025).
30. China National Radio Network. Blue New Opportunities | Fashionable ‘Metamorphosis’! From Ocean Plastic Waste to Clothes, Shoes, and Bags. Available online: https://finance.cnr.cn/jjgd/20250920/t20250920_527369807.shtml (accessed on 12 December 2025).
31. Bass, F.M.; Krishnan, T.V.; Jain, D.C. Why the Bass model fits without decision variables. *Mark. Sci.* **1994**, *13*, 203–223. [[CrossRef](#)]
32. Yang, Q.; Sun, L.; Wu, X.; Li, Y. Implications of retailer-owned digital twins services: The trade-offs between customer experience, misfit returns reduction, and investment costs. *J. Retail. Consum. Serv.* **2026**, *88*, 104478. [[CrossRef](#)]
33. Wang, K.; Xiong, Z.; Xiong, Y.; Yan, W. Remanufacturer-manufacturer collaboration in a supply chain: The manufacturer plays the leader role. *Asia-Pac. J. Oper. Res.* **2015**, *32*, 1550040. [[CrossRef](#)]

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