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Research article

Game-theoretic analysis of green investment decisions under service competition in shipping supply chains

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Abstract: Under decarbonization pressure, green investment has become a strategic choice for ocean shipping companies amid service competition across shipping supply chains. However, it remains unclear how green investment decisions shape service investment strategies. This paper investigates green investment strategies adopted by ocean shipping companies under service competition between shipping supply chains. A Stackelberg game model is established within two competing shipping supply chains, where each chain contains one ocean shipping company and one freight forwarder. Three scenarios are examined: neither ocean shipping company makes green investment, only one ocean shipping company makes green investment, and both ocean shipping companies make green investment simultaneously. Our main findings are as follows: (i) green investment can improve the service quality of the green ocean shipping company, which further increases the transport demand for its affiliated freight forwarder and enhances the profitability of both firms within the corresponding shipping supply chain; (ii) green investment effectively cuts overall carbon emissions when the carbon emission reduction coefficient stays at a moderate to high level; and (iii) the equilibrium strategy for both competing ocean shipping companies is simultaneous green investment. Nevertheless, a prisoner's dilemma emerges when the service cost coefficient remains low or the green investment cost coefficient is low.

Keywords: service competition; green investment; shipping supply chain; ocean shipping company; game theory
Mathematics Subject Classification: 91-10, 91A10

1. Introduction

Maritime transportation plays a fundamental role in facilitating international trade. More than 90% of global merchandise trade is transported by sea, making the shipping industry the backbone of international logistics systems [1, 2]. However, while supporting global economic activities, maritime transportation also generates significant environmental externalities [3]. The shipping industry is estimated to account for approximately 3% of global greenhouse gas (GHG) emissions [4], making its decarbonization a critical concern for the international community. The IMO's increasingly ambitious GHG reduction targets, together with regulatory measures such as the inclusion of maritime transport in the EU Emissions Trading System (EU ETS), have made decarbonization a strategic priority for ocean shipping companies and provided an important regulatory impetus for green investment.

Beyond regulatory pressure, increasing environmental awareness among cargo owners has further strengthened the market value of green shipping services. A survey conducted by the Boston Consulting Group (BCG) shows that over 80% of shippers are willing to pay a premium for sustainable shipping solutions [5]. Maersk has launched its ECO Delivery product, which helps reduce greenhouse gas emissions associated with ocean transportation. Well-known companies including Lenovo, Volvo Cars, and Nestlé have opted for this green shipping solution. Annual customer demand for ECO Delivery has risen by more than 170% [6]. Such evidence indicates that environmental performance has emerged as a dimension of service differentiation in the shipping market. Consequently, green transformation has become an essential strategic direction for ocean shipping companies, primarily implemented through green investments such as eco-friendly technology development [7], clean energy adoption [8], and vessel retrofitting [9]. For example, COSCO Shipping has actively promoted the installation of shore power receiving facilities across its fleet, and Maersk has invested in a large fleet of dual-fuel methanol-powered vessels.

Despite these regulatory and market incentives, green investment remains a challenging strategic decision for ocean shipping companies. Intuitively, the green transformation requires massive upfront capital outlays [8]. Such heavy spending exacerbates companies' financial pressure and may dampen their willingness to pursue green investments. More importantly, green investment is not merely an environmental decision but also a competitive strategy, as it may reshape shipping companies' service capabilities and market positions. Persistent capacity expansion and uncertainty surrounding global trade have intensified competition within the shipping industry [10]. Competition has increasingly extended beyond traditional freight rate competition to service-based competition [11], with strategic interactions occurring across integrated shipping supply chains rather than solely between individual firms. In this context, green investment and service competition may interact through firms' strategic decisions. On the one hand, green investment improves environmental performance, enhances the attractiveness of a shipping company's services to environmentally conscious shippers, and reduces its environmental management costs. The resulting demand benefits and cost savings jointly affect the company's profitability and its incentives to invest in service quality. On the other hand, changes in service quality influence transport demand and the profitability of the affiliated freight forwarder. When competing shipping supply chains offer partially substitutable services, these changes can further affect the rival supply chain's demand, profitability, and investment incentives. Green investment may therefore reshape service competition and profitability across supply chains, while the competitive environment may, in turn, influence companies' incentives to invest in green technologies.

Despite the importance of these interactions, existing research has not fully integrated green investment decisions with service competition in competing shipping supply chains. One stream examines green investment in the maritime industry, focusing on emission reduction technologies, environmental performance, and the economic feasibility of the green transformation. However, these studies generally place less emphasis on how green investment interacts with service decisions and competitive responses across supply chains. A parallel stream investigates service and supply chain competition, emphasizing pricing and service investment among competing members, but generally treats green investment as exogenous or overlooks it altogether. As a result, the relationship between green investment and service competition remains insufficiently understood. In particular, it is important to examine how green investment affects service investment incentives and competitive outcomes across supply chains, how service competition feeds back into green investment decisions, and how these strategic interactions influence firms' profitability and environmental performance.

Against the above backdrop, this study takes the prevailing regulatory environment as given and aims to investigate the following research questions: (1) How should ocean shipping companies determine their green investment strategies under inter-supply-chain service competition, and how does the competitive environment influence their investment decisions? (2) How do ocean shipping companies' green investment decisions reshape supply chain competition outcomes and affect the profitability of participants? (3) How does green investment influence environmental performance, and under what conditions can it effectively reduce carbon emissions?

To answer these questions, we develop a game-theoretic model consisting of two competing shipping supply chains, each comprising one ocean shipping company and one freight forwarder. Based on the green investment choices of both ocean shipping companies, three scenarios are considered: (1) neither ocean shipping company makes green investment; (2) only one ocean shipping company makes green investment; and (3) both ocean shipping companies make green investment simultaneously. By deriving and comparing the equilibrium solutions under different scenarios, we analyze the incentive for ocean shipping companies to make green investment. Furthermore, we examine the consequences of green investment, including its impacts on supply chain competitiveness, enterprise profitability, and environmental performance.

Our main findings are summarized as follows: First, intensified service competition does not necessarily discourage green investment. Instead, under favorable cost conditions, stronger service competition motivates shipping companies to increase green investment, suggesting that market competition can accelerate green transformation. Second, green investment can strengthen the competitive position of the green shipping supply chain by improving its service level while weakening the service performance of its rival, thereby enhancing transport demand and the profitability of affiliated freight forwarders. Moreover, green investment can effectively reduce total carbon emissions when emission reduction efficiency is sufficiently high. Third, although green investment always improves the competitiveness of green shipping companies, it does not necessarily increase industry profitability. When green investment cost or service cost is relatively low, competing ocean shipping companies may simultaneously choose green investment but eventually earn lower profits than under the non-investment scenario, resulting in a prisoner's dilemma.

This study makes three main contributions. First, we extend the green shipping literature from individual supply chains or policy-driven emission reduction perspectives to chain-to-chain strategic competition. By embedding endogenous green investment into two competing shipping supply

chains, we examine the two-way strategic interaction between green investment and service competition. Specifically, service competition shapes shipping companies' incentives to invest in green technologies, while green investment, in turn, influences service decisions and competitive outcomes across supply chains. Second, we uncover a distinction between the service differentiation effect and the service escalation effect. When only one ocean shipping company makes green investment, the resulting improvement in service capability can create a competitive advantage over its ordinary rival. When both shipping companies invest, however, this differentiation advantage may diminish, while simultaneous service upgrading can intensify competition and increase investment expenditure. Under certain conditions, lower green investment or service costs may therefore reduce both shipping companies' profits, giving rise to a prisoner's dilemma. Third, we reveal the potential divergence between the economic benefits and environmental consequences of green investment. Although green investment can reduce carbon emissions associated with transportation, it may also stimulate transport demand by enhancing service attractiveness. Consequently, the expansion of transport demand may offset the emission reductions achieved through green investment, meaning that green investment does not necessarily reduce total carbon emissions. This finding highlights the importance of accounting for demand expansion when evaluating the environmental effects of green investment.

The remainder of this paper is organized as follows: Section 2 reviews the related literature. Section 3 introduces the model and describes some relevant problems. Section 4 derives the equilibrium solutions under each scenario. Section 5 analyzes the effect of green investment by ocean shipping companies. Section 6 presents several model extensions. Section 7 concludes the paper.

2. Literature review

This study is closely related to three streams of literature: (1) shipping supply chains, (2) green investment, and (3) service competition. In the following, we compare our work with existing literature to highlight our contributions.

2.1. Shipping supply chains

With the increasing integration of global logistics networks, maritime transportation research has gradually shifted from the operational decisions of individual enterprises to the management of shipping supply chains. A basic shipping supply chain consists of ocean shipping companies and freight forwarders. The ocean shipping companies provide shipping services, while the freight forwarders integrate these services with other value-added activities to provide shippers with integrated logistics solutions [12, 13]. Existing studies have investigated operational decisions within shipping supply chains, such as technology adoption [14] and downstream market entry [15]. Chen et al. [16] examined the impact of e-commerce platform adoption on service improvement and revealed that leveraging platform-based marketing helps enhance the competitive advantage of shipping supply chains. Peng and Wang [17] adopted evolutionary game theory to investigate the dynamic channel selection behaviors of carriers and freight forwarders. Lyu et al. [18] explored capacity allocation and pricing decisions in a shipping supply chain facing capacity shortages and analyzed how these decisions influence supply chain resilience. To better capture the complexity of maritime logistics networks, some researchers have extended analytical frameworks by incorporating additional supply

chain participants, such as ports [19, 20] and inland shipping companies [1, 21]. Liu and Wang [22] examined the formation incentives of horizontal alliances between competing carriers and proposed a revenue-sharing and service-cost allocation mechanism to coordinate the port and carriers. Xing et al. [23] further investigated the freight forwarder's procurement strategy regarding inland logistics services. However, the above studies predominantly restrict their scope to a single shipping supply chain.

With growing competitive pressure in the maritime logistics industry, some researchers have explored the competitive interactions across shipping supply chains. Wang and Liu [11] investigated service competition between supply chains and demonstrated that contractual arrangements can influence service levels and market performance. Wang et al. [24] further revealed the impacts of structural differences in shipping supply chains under a bilateral negotiation framework. Zhang et al. [25] analyzed the interaction between ocean carriers' downstream market entry decisions and freight forwarders' outsourcing strategies. Although these studies have advanced the understanding of competitive shipping supply chains, most existing research focuses on pricing, contractual coordination, or channel strategies. The strategic role of environmental investment in shaping competition between shipping supply chains remains insufficiently explored.

2.2. Green investment

Green investment has become an important strategic decision for firms seeking sustainable development and long-term competitiveness. Existing supply chain literature has investigated green investment from various perspectives, including green technology adoption [26, 27], government policy [28–31], and supply chain coordination [32]. For example, Katariya et al. [33] investigated green investment decisions in a vendor-managed chemical product inventory supply chain with controllable deterioration. Wang et al. [34] studied pricing and green effort decisions in a three-level green supply chain and proposed coordination mechanisms to improve supply chain performance. Shang et al. [35] considered competing green and non-green supply chains under government subsidies and carbon taxes, and analyzed how government interventions influence firms' strategic choices. These studies demonstrate that appropriate green investment not only improves environmental performance but also enhances operational efficiency and supply chain competitiveness.

With the growing emphasis on maritime decarbonization, green shipping has become an important research topic in maritime management. Existing studies have examined green investment of transport companies from multiple perspectives, including government incentives, environmental regulations, and firms' strategic decisions. One stream of research investigates the role of government intervention in promoting green shipping. For example, Wang et al. [36] examined how government subsidies influence the marine fuel market, while Zhang et al. [37] analyzed the effects of alternative subsidy schemes on service decisions and corporate social responsibility investment in green shipping supply chains by considering shippers' environmental preferences. These studies suggest that appropriate policy support can effectively encourage firms' environmental initiatives. Beyond subsidy policies, another line of research emphasizes the importance of regulatory mechanisms in facilitating green transformation. Lu et al. [38] evaluated the impact of the European Union Emissions Trading System on shipping alliances' sustainability strategies and green investment decisions. Lyu et al. [39] proposed a multi-level optimization framework that simultaneously determines investments in

bunkering infrastructure, ship routing, and alternative-fuel fleets under carbon pricing policies. Xu et al. [40] further demonstrated that emission taxation significantly affects firms' environmental strategies, whereas Zhang et al. [41] showed that vertical cooperation under carbon cap-and-trade regulation can improve both supply chain coordination and carbon reduction performance. Recent studies have also explored how firms' operational and organizational strategies contribute to sustainable shipping development. Wang et al. [2] reviewed the applications of artificial intelligence and machine learning in green and intelligent shipping, highlighting their potential to facilitate maritime decarbonization. Yin et al. [42] investigated technological collaboration in green shipping using global patent data, while Xue et al. [43] analyzed investment strategies for shipping decarbonization technologies. Wang and Wang [44] studied green investment and vertical alliances within maritime supply chains. They characterized the corresponding optimal alliance strategy. Shang et al. [45] showed that shipping alliances can stimulate green investment, and Liu et al. [46] demonstrated that knowledge sharing enhances the effectiveness of emission reduction technologies in shipping supply chains.

Despite these valuable contributions, the above-mentioned research overlooked the fact that green investment by shipping enterprises might affect their service levels. Zhao et al. [47] is closely related to this study because it considers the coexistence of shippers' preferences for environmental performance and service quality. Nevertheless, their research focuses on a single shipping supply chain and does not consider competitive interactions among multiple shipping supply chains. Therefore, the competitive implications of green investment in maritime supply chains remain unclear.

2.3. Service competition

Service has become an increasingly important source of competitive advantage in modern markets. Existing studies have mainly examined how service decisions interact with firms' operational and pricing strategies. For instance, Yu and Guo [48] investigated how the adoption of artificial intelligence reshapes service competition and firms' strategic decisions. Feng et al. [49] analyzed service competition in a closed-loop supply chain and demonstrated that collection service decisions significantly affect firms' profitability and recovery performance. Ding et al. [50] further explored service competition under inventory and environmental constraints, while Dan et al. [51] showed that improvements in manufacturers' warranty services can alleviate value-added service competition between manufacturers and retailers. In the context of platform competition, Sui et al. [52] examined joint pricing and bilateral value-added service decisions and highlighted the importance of service investment in competitive markets. These studies consistently demonstrate that service investment significantly affects market demand, operational efficiency, and firms' profitability. Compared with the extensive literature on general supply chains, studies on service competition in transportation systems remain relatively limited. Sun et al. [53] investigated channel competition based on canvassing capability in liner shipping e-commerce and analyzed firms' optimal sales strategies under service competition. However, existing studies primarily treat service competition as an operational decision and focus on its impacts on market demand and firm performance. The interaction between service competition and firms' environmental investment decisions has received limited attention. In particular, little is known about how service competition influences ocean shipping companies' green investment decisions or how green investment, in turn, reshapes service competition between competing shipping supply chains.

2.4. Research gap

Among the existing studies, Wang and Liu [11], Shang et al. [45], and Zhao et al. [47] are particularly relevant to the present research. Wang and Liu [11] investigate service competition between shipping supply chains, but their focus is vertical contract selection and green investment is absent. Shang et al. [45] examine how shipping alliances influence green investment, but do not consider service competition between rival supply chains. Zhao et al. [47] jointly consider shippers' preferences for service quality and environmental performance, but focus on a single shipping supply chain and therefore do not capture cross-chain strategic interactions. Although these studies provide important foundations for understanding green investment and service competition in shipping, each considers only part of the strategic interaction examined in the present study. The bidirectional interaction between green investment and inter-supply-chain service competition remains insufficiently understood.

Overall, although previous studies have investigated the shipping supply chain, green investment, and service competition from different perspectives, limited attention has been paid to the strategic interactions among these three dimensions. This gap is increasingly relevant as service competition becomes an important dimension of competition in shipping supply chains. Understanding the interplay between green investment and service competition is essential for assessing not only firms' investment incentives and competitive strategies but also their profitability and environmental performance. Motivated by this research gap, this study develops a game-theoretic model consisting of two competing shipping supply chains. By explicitly incorporating ocean shipping companies' green investment decisions and inter-supply-chain service competition, we investigate how service competition affects green investment strategies, how green investment reshapes competitive interactions, and how these decisions influence firms' profitability and environmental performance. Accordingly, the contribution of this study lies in identifying the strategic transmission mechanism from green investment to inter-supply-chain service competition, rather than merely introducing an additional green decision into a conventional shipping supply chain model.

3. The model

We consider two symmetric competing shipping supply chains. Each chain consists of a freight forwarder (denoted as Fi, $i \in \{1, 2\}$) and an exclusive ocean shipping company (denoted as OSi). Upon receiving transportation orders from shippers, each freight forwarder purchases shipping services from its partnered ocean shipping company, which is responsible for the actual cargo transportation. The structure of the system is illustrated in Figure 1. To examine the green investment decisions of ocean shipping companies, we model the interactions among supply chain members as a Stackelberg game, in which the ocean shipping companies act as leaders and the freight forwarders act as followers.

Depending on the green investment decisions of the ocean shipping companies, four scenarios are considered: (1) scenario NN, in which neither ocean shipping company makes green investment; (2) scenario EN, in which only OS1 makes green investment, whereas OS2 does not; (3) scenario NE, in which only OS2 makes green investment, whereas OS1 does not; and (4) scenario EE, in which both ocean shipping companies (OS1 and OS2) make green investment. Because the two shipping supply chains are symmetric, scenarios EN and NE are mirror-image cases. Therefore, we derive the equilibrium solutions for scenarios NN, EN, and EE, with scenario NE omitted for brevity. For ease of

exposition, we refer to the ocean shipping company that makes green investment as the green company and the one that does not make green investment as the ordinary company in the rest of this paper.

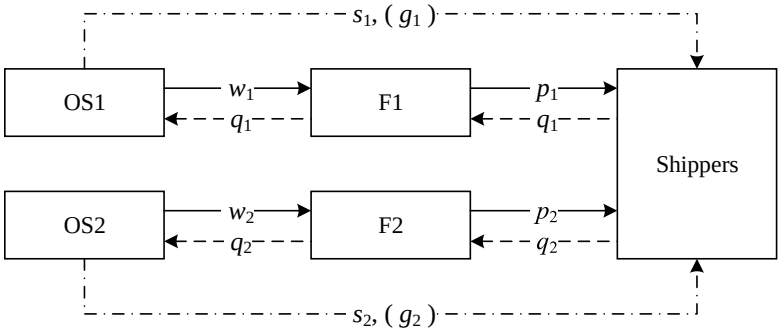


Figure 1. The structure of the shipping supply chain system.

3.1. Demand function

Following common practice in existing transportation literature [11, 47], we assume the demand function depends on the freight price, service quality, and environmental performance. Although competition between freight forwarders is often represented as Bertrand competition, as in [54], pricing competition in shipping markets is difficult to characterize precisely. In practice, the freight price typically consists of a base price and surcharges, which often account for a substantial share of the total freight price. Such surcharges are generally opaque and cannot be explicitly mapped to the actual costs incurred by shippers [22]. This opacity hinders the accurate measurement of price competition. Following [22], we therefore focus primarily on service competition between shipping supply chains.

Environmental performance has also become an important factor in shippers' transportation choices. A higher level of shipping greenness can make a shipping service more attractive to environmentally conscious shippers and thereby stimulate transport demand [47]. Let $g_i \geq 0$ denote the shipping greenness level achieved by OSi through green investment in cleaner fuels, vessel energy-efficiency technologies, emission-control equipment, and related retrofitting. It is a reduced-form measure of the environmental performance of the shipping service rather than the physical amount of carbon emissions. Parameter $k > 0$ measures shippers' sensitivity to shipping greenness. Thus, kg_i represents the incremental market value created by the environmental performance of the focal shipping service. The demand function for F_i is specified as follows:

$$q_i = a - p_i + s_i - bs_j + kg_i, \tag{3.1}$$

where q_i denotes the transport demand served by Fi, and p_i is the freight price charged by Fi. a represents the potential market size. s_i denotes the transport service level provided by OSi, and s_j denotes the transport service level provided by OSj. Parameter $b \in (0, 1)$ captures the degree of service substitutability between the two competing shipping supply chains. A larger value of b indicates stronger service competition, reflecting a higher degree of similarity in transportation capacity, service attributes, and cargo type served by the competing supply chains. The demand

function is designed to distinguish the intrinsic attractiveness of a focal shipping service from the horizontal substitution effect generated by the competing supply chain. Specifically, s_i captures the service attractiveness of the supply chain, whereas bs_j captures the loss of demand resulting from the rival chain's service capability. Thus, service quality constitutes the primary horizontal competitive dimension in the benchmark model. In contrast, g_i captures the environmental attractiveness of the focal shipping service. Consistent with the green supply chain literature, environmentally conscious shippers derive additional value from a higher greenness level [55], which is represented by kg_i. Hence, in our model, greenness is treated as a demand-enhancing attribute of the focal shipping supply chain, while the competitive interaction between the two shipping supply chains is captured through service substitutability.

3.2. Cost structure

The transport service level s_i should be interpreted as an aggregate index of the transport service quality perceived by shippers rather than as a single operational attribute. In practice, shipping service quality may include schedule reliability, transit efficiency, responsiveness, cargo handling, information visibility, and other value-added services. Empirical shipping studies show that these dimensions jointly determine shippers' evaluations of transport providers. Following the analytical literature on shipping service competition [11], we aggregate these attributes into a single service index to maintain tractability and focus on the strategic interaction between service competition and green investment. Improvements in transport service quality typically exhibit diminishing marginal returns, implying that further service enhancement becomes increasingly costly as the service level rises. Following the operations management and supply chain literature [10, 56], we capture this feature by assuming a quadratic service-cost function. Specifically, if OSi provides a transport service level s_i, the associated service cost is given by $\frac{m}{2}s_i^2$, where $m > 0$ denotes the service cost coefficient. A larger value of m indicates that the ocean shipping company incurs higher costs in improving transport service quality and is therefore less efficient in service provision.

The ocean shipping companies may make green investments to improve environmental performance and reduce carbon emissions. Examples include adopting alternative clean fuels (e.g., liquefied natural gas and methanol), improving vessel energy efficiency through technologies such as optimized hull designs and waste heat recovery systems, and retrofitting existing vessels with emission-reduction equipment. We use g_i to denote the shipping greenness level achieved through green investment. Greenness is a commonly used reduced-form measure of the environmental performance generated by investments in cleaner technologies, alternative fuels, energy-efficiency improvements, and vessel retrofitting. A higher greenness level increases the attractiveness of the shipping service to environmentally conscious customers, while achieving a higher level of greenness requires additional investment expenditure. Following the green operations literature [57], we assume that the green investment cost takes the quadratic form $\frac{n}{2}g_i^2$, where $n > 0$ is the green investment cost coefficient. A higher value of n implies that achieving a given level of shipping greenness requires greater investment expenditure.

The shipping greenness level may also generate operating benefits. Cleaner and more energy-efficient technologies can reduce environmental management and related operating costs. We therefore assume that the unit environmental management cost decreases from c to $c - \delta g_i$, where c is the unit environmental management cost in the absence of green investment, and satisfies $a > c$. δ

measures the cost-reduction efficiency of green investment. For analytical convenience, we normalize $\delta = 1$. To ensure that the unit environmental management cost remains non-negative, the green investment level is restricted to $g_i \leq c$. To maintain analytical tractability and focus on the strategic effects of green investment and service competition, following [58], we normalize the unit transport cost of ocean shipping companies and the operating cost of freight forwarders to zero. Our model therefore focuses on the demand and cost mechanisms associated with service quality and green investment, rather than explicitly modeling regulatory instruments such as carbon taxes, emission quotas, or allowance prices. It should be emphasized that g_i represents the level of shipping greenness rather than physical carbon emissions. The corresponding carbon emission reduction is evaluated separately in Section 5.3.

3.3. Notation and event sequence

Motivated by industry practice, we distinguish between green investment and transport service decisions. Green investment generally involves substantial capital expenditures and long-term asset commitments [59]. Such investments are strategic in nature because they require long-term resource allocation and are difficult to reverse once implemented. In contrast, transport service decisions concern the execution of a company's competitive strategy in the marketplace and can be adjusted more flexibly over time. Therefore, green investment decisions are assumed to precede transport service decisions.

The sequence of events is illustrated in Figure 2. The interactions among supply chain members unfold in three stages.

Stage 1. Green investment decision. Each ocean shipping company determines whether to make green investment. If it does, it determines the level of greenness to be achieved, g_i.

Stage 2. Operational decision. Each ocean shipping company simultaneously determines its transport service level, s_i, and shipping service fee, w_i, charged to its exclusive freight forwarder.

Stage 3. Market competition. The two freight forwarders simultaneously set their freight prices, p_i, in the transport market. The corresponding transport demand is then realized.

We use "*" to denote the equilibrium solutions and summarize the main notation mentioned above in Table 1.

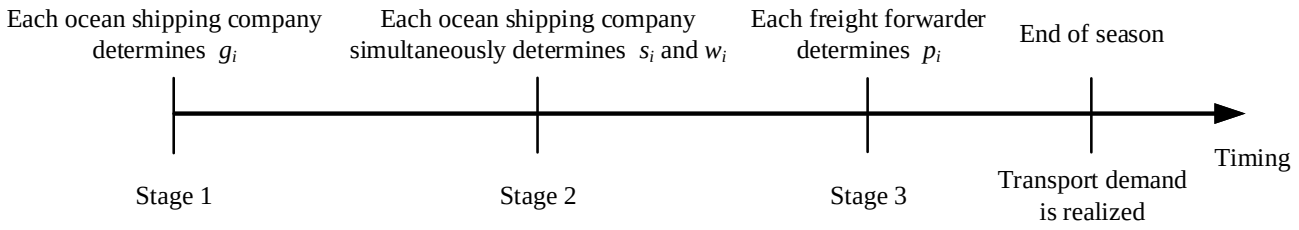


Figure 2. Event sequence.

Table 1. Notation.

Notation	Descriptions
Decision variables	
g_i	The shipping greenness level of the ocean shipping company OSi
s_i	The transport service level of the ocean shipping company OSi
w_i	The ocean shipping service fee of the ocean shipping company OSi
p_i	The freight price of the freight forwarder Fi
Auxiliary variables	
q_i	The transport demand
π_{OSi}	The profit of the ocean shipping company OSi
π_{Fi}	The profit of the freight forwarder Fi
Parameters	
a	The potential market size
b	The intensity of service competition between the two shipping supply chains
c	The unit cost of vessel pollution treatment prior to green investment
k	The shippers' environmental awareness
m	The service cost coefficient
n	The green investment cost coefficient

4. Equilibrium analysis

This section derives the optimal solutions and profits for the proposed model under scenarios NN, EN, and EE. Because the two shipping supply chains are symmetric, scenario NE is the mirror image of scenario EN. Thus, its equilibrium solutions can be obtained directly from those under EN by interchanging the subscripts 1 and 2.

4.1. Scenario NN

In this scenario, neither ocean shipping company makes green investment, i.e., $g_1^{NN} = g_2^{NN} = 0$. The optimization problem of each ocean shipping company is

$$\max_{w_i^{NN}, s_i^{NN}} \pi_{OSi}^{NN} = w_i^{NN} q_i^{NN} - c q_i^{NN} - \frac{1}{2} m s_i^{NN^2}. \tag{4.1}$$

In Equation (4.1), the first term denotes the profit from providing ocean shipping services to the freight forwarder. The middle term denotes the environmental management cost, and the last term denotes the transport service input cost.

The optimization problem of each freight forwarder is

$$\max_{p_i^{NN}} \pi_{Fi}^{NN} = p_i^{NN} q_i^{NN} - w_i^{NN} q_i^{NN}. \tag{4.2}$$

In Equation (4.2), the first term denotes the profit from selling transport services to shippers, and the second term denotes the procurement cost paid to the ocean shipping company for purchasing ocean shipping service.

The equilibrium solutions are derived by backward induction, and all analytical proofs are provided in the Appendix. The boundary condition for ensuring nonnegative equilibrium solutions is $m > \frac{1}{4}$.

Lemma 1. *In scenario NN, the impacts of service substitutability on the equilibrium solutions are characterized as follows:*

(1) *for transport service quality:* $\frac{\partial s_i^{NN*}}{\partial b} < 0$*;*

(2) *for transport demand:* $\frac{\partial q_i^{NN*}}{\partial b} < 0$*;*

(3) *for profits of supply chain members:* $\frac{\partial \pi_{OSi}^{NN*}}{\partial b} < 0$, $\frac{\partial \pi_{Fi}^{NN*}}{\partial b} < 0$.

Lemma 1 indicates that when neither ocean shipping company makes green investment, intensified service competition between shipping supply chains induces ocean shipping companies to adopt a cost-conserving strategy by lowering their transport service levels. The resulting deterioration in service quality reduces the attractiveness of the shipping supply chain, leading to a decline in the transport demand faced by freight forwarders. As a result, intensified service competition persistently erodes the profits of both ocean shipping companies and freight forwarders.

In this scenario, the transmission mechanism can be summarized as follows: Under competitive pressure, ocean shipping companies reduce service levels to contain costs, which then suppresses transport demand along the supply chain and ultimately leads to profit losses for all supply chain members.

4.2. Scenario EN

In this scenario, only OS1 makes green investment, while OS2 does not invest, i.e., $g_1^{EN} > 0$ and $g_2^{EN} = 0$. The optimization problem of the green company OS1 is

$$\max_{g_1^{EN}, w_1^{EN}, s_1^{EN}} \pi_{OS1}^{EN} = w_1^{EN} q_1^{EN} - \left(c - g_1^{EN}\right) q_1^{EN} - \frac{1}{2} m s_1^{EN^2} - \frac{1}{2} n g_1^{EN^2}. \tag{4.3}$$

The optimization problem of the ordinary company OS2 is

$$\max_{w_2^{EN}, s_2^{NN}} \pi_{OS2}^{EN} = w_2^{EN} q_2^{EN} - c q_2^{EN} - \frac{1}{2} m s_2^{EN^2}. \tag{4.4}$$

The optimization problem of each freight forwarder is

$$\max_{p_i^{EN}} \pi_{Fi}^{EN} = p_i^{EN} q_i^{EN} - w_i^{EN} q_i^{EN}. \tag{4.5}$$

The boundary conditions for ensuring nonnegative equilibrium solutions are $m > m_1$ and $n > n_1$, where $m_1 = \frac{1+b}{4}$, $n_1 = \frac{mA^2B^2}{(A-b)^2(A+b)}$, $A = 4m - 1$, and $B = 1 + k$.

Lemma 2. *In scenario EN, the impacts of service substitutability on the equilibrium solutions are characterized as follows:*

(1) *for shipping greenness: If* ① $m_1 < m \le m_2$*, or* ② $m > m_2$ *and* $n_1 < n < n_2$, $\frac{\partial g_1^{EN*}}{\partial b} > 0$*; otherwise,* $\frac{\partial g_1^{EN*}}{\partial b} < 0$*, where* $m_2 = \frac{1+3b}{4}$ *and* $n_2 = \frac{mA^3B^2}{(A-b)^2(A-3b)(A+b)}$*;*

(2) *for transport service quality and transport demand: If* $n_1 < n < n_3$, $\frac{\partial s_1^{EN*}}{\partial b} > 0$ *and* $\frac{\partial q_1^{EN*}}{\partial b} > 0$*; otherwise,* $\frac{\partial s_1^{EN*}}{\partial b} < 0$ *and* $\frac{\partial q_1^{EN*}}{\partial b} < 0$*, where* $n_3 = \frac{mA^3(A+3b)B^2}{(A-b)^3(A+b)^2}$*. Moreover,* $\frac{\partial s_2^{EN*}}{\partial b} < 0$ *and* $\frac{\partial q_2^{EN*}}{\partial b} < 0$*;*

(3) *for profits of supply chain members: If* $n_1 < n < n_4$, $\frac{\partial \pi_{OS1}^{EN*}}{\partial b} > 0$*; otherwise,* $\frac{\partial \pi_{OS1}^{EN*}}{\partial b} < 0$*, where* $n_4 = \frac{mA^3B^2}{(A-b)^3(A+b)}$*. If* $n_1 < n < n_3$, $\frac{\partial \pi_{F1}^{EN*}}{\partial b} > 0$*; otherwise,* $\frac{\partial \pi_{F1}^{EN*}}{\partial b} < 0$*. Moreover,* $\frac{\partial \pi_{OS2}^{EN*}}{\partial b} < 0$ *and* $\frac{\partial \pi_{F2}^{EN*}}{\partial b} < 0$*.*

Lemma 2(1) shows that, when only one ocean shipping company makes green investment, the effect of intensified service competition on shipping greenness depends jointly on the service cost coefficient and the green investment cost coefficient. When the service cost coefficient is low, the green ocean shipping company can improve service quality at a relatively low cost. In this case, it could allocate more corporate resources to green investment. When the service cost coefficient is high, but the green investment cost coefficient is low, the company relies more on green differentiation because green investment yields higher marginal returns than service improvement. Consequently, under both conditions, stronger service competition encourages the green ocean shipping company to increase its green investment, leading to higher shipping greenness. In contrast, when both the service cost coefficient and the green investment cost coefficient are high, the green ocean shipping company faces high costs in both service improvement and green transformation. Thus, stronger competition further weakens its incentive to invest in greening.

Lemma 2(2) shows that, when the green investment cost coefficient is low, intensified service competition encourages the green ocean shipping company to further improve its service level, thereby increasing the transport demand of its affiliated freight forwarder. Lower green investment costs enable the green ocean shipping company to attract environmentally conscious customers within its shipping supply chain at relatively limited expense. On this basis, the green ocean shipping company is able to accumulate sufficient resources to further upgrade its service quality. In contrast, stronger competition causes the ordinary ocean shipping company to reduce its service level, leading to lower demand for its affiliated freight forwarder. These findings suggest that, under favorable green investment conditions, service competition can accelerate green transformation through market selection, allowing early green adopters to establish a stronger competitive position.

Lemma 2(3) shows that intensified service competition increases the profits of the green ocean shipping company and its partnered freight forwarder when the green investment cost coefficient is low, but reduces their profits when the coefficient is high. In contrast, the profits of the ordinary ocean shipping company and its affiliated freight forwarder consistently decline as service competition intensifies. These findings suggest that green transformation can serve as an effective competitive strategy only when green investment can be undertaken at a low cost.

4.3. Scenario EE

In this scenario, both ocean shipping companies make green investment, i.e., $g_1^{EE} > 0$ and $g_2^{EE} > 0$. The optimization problem of each ocean shipping company is

$$\max_{g_i^{EE}, w_i^{EE}, s_i^{EE}} \pi_{OSi}^{EE} = w_i^{EE} q_i^{EE} - \left(c - g_i^{EE}\right) q_i^{EE} - \frac{1}{2} m s_i^{EE^2} - \frac{1}{2} n g_i^{EE^2}. \tag{4.6}$$

The optimization problem of each freight forwarder is

$$\max_{p_i^{EE}} \pi_{Fi}^{EE} = p_i^{EN} q_i^{EE} - w_i^{EE} q_i^{EE}. \tag{4.7}$$

Similarly, the boundary conditions for ensuring nonnegative equilibrium solutions are $m > m_1$ and $n > n_5$, where $n_5 = \frac{(1+k)^2 mA^3}{(A^2-b^2)^2}$.

Lemma 3. *In scenario EE, the impacts of service substitutability on the optimal outcomes are characterized as follows:*

(1) *for shipping greenness: If* $m_1 < m < m_2$, $\frac{\partial g_i^{EE*}}{\partial b} > 0$*; otherwise,* $\frac{\partial g_i^{EE*}}{\partial b} < 0$*;*

(2) *for transport service quality and transport demand: If* $m_1 < m < m_3$ *and* $n_5 < n < n_6$, $\frac{\partial s_i^{EE*}}{\partial b} > 0$ *and* $\frac{\partial q_i^{EE*}}{\partial b} > 0$*; otherwise,* $\frac{\partial s_i^{EE*}}{\partial b} < 0$ *and* $\frac{\partial q_i^{EE*}}{\partial b} < 0$*, where* $m_3 = \frac{1+2b}{4}$ *and* $n_6 = \frac{2bmA^2B^2}{(A^2-b^2)^2}$*;*

(3) *for profits of supply chain members:* $\frac{\partial \pi_{OSi}^{EE*}}{\partial b} < 0$*. If* $m_1 < m < m_3$ *and* $n_5 < n < n_6$, $\frac{\partial \pi_{Fi}^{EE*}}{\partial b} > 0$*; otherwise,* $\frac{\partial \pi_{Fi}^{EE*}}{\partial b} < 0$*.*

Lemma 3(1) shows that the effect of intensified service competition on shipping greenness depends primarily on the service cost coefficient when both ocean shipping companies make green investment. Shipping greenness increases with service competition when the service cost coefficient is low but decreases when it is high. These findings indicate that, once green investment becomes widespread, reducing service costs helps ocean shipping companies ensure the sustainable advancement of their green transformation in service competition.

Lemma 3(2) shows that intensified service competition improves transport service quality and increases the transport demand of affiliated freight forwarders when both the service cost coefficient and the green investment cost coefficient are low. However, these positive effects disappear once either service improvement or green investment becomes sufficiently costly. When the green cost coefficient is high, the burden of green investment is substantial, and competitive pressure is difficult to translate into incentives for service improvement. Alternatively, when the service cost coefficient is high, companies face significant cost pressure in service provision. In both cases, ocean shipping companies tend to reduce transport quality, which in turn leads to a decrease in transport demand for their cooperating freight forwarders.

Lemma 3(3) shows that intensified service competition always reduces green ocean shipping companies' profits once both companies make green investment. This suggests that green investment no longer provides the competitive advantage observed during the early stage of green transformation, and stronger service competition inevitably erodes ocean shipping companies' profitability. For freight forwarders, the effect of service competition on profits mirrors its effect on transport demand. Profits increase when both the service cost coefficient and the green investment cost coefficient are low but decrease when either coefficient is high. These findings imply that excessive service competition may reduce the overall profitability of the shipping industry after green transformation becomes widespread. To alleviate this effect, ocean shipping companies can adopt differentiated service positioning strategies to avoid homogeneous competition with rival shipping companies. For example, they may segment shipper groups based on their green sensitivity and logistics demands, launching customized shipping packages tailored to distinct customer segments.

Lemmas 1-3 together reveal a consistent co-movement among ocean shipping companies' service levels, transport demand, and freight forwarders' profits. Freight forwarders' profitability ultimately depends on transport demand, which is largely determined by ocean shipping companies' service quality. Therefore, freight forwarders should actively support their partners' service capability

development through strategic coordination, joint service standards, and information-sharing platforms. Such collaboration facilitates continuous service improvement, stabilizes transport demand, and ultimately promotes the sustainable growth of freight forwarders' profits.

The optimal results are shown in Table 2.

Table 2. Optimal solutions and profits in the three scenarios.

	Scenario NN	Scenario EN	Scenario EE
g_i^*	-	$g_1^* = \frac{(a-c)A^2B(A-b)m}{(A-b)^2(A+b)^2n-mA^3B^2}$	$\frac{(a-c)A^2Bm}{(A-b)(A+b)^2n-mA^2B^2}$
s_i^*	$\frac{a-c}{A+b}$	$s_1^* = \frac{(a-c)(A-b)^2(A+b)n}{(A-b)^2(A+b)^2n-mA^3B^2}$, $s_2^* = \frac{(a-c)[(A-b)^2(A+b)^2n+bB^2A^2m-B^2mA^3]}{(A+b)[(A-b)^2(A+b)^2n-mA^3B^2]}$	$\frac{(a-c)(A-b)(A+b)n}{(A-b)(A+b)^2n-mA^2B^2}$
q_i^*	$\frac{(a-c)m}{A+b}$	$q_1^* = \frac{(a-c)(A-b)^2m(A+b)n}{(A-b)^2(A+b)^2n-mA^3B^2}$, $q_2^* = \frac{(a-c)m[(A-b)^2(A+b)n-mA^2B^2]}{(A-b)^2(A+b)^2n-mA^3B^2}$	$\frac{(a-c)(A-b)m(A+b)n}{(A-b)(A+b)^2n-mA^2B^2}$
π_{OSi}^*	$\frac{(a-c)^2mA}{2(A+b)^2}$	$\pi_{OS1}^* = \frac{(a-c)^2(A-b)^2Amn}{2[(A-b)^2(A+b)^2n-mA^3B^2]}$, $\pi_{OS2}^* = \frac{(a-c)^2mA[(A-b)^2(A+b)n-mA^2B^2]^2}{2[(A-b)^2(A+b)^2n-mA^3B^2]^2}$	$\frac{(a-c)^2mnA[(A-b)^2(A+b)^2n-mA^3B^2]}{2[(A-b)(A+b)^2n-mA^2B^2]^2}$
π_{Fi}^*	$\frac{(a-c)^2m^2}{(A+b)^2}$	$\pi_{F1}^* = \frac{[(a-c)(A-b)^2m(A+b)n]^2}{[(A-b)^2(A+b)^2n-mA^3B^2]^2}$, $\pi_{F2}^* = \frac{\{(a-c)m[B^2A^2m-(A-b)^2(A+b)n]\}^2}{[(A-b)^2(A+b)^2n-mA^3B^2]^2}$	$\frac{[(a-c)(A-b)m(A+b)n]^2}{[(A-b)(A+b)^2n-mA^2B^2]^2}$

5. The effect of green investment

We next investigate how different green investment strategies affect the operational decisions, economic performance, and environmental outcomes of competing shipping supply chains.

5.1. Decision variables

We first compare the operational decisions across the three scenarios. Transport service level and transport demand are examined because they directly determine the competitiveness of shipping supply chains and provide the foundation for the subsequent profit analysis.

Proposition 1. *A comparison of the transport service level yields the following:*

(1) $s_1^{EN*} > s_1^{EE*} > s_1^{NN*}$;

(2) $s_2^{EE*} > s_2^{NN*} > s_2^{EN*}$.

Proposition 1 illustrates that green investment by ocean shipping companies drives them to improve their own transport service quality, while depressing the service quality of rival shipping companies in competing shipping supply chains. Therefore, green investment widens the service gap relative to rival supply chains and thereby strengthens the competitive position of the supply chain led by the green ocean shipping company. More specifically, unilateral green investment in scenario EN generates a service differentiation effect. The green shipping company increases its service level, whereas the ordinary shipping company reduces its service effort, thereby widening the service quality gap between the two supply chains. By contrast, in scenario EE, both shipping companies invest in green technologies, and their service levels are higher than those in the NN scenario, in which neither company invests. This pattern suggests that bilateral green investment reflects a service escalation effect. Unlike the service differentiation effect, which widens the service quality gap between the two supply chains, the service escalation effect is characterized by higher service levels under bilateral investment than under no investment. Amid competition across shipping supply chains, ocean shipping companies that have not yet launched green investment may regard green transformation as a critical channel to upgrade service capabilities and boost market competitiveness.

In contrast, shipping companies that have already implemented green investment should stay alert to the risk that competitors may narrow the gap via imitative green spending or intensified service upgrading strategies, which would erode their first-mover advantage.

Proposition 2. *A comparison of the transport demand yields the following:*

(1) $q_1^{EN*} > q_1^{EE*} > q_1^{NN*}$;

(2) $q_2^{EE*} > q_2^{NN*} > q_2^{EN*}$.

Proposition 2 shows the market consequences of the service adjustments described in Proposition 1. By improving transport service quality, the green ocean shipping company enables its partnered freight forwarder to attract more transport demand, whereas the competing supply chain experiences further demand loss. Thus, green investment creates a virtuous cycle of green investment–service improvement–demand expansion, in which enhanced service quality strengthens market competitiveness, attracts additional demand, and reinforces the incentives to maintain superior service performance.

5.2. Stakeholders' profits

We next examine how green investment influences the profits of supply chain members.

Proposition 3. *A comparison of the freight forwarders' profits yields the following:*

(1) $\pi_{F1}^{EN*} > \pi_{F1}^{EE*} > \pi_{F1}^{NN*}$;

(2) $\pi_{F2}^{EE*} > \pi_{F2}^{NN*} > \pi_{F2}^{EN*}$.

Proposition 3 indicates that freight forwarders benefit directly from their partnered ocean shipping companies' green investment. As shown by Propositions 1 and 2, green investment improves transport service quality and attracts more transport demand, thereby increasing the freight forwarder's profit without requiring the freight forwarder to bear the associated green investment costs. In this sense, freight forwarders enjoy a free-riding effect from their partners' green transformation. This alignment of economic incentives provides freight forwarders with strong motivation to support or even actively participate in their partners' green transformation. A representative example is the collaboration between DB Schenker and MSC, under which DB Schenker purchases biofuel to support MSC's shipping operations, enabling the two firms to jointly provide greener shipping services.

Proposition 4. *A comparison of the ocean shipping companies' profits yields the following:*

(1) $\pi_{OS1}^{EN*} > \max\left\{\pi_{OS1}^{NN*}, \pi_{OS1}^{EE*}\right\}$, *where if* $m > m_3$ *and* $n > n_7$, $\pi_{OS1}^{NN*} < \pi_{OS1}^{EE*}$; *otherwise,* $\pi_{OS1}^{NN*} > \pi_{OS1}^{EE*}$.

(2) $\min\left\{\pi_{OS2}^{NN*}, \pi_{OS2}^{EE*}\right\} > \pi_{OS2}^{EN*}$, *where if* $m > m_3$ *and* $n > n_7$, $\pi_{OS2}^{NN*} < \pi_{OS2}^{EE*}$; *otherwise,* $\pi_{OS2}^{NN*} > \pi_{OS2}^{EE*}$, $n_7 = \frac{(1+k)^2A^2m}{(A-2b)(A+b)^2}$.

Corollary 1. $\frac{\partial n_7}{\partial b} > 0$. *If* $m > \frac{1}{4}(1+2b)$, $\frac{\partial n_7}{\partial k} > 0$; *otherwise,* $\frac{\partial n_7}{\partial k} < 0$.

Proposition 4 shows the effects of green investment on the profits of the two competing ocean shipping companies. Under scenario EN, the green shipping company (OS1) earns a higher profit than under either NN or EE, whereas the ordinary company (OS2) earns a lower profit than under either of these two scenarios. Thus, unilateral investment benefits the green shipping company while

putting its rival at a disadvantage. By contrast, the profit comparison between scenarios EE and NN depends on the service and green investment cost coefficients. When the service cost coefficient is relatively high ($m > m_3$) and the green investment cost coefficient is relatively high ($n > n_7$), both companies earn higher profits under scenario EE than under NN. Under the complementary parameter conditions specified in Proposition 4, both companies earn higher profits under scenario NN than under EE. These results indicate that mutual green investment does not necessarily improve profitability. These findings suggest that, although green transformation is an inevitable industry trend, ocean shipping companies should carefully evaluate their cost structures and competitive environments before making green investments. Otherwise, they may become trapped in a situation of higher transport demand but lower profitability, in which intensified green investment increases market activity without improving financial performance.

Proposition 5. *Green investment is a strictly dominant strategy for both ocean shipping companies. Therefore, EE is the unique Nash equilibrium of the game.*

Proposition 5 establishes the equilibrium investment strategies of the two ocean shipping companies. Each ocean shipping company benefits from investing regardless of its rival's investment decision. Consequently, mutual green investment becomes the equilibrium outcome. However, Proposition 4 shows that, when the service cost coefficient is low, or when the green investment cost coefficient is low, both shipping companies earn lower profits under EE than under scenario NN, in which neither company invests. Thus, although green investment is individually optimal for each shipping company, mutual investment can leave both worse off than mutual non-investment, giving rise to a prisoner's dilemma. The prisoner's dilemma arises from a symmetric service escalation mechanism. When only one ocean shipping company invests, green investment creates a relative differentiation advantage. Once both ocean shipping companies adopt green investment, neither ocean shipping company can retain this relative advantage. When service improvement or green investment is sufficiently inexpensive, both ocean shipping companies maintain relatively high levels of green investment and service effort, thereby increasing investment and operating expenditures without generating a corresponding relative competitive advantage. Consequently, both ocean shipping companies may earn less than under scenario NN. To intuitively illustrate the results, we plot Figure 3 to compare the profits of ocean shipping companies under scenarios NN and EE, where region NN denotes the parameter range corresponding to the prisoner's dilemma. The parameters are set as $a = 1$, $b = 0.8$, $k = 0.2$, and $c = 0.8$.

The threshold $n_7(b, k, m)$ is found to decline as the service cost coefficient rises, which implies the prisoner's dilemma region gradually shrinks. We further investigate how this threshold varies with the service substitutability (b) and the shippers' environmental awareness (k) in Corollary 1. Specifically, $n_7(b, k, m)$ increases with b, meaning fiercer service competition expands the prisoner's dilemma region. The effect of shippers' environmental awareness k on the threshold n_7 depends on the service cost coefficient m. Specifically, n_7 increases with k when $m > \frac{1+2b}{4}$, whereas it decreases with k when $\frac{1+b}{4} < m < \frac{1+2b}{4}$, subject to the feasibility conditions of the model. These findings suggest that intensified service competition increases the likelihood that shipping companies become trapped in the prisoner's dilemma. Intense competition compels shipping companies to increase both green investment and service quality simultaneously, driving up operational expenditures and eroding corporate profits. Moreover, shippers' environmental awareness is not always beneficial at higher levels. Strong environmental awareness may strongly incentivize both ocean shipping companies to

continuously raise their green investment and service levels to preserve competitive positions, triggering further cost escalation and expanding the parameter region where the prisoner's dilemma emerges. Managers should therefore avoid assuming that increasing environmental awareness will uniformly alleviate or intensify strategic conflicts. Instead, they should assess environmental awareness alongside the relevant cost conditions when formulating strategies for competing shipping supply chains.

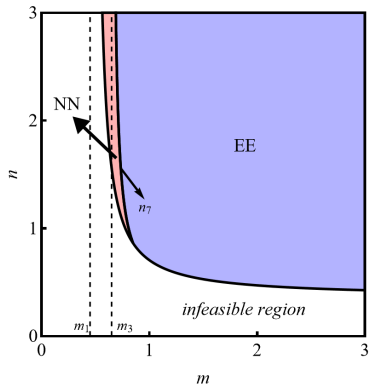


Figure 3. The profit comparison of ocean shipping companies in scenarios NN and EE.

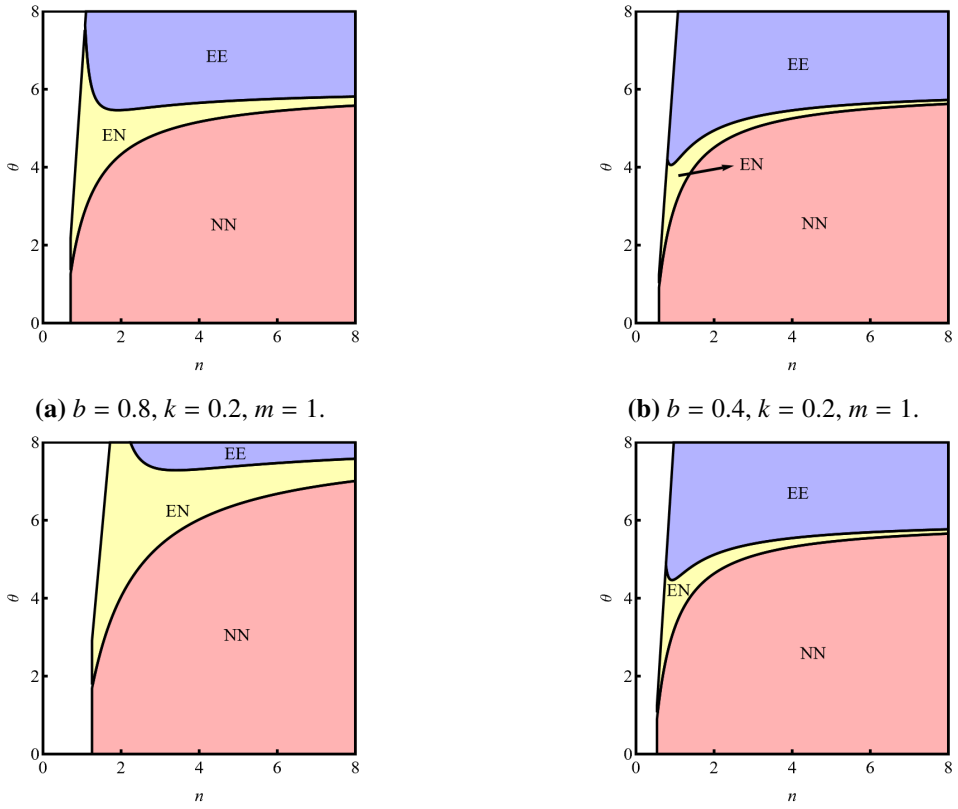
5.3. Environmental impact

To characterize the impact of green investment on carbon emissions, we introduce a carbon emission reduction coefficient, denoted by $\theta > 0$, and express the unit carbon emissions of ocean shipping company OSi after green investment as $e-\theta g_i$, where e denotes the unit carbon emissions without green investment. To ensure economic meaningfulness, we require $e-\theta g_i \geq 0$. Combining this condition with the constraint $g_i < c$ imposed in Section 3.2, we require $g_i \leq \bar{g}$, where $\bar{g} = \min\left\{c, \frac{e}{\theta}\right\}$. Accordingly, the total carbon emissions E under the three scenarios are given by (1) $E^{NN} = e\left(q_1^{NN} + q_2^{NN}\right)$; (2) $E^{EN} = \left(e - \theta g_1^{EN}\right) q_1^{EN} + e q_2^{EN}$; and (3) $E^{EE} = \left(e - \theta g_1^{EE}\right) q_1^{EE*} + \left(e - \theta g_2^{EE}\right) q_2^{EE}$.

Given the complexity of the results, we illustrate the conclusion through numerical simulation. To satisfy the parameter requirements and ensure the feasibility of the resulting greenness levels, the parameters are set as $a = 1$, $c = 0.8$, and $e = 1$.

Figure 4 illustrates the regions in which each investment scenario yields the lowest total carbon emissions under different combinations of the green investment cost coefficient and the carbon emission reduction coefficient. When the carbon emission reduction coefficient is low, green investment has only a limited effect on reducing unit carbon emissions. In this case, the additional transport demand generated by green investment outweighs the emission reduction effect, resulting in higher total carbon emissions than under scenario NN. When the green investment cost coefficient is low, and the carbon emission reduction coefficient is high, unilateral green investment minimizes total carbon emissions because the green shipping company captures market share from its ordinary competitor without triggering excessive transport demand. Similarly, when the green investment cost coefficient is high, but the carbon emission reduction coefficient is moderate, unilateral green investment remains environmentally preferable because market expansion is relatively limited. When

both the green investment cost coefficient and the carbon emission reduction coefficient are high, scenario EE yields the lowest total carbon emissions. Under this equilibrium, both shipping companies adopt highly efficient emission reduction technologies, thereby maximizing environmental benefits.



(a) $b = 0.8$, $k = 0.2$, $m = 1$.

(b) $b = 0.4$, $k = 0.2$, $m = 1$.

(c) $b = 0.8$, $k = 0.6$, $m = 1$.

(d) $b = 0.8$, $k = 0.2$, $m = 1.5$.

Figure 4. The comparison of total carbon emissions.

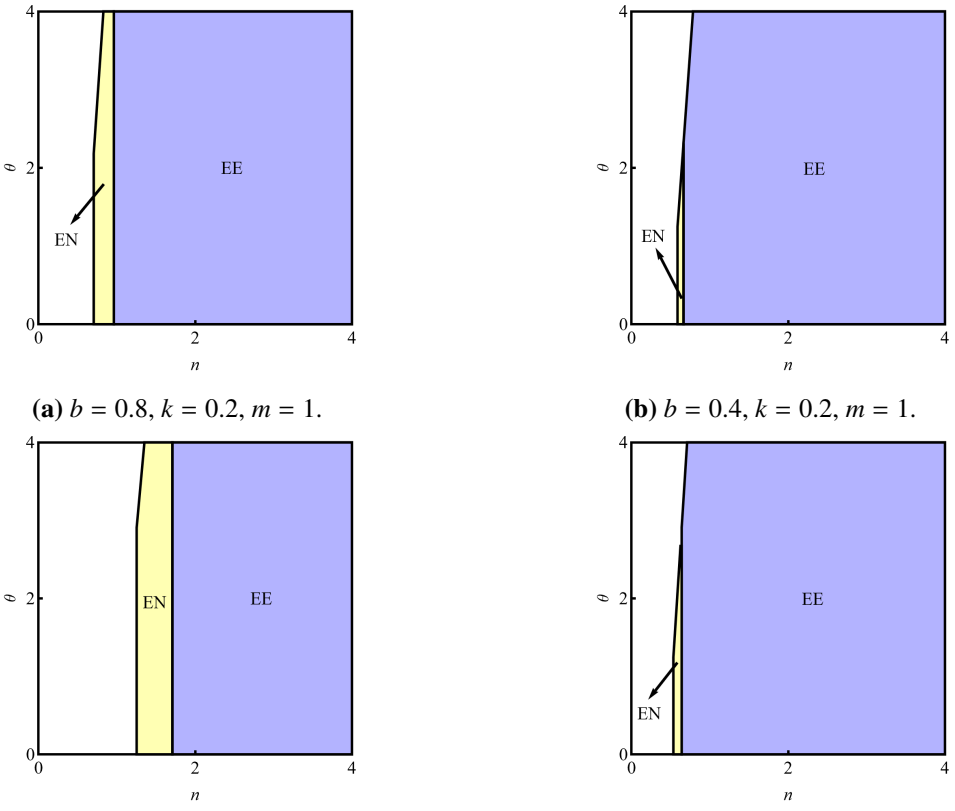
Overall, the environmental effectiveness of green investment depends on the balance between market expansion and emission reduction efficiency. Green investment reduces total carbon emissions only when improvements in emission efficiency outweigh the additional emissions generated by increased transport demand. These findings provide important policy implications. Governments should encourage shipping companies to adopt green technologies with higher emission reduction efficiency by linking incentive policies to environmental performance. In addition, targeted subsidies, low-interest loans, and other financial support can alleviate firms' green investment burdens and facilitate the smooth implementation of green transformation.

5.4. Shipper surplus

To further examine the welfare implications of green investment, we compare shipper surplus under the three scenarios: NN, EN, and EE. The total shipper surplus can be calculated as

$$CS = \frac{1}{2}q_1^2 + \frac{1}{2}q_2^2. \tag{5.1}$$

Analytical results show that $\min\left\{CS^{EE*}, CS^{EN*}\right\} > CS^{NN*}$, indicating that green investment by at least one ocean shipping company increases shipper surplus relative to the no-investment scenario. This suggests that green investment can also benefit shippers by increasing their surplus. However, the comparison between CS^{EE*} and CS^{EN*} is more complex. We therefore conduct a numerical analysis to illustrate the comparison, as shown in Figure 5. The results indicate that when the green investment cost coefficient is relatively low, unilateral green investment (scenario EN) generates higher shipper surplus than mutual green investment (scenario EE). Conversely, when the green investment cost coefficient is relatively high, mutual green investment yields higher shipper surplus. When green investment cost is low, the green shipping company in scenario EN has a stronger incentive to invest, achieves a higher level of shipping greenness, and attracts more demand than under scenario EE. The resulting demand distribution favors scenario EN in terms of total shipper surplus. When green investment cost is high, however, the advantage of unilateral investment diminishes. Under scenario EE, both shipping companies improve their service levels, resulting in higher total shipper surplus than under scenario EN. These findings highlight that greater participation in green investment does not necessarily yield greater shipper surplus. Instead, the welfare effects depend on investment costs. For policymakers, the results caution against assuming that broader participation in green investment necessarily leads to greater shipper welfare. Policies promoting green shipping should therefore consider how investment costs and firms' strategic interactions jointly shape service provision and market demand, rather than focusing solely on increasing the number of investing companies.



(a) $b = 0.8$, $k = 0.2$, $m = 1$.

(b) $b = 0.4$, $k = 0.2$, $m = 1$.

(c) $b = 0.8$, $k = 0.6$, $m = 1$.

(d) $b = 0.8$, $k = 0.2$, $m = 1.5$.

Figure 5. The comparison of shipper surplus.

6. Extensions

6.1. Asymmetrical potential market sizes

In the main model, we assume that the two freight forwarders have identical potential market sizes. In this section, we relax this assumption by allowing the freight forwarders to have heterogeneous market sizes. Specifically, F1 is assumed to have a larger potential market size, which remains a, whereas the potential market size of F2 is assumed to be λa, where $0 < \lambda < 1$. As λ rises, the gap in potential market sizes between the two freight forwarders gradually narrows.

Owing to the asymmetry in market sizes, four scenarios are considered in this extension: (1) neither ocean shipping company makes green investment; (2) only OS1 makes green investment; (3) only OS2 makes green investment; and (4) both ocean shipping companies make green investment. Under these scenarios, the demand functions are reformulated as follows:

$$q_1 = a - p_1 + s_1 - bs_2 + kg_1,\ q_2 = \lambda a - p_2 + s_2 - bs_1 + kg_2. \tag{6.1}$$

We continue to solve the model using backward induction. Given the complexity of the results under asymmetric market sizes, we adopt numerical simulation to examine the impacts of market-size heterogeneity on companies' green investment decisions and the corresponding equilibrium outcomes. To satisfy the parameter requirements and ensure that the resulting greenness levels remain within the feasible region, the parameters are set as $a = 2$, $b = 0.1$, $c = 1$, $m = 0.8$, $n = 1$, and $k = 0.2$. Parameter λ is assumed to vary within the range $(0.6, 1)$, such that all transport demands are always positive. Moreover, under asymmetric freight forwarder market sizes, the service levels of ocean shipping companies, transport demand, and freight forwarders' profits continue to exhibit the same directional changes as those observed in the main model. Therefore, for brevity, we present only the changes in freight forwarders' profits.

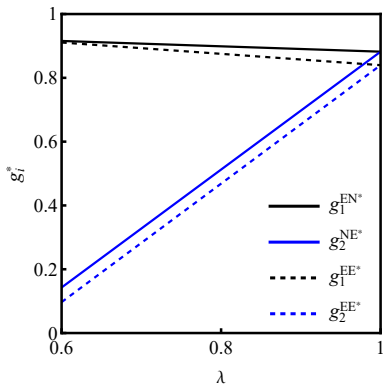
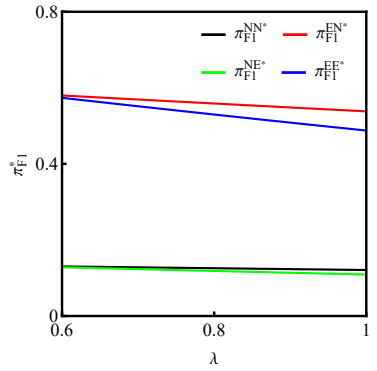


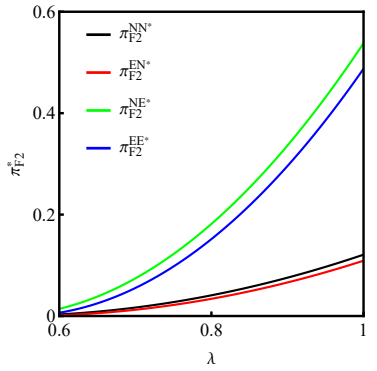
Figure 6. The effects of λ on the shipping greenness level.

From Figure 6, as the potential market size of F2 increases, its partnering ocean shipping company (OS2) increases its green investment, whereas OS1 slightly reduces its own green investment, if any. However, the reduction in OS1's greenness level is relatively limited. These results suggest that partnering with a larger freight forwarder strengthens an ocean shipping company's incentives to undertake green investment, as the larger customer base enables it to recoup green investment costs

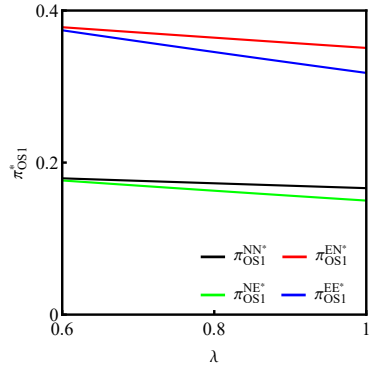
more effectively through increased transport demand. Therefore, establishing partnerships with large-scale freight forwarders can be an effective strategy for ocean shipping companies to enhance the economic benefits of green investment while accelerating their green transition.



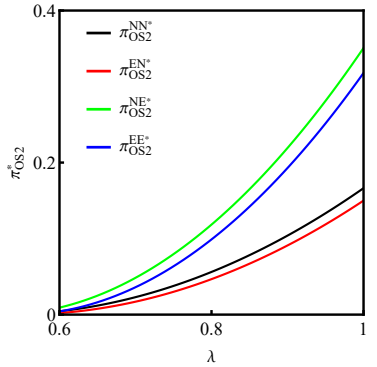
(a) The effects of λ on the profit of F1.



(b) The effects of λ on the profit of F2.



(c) The effects of λ on the profit of OS1.



(d) The effects of λ on the profit of OS2.

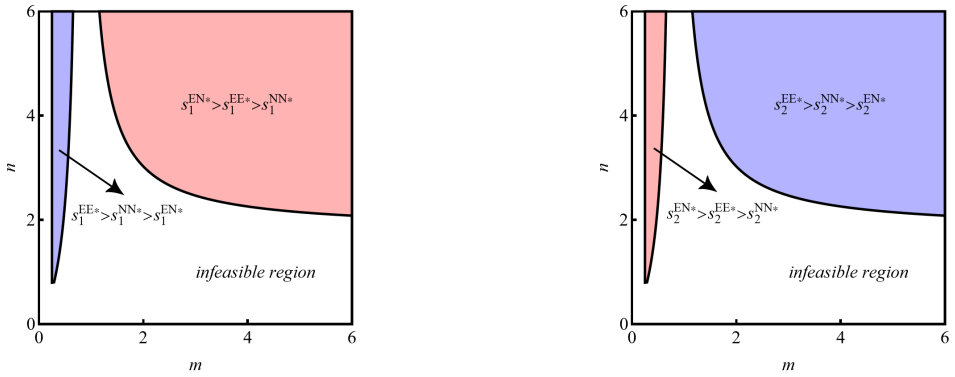
Figure 7. The effects of λ on the profits of shipping supply chain members.

As shown in Figure 7, the profit of F2 increases continuously as its potential market size expands, indicating that market expansion directly benefits the freight forwarder by attracting additional transport demand. In contrast, although F1's profit gradually declines, the magnitude of the decrease is relatively small. This finding suggests that as the smaller freight forwarder expands its market, it captures part of its rival's transport demand, thereby increasing its own profitability, while the larger freight forwarder remains relatively resilient to competitive pressure from a smaller rival. Correspondingly, OS1's profit declines because it loses part of its transport demand, whereas OS2 benefits from increased demand and consequently earns higher profits. Moreover, Figure 7 further demonstrates that several key findings of the main model remain robust when freight forwarders have heterogeneous market sizes. Specifically, green investment by an ocean shipping company consistently improves its service level, increases transport demand, and enhances the profitability of both the shipping company and its partnering freight forwarder.

6.2. Shipping alliance

As shipping alliances have become increasingly common in the liner shipping industry, some ocean shipping companies cooperate to improve operational efficiency, share resources, and

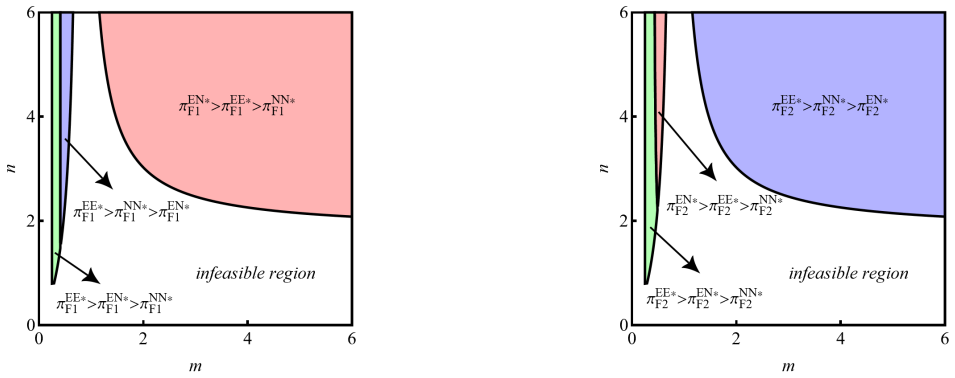
strengthen their market competitiveness [45]. Motivated by this industrial practice, this section examines the impacts of green investment when the two ocean shipping companies form an alliance. In this situation, each ocean shipping company makes decisions to maximize the joint profit of the alliance. Given the complexity of the analytical results under a shipping alliance, we employ numerical simulation to investigate the impacts of green investment. The parameters are set as $a = 1$, $b = 0.8$, $c = 0.8$, and $k = 0.2$.



(a) The comparison of s_1. **(b)** The comparison of s_2.

Figure 8. The comparison of service levels.

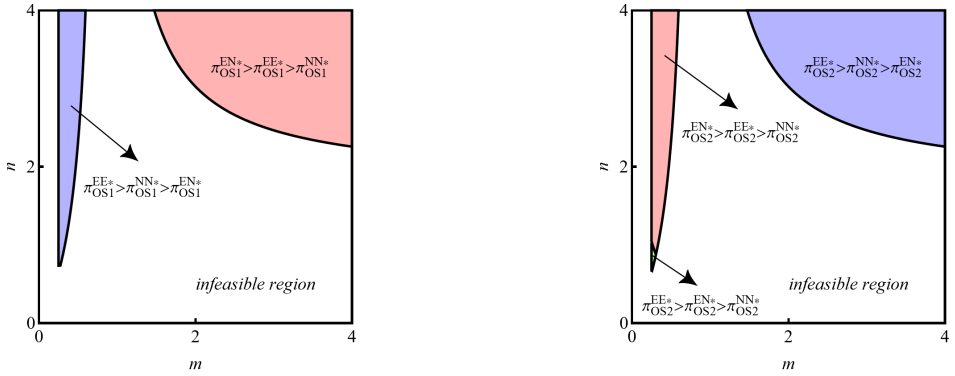
Figure 8 shows that the formation of a shipping alliance alters the positive effects of green investment under some conditions. When the service cost coefficient is relatively low and only one ocean shipping company makes green investment, the green ocean shipping company unexpectedly reduces its service level, whereas the ordinary ocean shipping company increases its service level. This phenomenon arises because each ocean shipping company prioritizes maximizing the alliance's collective profit rather than individual profit. Service efforts are optimally reallocated between the two member firms, eliminating redundant service investments. Furthermore, when both ocean shipping companies make green investment, their service levels consistently outperform those under scenario NN. This demonstrates that once green investment becomes an industry consensus, shipping alliances can facilitate the coordinated advancement of environmental sustainability and service quality across the shipping sector.



(a) The comparison of π_{F1}. **(b)** The comparison of π_{F2}.

Figure 9. The comparison of the freight forwarder's profit.

As discussed above, under relatively low service costs, unilateral green investment may reduce the green ocean shipping company's service level. Figure 9 shows that, within this parameter region, green investment may also reduce the profit of the investing company's partnering freight forwarder. This is because the reduction in service level weakens transport demand. Although green investment generates additional demand by improving environmental competitiveness, this positive effect becomes insufficient to fully offset the demand loss caused by lower service levels as the service cost coefficient increases. Consequently, the partnering freight forwarder experiences a decline in profitability.



(a) The comparison of π_{OS1}. **(b)** The comparison of π_{OS2}.

Figure 10. The comparison of the ocean shipping company's profit.

Figure 10 indicates that, when the service cost coefficient is relatively low, green investment may even reduce the profit of the green ocean shipping company. Only when the service cost coefficient exceeds a certain threshold does green investment become profitable. Furthermore, when both the service cost coefficient and the green investment cost coefficient are low, green investment only by one shipping company unexpectedly increases the profit of the ordinary shipping company. This finding indicates that part of the economic benefits generated by green investment is redistributed within the alliance, thereby weakening the investing ocean shipping company's incentives to make green investment. In addition, when both shipping companies undertake green investment, the prisoner's dilemma observed in the benchmark model no longer arises. Both shipping companies achieve higher profits than in scenario NN, indicating that alliance cooperation effectively mitigates the excessive competition associated with independent green investment and enables member firms to jointly benefit from green transformation.

The numerical results suggest that a shipping alliance may change the profitability of green investment. To establish this finding rigorously, we analytically compare the equilibrium profits under NN and EE. The following proposition shows that, under a shipping alliance, both ocean shipping companies earn higher profits under EE than under NN, indicating that the prisoner's dilemma associated with green investment in the non-cooperative setting no longer arises under the alliance.

Proposition 6. *Under a shipping alliance, the equilibrium profits of both ocean shipping companies are always higher under EE than under NN. That is,* $\pi_{OS1}^{EE*} > \pi_{OS1}^{NN*}$ *and* $\pi_{OS2}^{EE*} > \pi_{OS2}^{NN*}$.

Proposition 6 highlights the role of a shipping alliance in shaping the economic consequences of green investment. In the non-cooperative setting, mutual green investment may lead to a prisoner's dilemma, in which both ocean shipping companies earn lower profits under scenario EE than under

NN. Under a shipping alliance, however, both companies earn higher profits under EE than under NN. This result suggests that cooperation through a shipping alliance can better align the companies' economic interests with mutual green investment, thereby eliminating the prisoner's dilemma observed in the non-cooperative setting. These findings highlight the potential value of cooperation in promoting green investment in the shipping industry.

6.3. Common freight forwarder

In the main model, each ocean shipping company sells its transportation services through its own freight forwarder. To examine whether our main findings depend on this one-to-one matching structure, we consider an alternative setting in which both ocean shipping companies sell their services through a common freight forwarder, denoted by F^C. The common freight forwarder purchases transportation services from both ocean shipping companies and determines the corresponding freight prices p_1 and p_2. Its profit is given by

$$\pi_F^C = (p_1 - w_1)q_1 + (p_2 - w_2)q_2. \tag{6.2}$$

The demand functions for the two transportation services and the profit functions of the ocean shipping companies remain the same as those in the main model. Therefore, the only difference between the two settings is whether the ocean shipping companies sell their services through separate freight forwarders or a common freight forwarder.

Proposition 7. *The main results of the main model remain robust when the two ocean shipping companies sell their transportation services through a common freight forwarder.*

This result suggests that the main findings are not driven solely by the one-to-one matching structure. From a managerial perspective, the findings provide ocean shipping companies with greater flexibility in choosing their relationships with freight forwarders, as the main implications of their green investment decisions remain robust under both separate and common freight forwarder structures.

6.4. Environmental responsibility

To account for ocean shipping companies' environmental responsibility, we introduce an environmental responsibility parameter $\rho \in (0, 1)$, which captures the extent to which a company internalizes the carbon emissions generated by its operations. The objective function of ocean shipping company OSi is modified as

$$U_{OSi} = \pi_{OSi} - \rho E_i, \tag{6.3}$$

where π_{OSi} denotes OSi's profit and E_i represents its carbon emissions. A higher value of ρ indicates that the company places greater weight on reducing its carbon emissions when making operational and green investment decisions.

Given the complexity of the equilibrium outcomes, we conduct numerical simulations to examine how environmental responsibility affects green investment decisions and the resulting equilibrium outcomes. To ensure that shipping greenness remains within the feasible region and all transport demands are positive, we set $a = 2$, $b = 0.2$, $c = 1$, $m = 0.8$, $n = 1$, and $k = 0.2$. Parameter ρ is assumed to vary within the range $(0, 0.16)$, such that all transport demands are always positive. The

numerical results show that the service levels of ocean shipping companies, transport demand, and freight forwarders' profits exhibit the same directional changes as those observed in the main model. For brevity, we focus on the effects of environmental responsibility on shipping greenness and the profits of supply chain members.

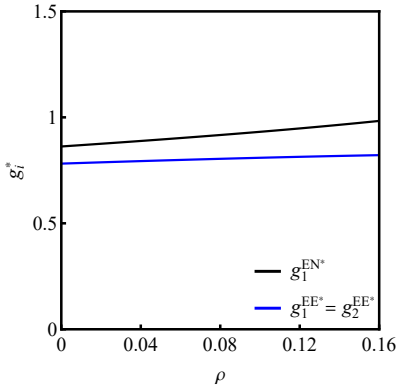


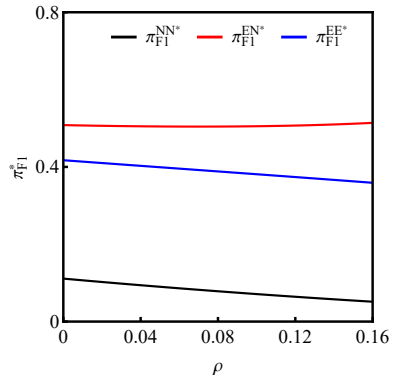
Figure 11. The effects of ρ on the shipping greenness level.

From Figure 11, consistent with intuition, as ocean shipping companies' environmental responsibility awareness increases, they raise their green investment, thereby achieving higher shipping greenness.

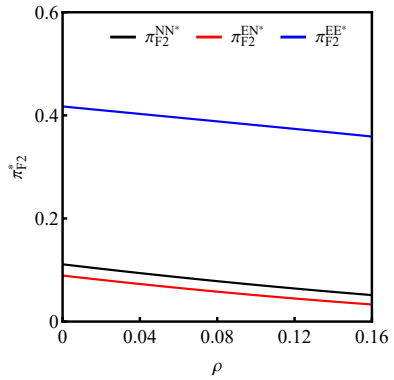
Figure 12 illustrates the effects of environmental responsibility on the profits of supply chain members under different green investment scenarios. When neither shipping company makes green investment, stronger environmental responsibility induces the shipping companies to reduce their service levels to account for the carbon emissions associated with their operations. Consequently, transport demand declines, reducing both shipping companies' profits and the profits of their partner freight forwarders. When only one shipping company makes green investment, stronger environmental responsibility encourages the green shipping company to increase its green investment, resulting in higher shipping greenness. Initially, the additional resources devoted to green investment constrain the shipping company's service provision, leading to lower service levels and transport demand. As shipping greenness continues to increase, the green shipping supply chain becomes more attractive to shippers and subsequently expands its service provision. The resulting increase in transport demand and service levels also benefits its partner freight forwarder. Nevertheless, the additional revenue generated by the increased demand is insufficient to offset the green shipping company's green investment and service provision costs. Consequently, its profit continues to decline as environmental responsibility increases. When both shipping companies make green investment, stronger environmental responsibility encourages both shipping companies to increase their green investment and achieve higher shipping greenness. However, the additional resources allocated to green investment constrain their service provision, reducing service levels and transport demand. As a result, the profits of both shipping companies and their partner freight forwarders decline.

Overall, this extension shows that stronger environmental responsibility promotes greener shipping but does not necessarily improve the economic performance of supply chain members. Although greater environmental responsibility encourages green investment, the associated investment and operational costs may outweigh the additional revenue generated by increased demand. These

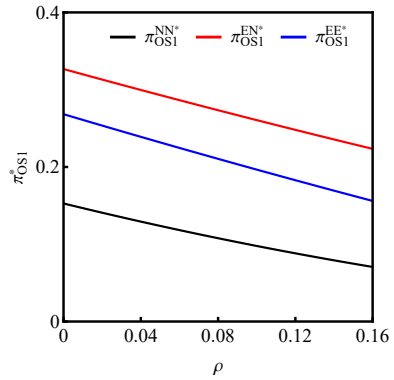
findings highlight the potential trade-off between environmental objectives and economic profitability and demonstrate the importance of accounting for firms' environmental responsibility when evaluating green investment decisions in the shipping industry.



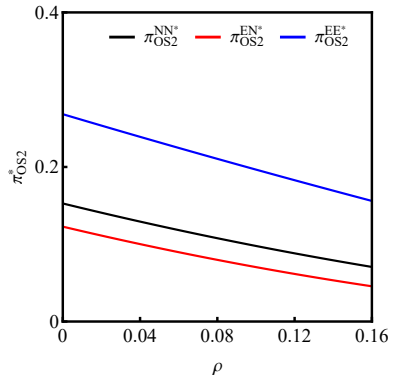
(a) The effects of ρ on the profit of F1.



(b) The effects of ρ on the profit of F2.



(c) The effects of ρ on the profit of OS1.



(d) The effects of ρ on the profit of OS2.

Figure 12. The effects of ρ on the profits of shipping supply chain members.

7. Concluding remarks

7.1. Conclusion

This study investigates ocean shipping companies' green investment strategies under inter-supply-chain service competition. To this end, we develop a game-theoretic model consisting of two competing shipping supply chains and analyze three green investment scenarios. The model examines how service competition influences green investment decisions and how green investment reshapes companies' competitiveness, profitability, and environmental performance. The findings are summarized as follows:

First, we investigate how inter-supply-chain service competition affects ocean shipping companies' green investment decisions. The results show that intensified service competition does not necessarily discourage green investment. Under unilateral green investment, that is, scenario EN, when the service cost coefficient is low, or when the service cost coefficient is high but the green investment cost coefficient is low, intensified service competition motivates the green shipping company to increase its green investment. Under bilateral green investment, that is, scenario EE, intensified

service competition also promotes higher green investment when the service cost coefficient is relatively low.

Second, we examine the impacts of ocean shipping companies' green investment behavior. In the baseline non-cooperative model, green investment can offset the adverse effects of service competition under certain conditions. Specifically, green investment induces the investing shipping company to improve its service level while forcing the competing shipping company to reduce its service level, thereby alleviating service competition between competing shipping supply chains. Under the conditions identified in the baseline model, green investment also increases transport demand and improves the profitability of the investing company's partnering freight forwarder. However, the shipping alliance extension reveals that these effects are not universal. When only one alliance member undertakes green investment, the investing company may reduce its service level under relatively low service costs. Moreover, its individual profit and the profit of its partnering freight forwarder may decline under certain conditions. Considering the dual effects of green investment on carbon emissions, that is, green investment reduces emissions intensity while increased transportation demand may increase total emissions, we further examine its environmental implications. The results show that when the emission reduction efficiency coefficient is moderate or high, green investment by ocean shipping companies can effectively reduce total carbon emissions.

Third, we explore the motivations behind ocean shipping companies' green investment decisions. In the baseline non-cooperative model, green investment can increase the investing company's profit under the conditions identified in our analysis. However, when the service cost coefficient is low, or when the service cost coefficient is high while the green investment cost coefficient remains low, the additional profits generated by increased transport demand may be insufficient to offset the costs associated with enhanced service levels and green investment. Consequently, both shipping companies may face a prisoner's dilemma, obtaining lower profits despite achieving higher transport demand than in the scenario where neither company invests. Forming a shipping alliance can help alleviate this dilemma by enabling cooperative decision-making. Our results show that when both alliance members undertake green investment, both can achieve higher profits than in the no-investment scenario.

7.2. Managerial implications

The findings of this study provide some managerial implications for ocean shipping companies, freight forwarders, and policymakers.

Our results caution ocean shipping companies against assuming that lower green investment costs necessarily translate into higher profitability. When competitors can also make green investment and service improvement is relatively inexpensive, an ocean shipping company may have an incentive to invest even when simultaneous investment by both ocean shipping companies ultimately reduces their profits relative to the no-investment scenario. Ocean shipping companies should therefore evaluate green investment not only in terms of its direct demand and cost effects but also by anticipating competitors' responses in service decisions.

The results also imply that regulators should not assess green-shipping programs solely on the basis of firms' investment levels. Green investment can stimulate transport demand and may increase total emissions when the emission-reduction efficiency of the adopted technology is insufficient to offset the additional emissions associated with demand growth. Policy support should therefore place greater emphasis on verified emission reductions rather than investment expenditure alone.

Finally, because freight forwarders may benefit from the additional demand generated by ocean shipping companies' green investment without directly bearing the investment costs, vertical cooperation may help align their incentives. Potential arrangements include cost-sharing agreements, long-term procurement contracts, and green-service partnerships. The DB Schenker-MSC biofuel agreement illustrates this type of cooperation. DB Schenker secured biofuel-based ocean transport from MSC and made an upfront investment in biofuel purchases, enabling it to offer lower-emission shipping services to its customers.

7.3. Future research

While this study provides several important insights, it is subject to several limitations that offer opportunities for future research. First, the model assumes that ocean shipping companies have sufficient financial resources to make green investments. In reality, however, shipping companies often face financing constraints during the green transition, which may influence their investment decisions. Future research could explicitly incorporate capital constraints to investigate their impact on companies' green investment strategies and competitive behavior. Second, this study assumes that freight forwarders procure transportation capacity from ocean shipping companies through wholesale price contracts, with shipping fees determined solely by the shipping companies. In practice, freight forwarders could also negotiate shipping fees with shipping companies based on their bargaining power and long-term cooperative relationships. Incorporating bargaining mechanisms or alternative contract forms into the analytical framework would provide a more comprehensive understanding of green investment decisions and supply chain competition. Third, future research may disaggregate the composite service level into specific operational dimensions. This extension would be particularly meaningful because service attributes may have different environmental consequences; for example, shortening transit time through higher sailing speed may increase fuel consumption and emissions, whereas better cargo handling or information services may improve service quality without creating the same carbon tradeoff. In addition, while this study focuses on the market and operating channels through which green investment affects competitive shipping supply chains, the explicit interaction between environmental regulation and service competition remains an important direction for future research. Extending the model to incorporate this interaction could provide further insights into how environmental policies shape firms' service decisions, green investment strategies, and competitive outcomes. Finally, future research could also consider more realistic settings, such as information asymmetry, heterogeneous customer preferences for green transportation services, and demand uncertainty, to further enrich the analysis and advance research on sustainable shipping supply chains.

Author contributions

Huawei Sun: conceptualization, writing-original draft; Jing Xu: writing-review & editing; Yang Lu: writing-review & editing; Zhuanzhuan Ren: funding acquisition, supervision.

Use of Generative-AI tools declaration

During the preparation of this manuscript, the authors used ChatGPT for language polishing and expression improvement. All AI-assisted content was critically reviewed and revised by the authors,

who take full responsibility for the final published version.

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Conflict of interest

All authors declare no conflicts of interest in this paper.

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