EVALUATING LOGISTICS SERVICE PROVIDERS' GREEN TRANSITION AND ITS IMPACTS WITHIN AND BETWEEN FIRMS: THREE EMPIRICAL STUDIES IN CHINA

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Evaluating Logistics Service Providers' Green Transition and Its Impacts Within and Between Firms: Three Empirical Studies in China

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CERTITICATE OF ORIGINITY

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Abstract

The logistics industry, integral to economic development through its facilitation of economic exchanges, also significantly impacts the environment due to extensive cargo movement activities. This dichotomy critically emphasizes reducing environmental pollution and resource consumption, particularly in China, where the scale and scope of logistics operations are vast to meet growing demands. This thesis comprises three interrelated studies aimed at identifying green practices among Logistics Service Providers (LSPs), exploring the characteristics and evolution of these practices across different transportation modes, and assessing the impact of LSPs' green innovation on intra- and inter-firm outcomes.

Study 1 investigates publicly listed Chinese LSPs from 2015 to 2021 to identify their green practices' characteristics and evolution in different transportation modes (including road, maritime, and aviation). Through probabilistic topic modeling and interviews, the study analyzes environmental texts from LSPs' corporate social responsibility reports, identifying 18 distinct green practice topics driven by social or technological factors. The analysis reveals transportation mode-specific priorities and a transition in focus from cost-efficiency to advanced green technologies and varied social-driven practices. To deepen the understanding of these findings, interviews with eight LSPs were conducted to probe the drivers of these green practices and the mechanisms underlying their adoption.

Study 2 explores the relationship between LSPs' green innovation and market value using panel data from 53 publicly listed Chinese LSPs from 2011 to 2020. The results show an inverted U-shaped relationship between green innovation and market value, influenced differentially by stakeholder engagements. Engagement with supply chain partners amplifies this relationship, while involvement with scientific institutions and public attention tends to attenuate it.

Study 3 assesses the differential impacts of incremental (IGI) and radical green innovation (RGI) on supply base stability (SBS) by analyzing data from 88 publicly traded Chinese LSPs spanning 2011-2019. Findings reveal a positive effect of IGI on SBS and a negative impact on RGI. Additionally, the study highlights that growth orientation and board environmental expertise can mitigate the adverse effects of RGI on SBS yet have negligible influence on the IGI-SBS relationship.

Overall, this thesis enriches the green logistics and innovation literature by detailing the classification, characteristics, and evolution of green practices among Chinese LSPs, providing academic and practical insights. Furthermore, it extends the logistics and innovation management literature by clarifying the nuanced relationships between green innovation and market value, stakeholder engagement's moderating effects, and the distinct impacts of different types of green innovations on supply base stability. This comprehensive approach offers valuable implications for policymakers and industry leaders in navigating the complexities of implementing sustainable practices in the logistics industry.

Keywords: Green practices; Green innovation; Logistics service providers; Market value; Supply base stability; China

Publications Arising from the Thesis

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Jianhu Cai, Lishuang Jia, **Chang Wu**, Yongyi Shou. (2022). R&D investment in new energy vehicle enterprises: The differential moderating effects of financial slack and government subsidies. *Journal of Industrial Engineering and Engineering Management*, 36(05), 11-24. (In Chinese, CSSCI)

Working Papers:

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Chapter 1 Introduction

1.1 Research Background

1.1.1 Practical Background

Indirect Scope 3 emissions, stemming from supply chains, can make up more than 90% of a typical organization's carbon footprint (BDO, 2023). Alarmingly, emissions from transportation were responsible for the premature deaths of 385,000 individuals in 2015, incurring an estimated health damage cost of up to 1 trillion dollars (ICCT, 2020). Currently, the transportation sector generates approximately 30% of global greenhouse gas (GHG) emissions, primarily from burning fossil fuel for cars, trucks, ships, trains, and planes (USEPA, 2023). In parallel, China's emergence as a global leader in e-commerce led to a nearly sevenfold increase in its inland total freight volume over the past two decades, culminating in 15.25 million ton-kilometers in 2018, a figure that was more than twice that of the United States (OECD, 2023). Such expansive growth in transportation, distribution, and storage utilizes immense resources and causes excessive waste, presenting critical challenges for sustainability and environmental conservation. For instance, in 2020, China's express delivery sector generated a staggering 16 million tons of solid waste, equivalent to the weight of 150 million adults. While 80% of paper packaging in this sector is recyclable, the low value of plastic waste leads to 99% of it going unrecycled (Xinhua News, 2020).

Indeed, environmental conservation is a fundamental state policy in China, as repeatedly highlighted by President Xi Jinping on the concept that clean water and green mountains are as valuable as gold and silver mountains (綠水青山就是金山銀

山) in his various government reports. The 14th Five-Year Plan of China includes directives to reduce effluent, emissions, noise, and water pollution and to enhance green packaging, cleaner energy, and electric vehicles. Such directives require Logistics Service Providers (LSPs) to strictly adhere to environmental regulations to avoid legal repercussions, including fines and penalties imposed by government regulators (Touratier-Muller et al., 2019; Yan et al., 2021). For example, in 2022, Greek shipping companies Empire Bulkers and Joanna Maritime faced a 2 million USD fine for violating environmental regulations by illegally discharging pollutants into waterways and falsifying oil records (U.S. Department of Justice, 2022). Additionally, stakeholders such as suppliers, customers, peers, and the general public are crucial in promoting and supporting the green transition among LSPs. For instance, in 2021, China Eastern Airlines, in collaboration with COSCO Shipping and SINOPEC, completed the "Whole Life Cycle Carbon Neutral Oil" project, achieving carbon neutrality from the production to the combustion of aviation fuel (China Eastern, 2022).

Nowadays, the concept and practices of green logistics are widely advocated and adopted in the Chinese logistics industry to mitigate the environmental impact of massive cargo flows. For example, in 2017, the Cainiao Green Alliance Foundation, involving major Chinese LSPs such as YTO Express and ZTO Express, established a charity fund of 300 million RMB to support green logistics research and initiatives (Cainiao, 2017). This move underscores the urgent need to green the logistics industry, given the excessive use of packaging materials, low resource recycling rates, and the vast volume of logistics deliveries in the digital age. In 2020, COSCO Shipping Group signed contracts for three 174000-cubic-meter Liquefied Natural Gas (LNG) transport vessels. It developed a high-quality LNG ship management platform, comprehensive system, and crew training program (COSCO, 2020). In 2022, China Southern Airlines took delivery of its 14th A350 aircraft at the Airbus Tianjin Delivery Centre, marking the first use of “made in China” sustainable aviation fuel on a wide-body aircraft for a delivery flight (China Southern, 2022).

While some LSPs have proactively implemented these green logistics activities, many other firms are reactive in undertaking these technical and environmental innovations due to the associated high costs and uncertain financial benefits. As an essential role in promoting the green transition of the logistics industry, LSPs must consider the increased logistics costs induced by the green transition, including external, hidden, and opportunity costs (Rennings, 2000). This careful consideration is essential for contributing to the industry’s green transition while ensuring their development. Therefore, LSPs face several critical questions: How should they go green? What will be the impact of such a transition on their intra- and inter-firm performance? Answers to these questions are crucial because they can help LSPs achieve better environmental and financial performance.

1.1.2 Theoretical Background

Scholars in operations and logistics management, as well as in various business disciplines, have consistently demonstrated interest in the greening of LSPs and the associated outcomes (Centobelli et al., 2017; Layaoen et al., 2023; Lieb and Lieb, 2010;

Sureeyatanapas et al., 2018). Green logistics emphasizes reducing environmental impact and resource consumption throughout logistics operation and management, mainly including transportation, warehousing, and distribution (Lai and Wong, 2012; McKinnon, 2010, 2018; Ubeda et al., 2011). The green development of the logistics industry increasingly prompts more LSPs to adopt advanced green practices, thereby enhancing their environmental performance and competitive advantage (Kang et al., 2021; Sureeyatanapas et al., 2018). Existing literature on LSPs' green practices highlights the critical importance of technological solutions to minimize their environmental footprint, such as logistics optimization, alternative fuels, smart logistics systems, and sustainable packaging solutions (Centobelli et al., 2017). Consequently, green innovation, as a crucial source of these advanced green technologies (Milliman and Prince, 1989), is essential for the green transition of LSPs.

In this thesis, we undertake three interconnected studies that explore LSPs' adoption of green practices across different transportation modes and evaluate intra- and inter-firm outcomes of LSPs' green innovation. An exhaustive review of the extant literature forms the foundation of our research, enabling the identification of significant gaps that each study aims to address.

Study 1 identifies and classifies the green practices adopted by LSPs under different transportation modes within the Chinese logistics industry. Current research primarily concentrates on the decarbonization strategies of regional and manufacturer-specific logistics systems. For instance, McKinnon (2018) proposes five core pathways for decarbonizing the logistics system: (1) reducing the demand for freight movement;

(2) shifting freight to transportation modes with lower carbon emissions; (3) enhancing asset utilization; (4) increasing energy efficiency; and (5) adopting lower-carbon energy sources. However, studies specifically addressing the green transition of LSPs, a crucial actor in the logistics system, remain sparse. Centobelli et al. (2017) have conducted a systematic literature review on the environmental sustainability of LSPs, revealing that limited studies have identified and classified the green practices of LSPs. These studies have shown a predominant focus on technical solutions to environmental issues associated with logistics activities, but green practices related to employees, organizations, and cultures still require further investigation. Drawing on the socio-technical system (STS) theory, it is evident that while emerging environmental technologies are crucial, successful green transition of a company or industry requires coordinated development of technical and social subsystems (Antonio Ruiz-Quintanilla et al., 1996). With the rapid emergence of environmental technologies in the logistics and transportation sector, the existing literature needs to pay more attention to the actual green practices adopted by LSPs and whether these practices address both social and technical subsystems, for which there is no empirical evidence in the Chinese context. In addition, Study 1 further explores the characteristics and evolution trends in LSPs' green practices under different transportation modes. To identify and classify LSPs' green practices, traditional research methods, mainly including case studies or surveys, are commonly employed at a single point in time (El Baz and Laguir, 2017; Perotti et al., 2012; Sureeyatanapas et al., 2018), which face challenges in accurately measuring the intensity and temporal variations of these practices.

Study 2 focuses on the intra-firm performance of LSPs' green innovation and investigates the impact of LSPs' green innovation on their market value, which is an important indicator of corporate financial performance. While numerous studies have examined the impact of green innovation on financial performance, these primarily concentrate on manufacturing markets in developed countries (e.g., the automobile and chemical industries), and the results of these studies are inconsistent and even contradictory (Ba et al., 2013; Driessen et al., 2013; Wijethilake et al., 2018; Wong et al., 2020). Drawing on the resource-based view (RBV) and stakeholder theory, Study 2 aims to illuminate the green logistics and green innovation literature by examining the nonlinear relationship between green innovation and corporate market value in the context of the Chinese logistics industry. Additionally, Study 2 assesses the moderating effects of stakeholders' sustainability engagement, such as scientific institutions, supply chain partners, and the public. Sustainability engagement, an emerging approach for shipping and logistics management, involves engaging stakeholders, deploying technology applications, and pursuing process innovations to strive for sustainable development in logistics operations and management (Ab Wahab, 2021; Saunila et al., 2019). However, a systematic and comprehensive examination of the effects of different stakeholder engagements in green innovations is lacking in the literature, especially within the Chinese logistics context.

Study 3 examines the inter-firm performance of LSPs' green innovation, specifically analyzing how such innovations affect LSPs' supply base stability. Although extensive research has been conducted on the impact of green innovation on firm performance (Lin et al., 2020; Rehman et al., 2021; Valero-Gil et al., 2023; Wong et al., 2020), there remains a significant gap regarding green innovations' effects on LSPs' upstream supply chain. In the logistics service sector, primary suppliers provide LSPs with essential components and services like transport outsourcing, vehicles, fuels, and various logistics equipment and materials (Bellingkrodt and Wallenburg, 2013), which present significant opportunities for environmental performance enhancements through the adoption of green packaging, logistics optimization, clean fuels, and energy-efficient vehicles. Utilizing the recombinant search theory (RST) (Fleming, 2001; Jung and Lee, 2016), this study differentiates between incremental and radical green innovations to explore their effects on LSPs' supply base stability. Moreover, Study 3 assesses the moderating effects of values and characteristics of the top management team (i.e., growth orientation and board environmental expertise). Previous research has shown that top managers' values and characteristics, such as attention allocation and academic experience, significantly affect the implementation and outcomes of green initiatives (He et al., 2021; Liao et al., 2022; Ma et al., 2021). However, the literature does not analyze how executive factors influence changes in LSPs' supply base stability resulting from green innovation.

1.2 Research Questions

To address the identified gaps in the existing literature, this thesis seeks to answer the following research questions (RQs):

RQs of Study 1: What actual green practices are adopted by LSPs, and what is the intensity of different practices within technical and social subsystems? How does the preference for green practice among LSPs differ across transportation modes such as road, maritime, and aviation? In what ways and for what reasons do green practices of LSPs evolve?

RQs of Study 2: How does green innovation influence LSPs' market value? Linear relationship or nonlinear relationship? Do external stakeholder engagement (i.e., scientific institutions, supply chain partners) and public attention moderate this relationship?

RQs of Study 3: How do the types of green innovation (incremental versus radical) influence LSPs' supply base stability? Are these influences similar or disparate? Does top management team heterogeneity (i.e., growth orientation and board environmental expertise) moderate these relationships?

1.3 Research Objectives

To address the research questions outlined, this thesis sets forth several objectives to guide our investigation. This thesis aims to identify the green practices adopted by LSPs, explore characteristics and evolution trends of these practices under different transportation modes, and examine how LSPs' green innovation influences their inter- and intra-firm outcomes. Specifically, our research aims to achieve the following objectives:

(1) To identify and rank Chinese LSPs' green practices by applying topic modeling on the environmental text in corporate social responsibility (CSR) reports and to

classify these practices according to the STS theory.

(2) To investigate the characteristics of green practices among LSPs across road, maritime, and aviation transportation modes and explore the evolution trend of these practices within Chinese LSPs.

(3) To investigate the impact of green innovation on the market value of LSPs and explore how sustainability engagement (with scientific institutions versus supply chain partners) and public attention moderate this relationship.

(4) To explore the effect of the types of green innovation (incremental versus radical) on LSPs' supply base stability and the moderating effects of the value and characteristics within top management teams (i.e., growth orientation and board environmental expertise).

(5) To make theoretical contributions to the green logistics and innovation literature, especially focusing on the Chinese context.

(6) To provide practical implications for managers of LSPs and policymakers, aiming to enhance their understanding of green practice implementation and the influence of LSPs' green innovation on intra- and inter-firm performance.

1.4 Research Framework and Methods

Three interrelated studies are conducted to systematically examine the adoption of green practices by LSPs across various transportation modes and to assess the consequential intra- and inter-firm impacts of green innovations. This section elaborates on the interrelationships between the three empirical studies of the thesis. From a holistic perspective, Study 1 identifies the green practices adopted by LSPs, classifies these practices into social and technical subsystems, and explores the characteristics and evolutionary trends of these practices under different transportation modes. Furthermore, current research on the environmental sustainability of LSPs has mainly focused on technological solutions to solve environmental problems (Centobelli et al., 2017). Green innovation, as the source of green technologies, involves introducing new or significantly improved products and processes to reduce environmental issues (Karimi Takalo et al., 2021; Kunapatarawong and Martínez-Ros, 2016). Therefore, we further examine the potential implications of LSPs engaging in green innovation. Following this, Study 2 evaluates the influence of green innovation on LSPs' market value and probes the moderating role of external stakeholder engagement, including collaborations with scientific institutions, supply chain partners, and public attention.

Given that green innovation can influence LSPs' performance and modify their existing supplier relationships and structures (Kocabasoglu-Hillmer et al., 2023), Study 3 analyzes how green innovations (incremental versus radical) affect LSPs' supply base stability. This analysis also assesses the moderating effects of values and characteristics within the top management team, such as growth orientation and board environmental expertise. Figure 1.1 illustrates the comprehensive research framework and the connections between the three studies in our thesis.

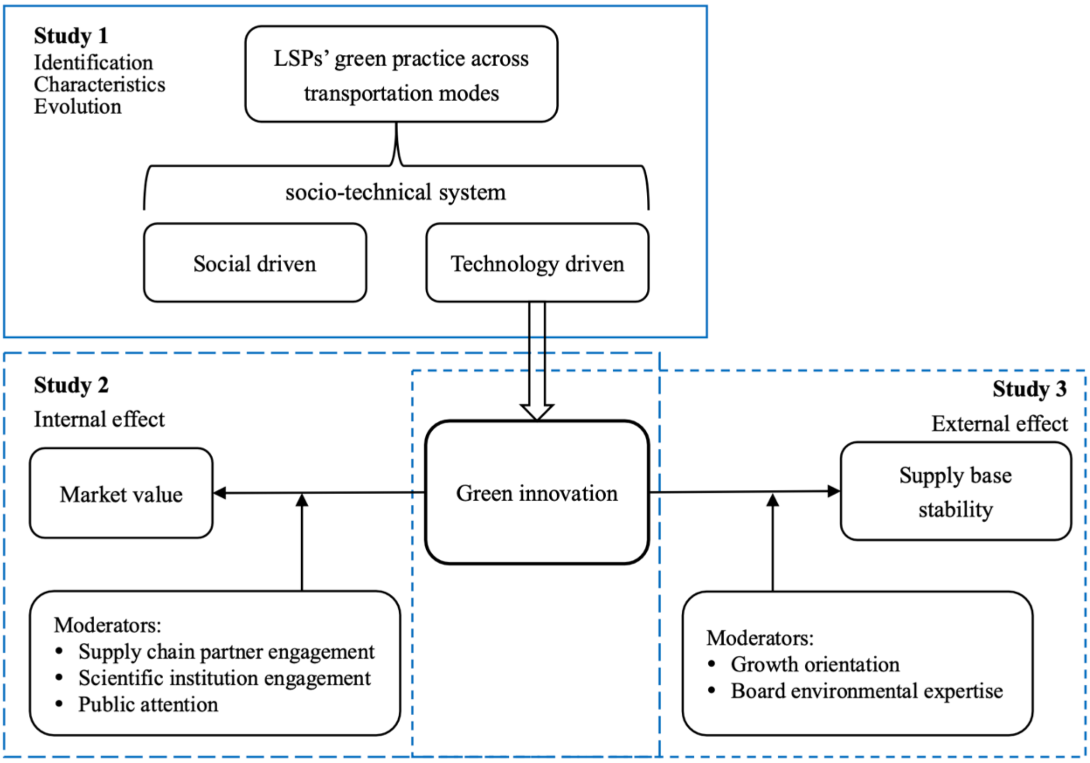


Figure 1.1 The overall framework of the thesis

Since the three studies in this thesis focus on different research questions, we employ different theories as the theoretical lenses for the three studies. In Study 1, we choose the STS theory as our theoretical lens because it provides a comprehensive framework for understanding social and technical elements and their interaction during LSPs' green transition process. STS theory proposes that organizations can be viewed as complex entities consisting of social and technical subsystems (Bostrom and Heinen, 1977). Successfully addressing environmental issues involves technological solutions and necessitates considering organizational strategies and human factors (Ruiz-Quintanilla and Freeman-Gallant, 1996). By applying STS theory, we can categorize and analyze the green practices of LSPs into technical and social dimensions, thus understanding their green practices' characteristics and evolution trends. For Study 2, we employ RBV and stakeholder theory because they are helpful for us to explain the inverse U-shaped effect of green innovation on market value. These theories are instrumental in understanding how the marginal benefits of green innovations gradually diminish while associated costs increase (Li et al., 2021).

Furthermore, these theories provide insights into how stakeholder engagement can moderate this nonlinear relationship. In Study 3, we utilize the RST to analyze the effects of green innovation on LSPs' supply base stability. RST asserts that innovation, whether in art, science, or practical applications, predominantly involves recombining existing knowledge components (Jung and Lee, 2016; Kaplan and Vakili, 2015). This theory allows us to distinguish between the impacts of incremental and radical green innovations on LSPs' supply base stability and to explore the mechanisms driving their distinct effects. Overall, each study aligns with the most appropriate theoretical lenses to effectively address the research context and questions.

The philosophical foundation of this research adopts a combined approach of post-positivism and interpretivism. Specifically, because this thesis focuses on the objective characteristics, performance impacts, and supply chain stability of green practices among logistics enterprises, it emphasizes both objective facts and patterns, as well as the interactions and cognitive differences of social actors, necessitating an integration of diverse philosophical perspectives.

In Study 1, which categorizes and analyzes the characteristics and evolutionary trends of green practices, an interpretivist approach is utilized. Through quantitative latent Dirichlet allocation (LDA) topic modeling and qualitative interviews, the study deeply explores the interaction of green practices within technical and social subsystems. This philosophical perspective stresses a nuanced understanding of motivations, firm behaviors, and evolutionary patterns, rather than simple causal inferences.

For Studies 2 and 3, examining the impacts of green innovation on market value and supply base stability, the research leans towards a post-positivist approach. This emphasizes hypothesis-driven theoretical frameworks and rigorous quantitative methods, such as fixed-effect regression models, to validate hypotheses. This philosophical stance acknowledges the complexity and theoretical uncertainties inherent, allowing researchers to progressively approach facts and patterns through hypothesis testing, complemented by post hoc interview data to enhance robustness and explanatory power. Table 1.1 in the thesis summarizes the theoretical lenses and research methods employed across the studies.

Table 1.1 A summary of theoretical lenses and research methods used in the thesis

	Study 1	**Study 2**	**Study 3**
Theoretical lenses	• Socio-technical system theory	• Resource-based view • Stakeholder theory	• Recombinant search theory
Sample	• 41 Chinese LSPs • 2015-2021	• 53 Chinese LSPs • 2011-2020	• 88 Chinese LSPs • 2011-2019
Research methods	• LDA topic modeling • Interviews	• Fixed-effect regression models • *Post hoc* interview	• Fixed-effect regression models

1.5 Research Significance

The contributions of this thesis are summarized at the end of each study, with an in-depth discussion provided in Chapter 6. Here, we briefly outline the key contributions:

Study 1 advances the green logistics literature by identifying and classifying listed LSPs' green practices from an STS perspective, differentiating between technology-driven and social-driven green practices. Unlike previous studies that predominantly focus on technological aspects (Centobelli et al., 2017), this study identifies a spectrum of 18 green practice topics relevant to Chinese LSPs, with a notable presence of eight social-driven topics, such as regulatory compliance and environmental performance assessment. Second, it advances knowledge on green practices across different transportation modes, revealing distinct focuses for maritime, aviation, and road freight. Third, it explores the evolution of green practices in the logistics industry, highlighting a shift from efficiency-driven initiatives to innovative green technologies and multiple social-driven practices. Finally, it investigates the driving forces behind technology-driven and social-driven green practices, emphasizing the importance of technological maturity, market requirements, and legal compliance.

Study 2 sheds light on green logistics and innovation literature by empirically uncovering the inverted U-shaped impact of green innovation on market value in the Chinese logistics context, addressing a gap in existing research primarily focusing on manufacturing industries. It also highlights the boundary conditions of this relationship, revealing that supply chain partner engagement enhances the market value impact of green innovation, while scientific institution engagement and public attention diminish it. Finally, this study enriches the RBV and stakeholder theory literature by illustrating the interplay between green innovation, stakeholder engagement, and public attention in influencing the market value of LSPs.

Study 3 broadens green logistics and green innovation literature by empirically demonstrating that incremental green innovation enhances supply base stability in the Chinese logistics industry while radical green innovation diminishes it. Focusing on upstream supply chain impacts, this research addresses a gap in prior studies that mainly explored financial and environmental performance (Rehman et al., 2021; Wong et al., 2020). It enriches RST by differentiating the effects of local and distant knowledge searches on supply base stability, extending this theory into the supply chain management domain. Furthermore, it highlights the boundary conditions, showing that the top management team's growth orientation and board environmental expertise weaken the negative impact of radical green innovation on supply-base stability but do not affect the relationship between incremental green innovation and supply-base stability.

1.6 Structure of the Dissertation

This dissertation is organized into six chapters: introduction, literature review, Study 1, Study 2, Study 3, and Conclusions. The specific contents are as follows:

Chapter 1 sets the stage by elaborating on the practical and theoretical background, formulating the research questions and objectives, and highlighting the contributions of the thesis. It also introduces the overall structure of the dissertation.

Chapter 2 presents a comprehensive review of existing literature, identifies the gaps in current research, and provides a theoretical foundation for the studies conducted in this thesis. This chapter discusses the definitions and frameworks of green logistics, the definitions of green innovation, the relationship between green innovation and intra-firm performance, and the role of green innovation in the supply chain.

Chapter 3 investigates publicly listed Chinese LSPs from 2015 to 2021 to identify their green practices' classification, characteristics, and evolution in different transportation modes (including road, maritime, and aviation). This chapter combines topic modeling and interviews to analyze LSPs' CSR reports' environmental text, discussing theoretical and practical implications.

Chapter 4 examines the impact of green innovation on the market value of LSPs and explores the moderating effects of stakeholder engagement and public attention. It analyzes panel data from 53 publicly listed Chinese LSPs from 2011 to 2021, discussing theoretical and practical implications.

Chapter 5 investigates whether LSPs' incremental and radical green innovation exert differential effects on their SBS and further explores the moderating effects of growth orientation and board environmental expertise. This chapter analyzes data from 88 publicly traded Chinese LSPs from 2011–2019 and discusses the implications for theory and practice.

Chapter 6 comprehensively summarizes the dissertation's findings, synthesizing the research outcomes from the three interrelated studies. It further delves into the theoretical contributions of the thesis, exploring how the insights derived advance current understandings within the field of green logistics. The chapter also highlights the managerial implications, offering practical guidance. In addition, this chapter critically evaluates the limitations of the research conducted. It discusses potential weaknesses in research design, data sample, methodologies, and measurement techniques used throughout the studies. Finally, it outlines directions for future research.

Chapter 2 Literature Review

2.1 Green Logistics Management

"Logistics" is now a widely used term to describe activities mainly including the transportation, storage, and value-added services from the source of raw materials, through production systems, to final sale or consumption (McKinnon, 2010). It forms the cornerstone for the efficient and high-quality functioning of businesses, people's lives, and regional economies. On the other hand, the word "green" denotes products, services, and processes designed to achieve harmony with the environment (Milliman and Prince, 1989). Each term carries its distinct meaning, but when combined, they form a particularly evocative phrase, "green logistics", which refers to pursuing profitable growth in logistics operations and management while minimizing environmental damage (Lai and Wong, 2012). Identifying the exact origin of green logistics research is challenging. One potential starting point could be publishing the first environment-themed paper in a mainstream logistics journal. However, this perspective overlooks substantial early research on the environmental impact of freight transport that predates the recognition of logistics as an academic field. Concerns about the detrimental impact of freight transport were expressed as early as the 1950s, but most substantial research on this topic did not emerge until the mid-1960s. Murphy and Poist (2003) assert that before the 1960s, there was relatively little concern about environmental degradation in logistics management research. Aronsson and Huge Brodin (2006), in their review of ten logistics, supply management, and transport journals between 1995 and 2004, find that out of 2026 papers, only 45 (2.2%) addressed environmental issues.

Over the past two decades, increasing government and public attention to environmental issues has led to a growing body of research focused on the popular theme of green logistics. In this context, the research on green logistics has become more structured and mature. McKinnon (2010, 2018) has conducted extensive studies on green logistics and summarized these findings into a comprehensive green logistics framework. His framework offers practical strategies to reduce the environmental impact of the logistics system, which comprises five key components:

1. **Reducing the demand for freight movement**: Reducing the freight transport intensity of economic activity within the bounds of logistics management. By optimizing supply chains and logistics processes, businesses can minimize unnecessary freight movements and thus lower their overall environmental impact.
2. **Shifting freight to lower-carbon transportation modes**: Taking advantage of the wide variations in carbon intensity between different transportation modes. For example, shifting from road to rail or maritime transport can significantly reduce carbon emissions associated with freight transport.
3. **Improving asset utilization**: Effective use of vehicle and warehouse capacity. This involves maximizing the load capacity of transport vehicles and optimizing warehouse space utilization.
4. **Increasing energy efficiency**: Reducing energy consumption relative to freight tonne-kilometers and warehouse throughput. For example, fuel-efficient vehicles, aerodynamic modifications to trucks, and energy-efficient lighting and heating

systems in warehouses can contribute to significant energy savings.

5. **Switching to lower-carbon energy**: Reducing the carbon content of the energy used in logistics operations. This includes using renewable energy sources and alternative fuels to power logistics activities.

Grant et al. (2017) have also contributed substantially to the field with their work on sustainable logistics and supply chain management. Their framework complements McKinnon's by addressing additional aspects of logistics sustainability beyond the commonly discussed factors such as road mileage, fuel use, and GHG emissions:

1. **Reverse logistics**: This involves the process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption back to the point of origin. The goal is to recapture value or ensure proper disposal, thereby minimizing waste and promoting sustainability.
2. **Assessment of emissions**: Comprehensive emissions assessments are critical. This includes evaluating transportation emissions and those from warehouses and buildings to identify areas where reductions can be made.
3. **The 'greening' of logistical activities and supply chains**:

- *Transportation, vehicles, and infrastructure networks*: Increasing the adoption of new technologies, fuels, and processes and switching to more environmentally friendly transportation modes.
- *Green buildings*: Improving existing facilities through retrofitting green technologies, boosting investment in new building technologies.

- *Sourcing, product, and packaging design*: Reducing the carbon footprint designed into a product through carefully selecting raw materials, minimizing the production process's carbon intensity, and optimizing the supply chain's length and speed.
- *Administrative issues*: Implementing managerial solutions like carbon offsetting to manage and mitigate carbon footprints.

However, studies related to green logistics often focus on how the logistics systems of a country, region, or manufacturing enterprise can go green, with relatively limited attention given to the critical role of these systems, namely LSPs. Centobelli et al. (2017) conducted a systematic review of the environmental sustainability of LSPs. They found that, out of all the research conducted between 1960 and 2014, only 46 papers were relevant to LSPs' greenness. Since LSPs' direct involvement in the movement and storage of goods (Lai and Wong, 2012; McKinnon, 2010), their green transition is crucial for the overall sustainability of the logistics system. Moreover, the existing research on green logistics primarily emphasizes technological solutions to address environmental issues in logistics activities (Martinsen and Huge-Brodin, 2014; Perotti et al., 2012; Sureeyatanapas et al., 2018). Green innovation, as the source of green technologies, involves introducing new or significantly improved products and processes to reduce environmental issues (Karimi Takalo et al., 2021; Kunapatarawong and Martínez-Ros, 2016). Therefore, in this thesis, we conduct three interrelated studies to identify the green practices adopted by LSPs and examine both intra-firm and inter-firm effects of LSPs' green innovation.

2.2 Green Innovation and its Impacts on Firm Performance

As shown in Table 2.1, current research provides a mature understanding of green innovation, predominantly focusing on the impact of new technologies and processes on environmental protection. Thus, in our thesis, green innovation refers to the development and implementation of new or improved products, processes, and practices that significantly reduce environmental impact, conserve natural resources, and promote sustainability through the use of sustainable materials, renewable energy, and advanced technologies (Berrone et al., 2013; Dangelico and Pujari, 2010; Karimi Takalo et al., 2021; Rennings, 2000). The benefits of corporate green innovation on the external natural environment are undeniable. However, research on the intra-firm performance effect of green innovation varies across different industries, with most studies focusing on the manufacturing industries. Table 2.2 summarizes the research findings from various industries and regions on the relationship between green innovation and firm performance.

Most studies have found positive relationships between green innovation and firm performance. For instance, Ba et al. (2013) focus on the automobile industry and discovered that the stock market reacts positively to green innovations announced by car makers, highlighting that the type of innovation and market segment directly affect stock returns. Similarly, Eiadat et al. (2008) explored the chemical industry in Jordan and concluded that green innovation fully mediates the relationship between environmental pressure and firms' business performance. Leal-Rodríguez et al. (2018) identify that green innovation partially mediates the relationship between market orientation and operational and financial performance in the automotive component industry in Spain. In Japan, Lee et al. (2015) analyzed manufacturing industries and reported a positive market response to green innovation, emphasizing that the market rewards active pollution reduction strategies.

Additionally, Raza (2020) finds that regulatory pressure promotes green innovations that improve both environmental and economic performance in the sea shipping industry in Europe. Xie et al. (2019) report positive relationships between green product and process innovations and financial performance in heavily polluted manufacturing industries in China. Finally, Wong et al. (2020) highlight that green customer integration improves cost performance through green process innovation in Hong Kong.

However, some studies have found negative or non-significant relationships between green innovation and firm performance. Aguilera-Caracuel and Ortiz-de-Mandojana (2013) conducted a worldwide study across material, industrial, personal health, and technology industries. They found no significant improvement in financial performance for green innovative firms compared to their non-green counterparts. Wijethilake et al. (2018) report that green innovation does not significantly improve performance in Sri Lanka's manufacturing and services industries unless management control systems are extensively used. Moreover, Driessen et al. (2013), examining the chemical and food industries in the Netherlands, found that green innovation generally leads to lower financial and customer performance, possibly due to high development costs and market resistance to higher prices. These findings suggest that while green innovation is crucial for environmental sustainability, it may not always translate directly into financial gains or improved performance without complementary systems and strategies.

Despite substantial research efforts across various regions and industries, consensus remains elusive regarding the impact of green innovation on firm performance, with notably scant discussion in the logistics industry. The logistics industry in China, which commands a significant position in the global market due to its extensive freight volume, continues to be a massive contributor to GHG emissions (OECD, 2023). However, green innovation's effects on the performance of LSPs, whether positive, negative, or nonlinear, are still poorly examined. This deficiency necessitates critically exploring how LSPs can effectively strategize and implement green innovations. These identified gaps underscore the urgent need for more focused research on the intra-firm performance impacts of green innovation within the Chinese logistics industry.

Table 2.1 The definitions of green innovation

Authors	Definition
Rennings (2000)	"[Green] innovations consist of new or modified processes, techniques, practices, systems and products to avoid or reduce environmental damage. [Green] innovations may be developed with or without the explicit aim of reducing environmental damage. They also may be motivated by usual business goals such as reducing costs or enhancing product quality. Many [green] innovations combine environmental benefit with a benefit for the establishment or user"
Horbach (2008)	"[Green] innovation consists of new or modified processes, techniques, systems and products to avoid or reduce environmental damage"

Dangelico and Pujari (2010)	"[Green innovation] strive to protect or enhance the natural environment by conserving energy and/or resources and reducing or eliminating use of toxic agents, pollution, and waste"
Berrone et al. 2013)	"the development of products, processes, and services aimed at reducing environmental harm by using new methods for treating emissions, recycling or reusing waste, finding cleaner energy sources, and so on"
Shou et al. (2018)	"a specific kind of technical innovation that develops new or modified products, processes and practices to avoid or reduce environmental burdens"
Karimi Takalo et al. (2021)	"a process that contributes to the creation of new production and technologies with the aim of reducing environmental risks, like pollution and negative consequences of resource exploitation (e.g. energy)"

Table 2.2 A literature review on the relationship between green innovation and performance

Studies	Region	Industry	Dependent variable	Relationship
Aguilera-Caracuel and Ortiz-de-Mandojana (2013)	Worldwide	Material, industrial, personal health, and technology industries	Financial performance	N.S.
Ba et al. (2013)	Worldwide	Automobile industry	Stock returns	Positive
Driessen et al. (2013)	Netherlands	Chemical and food industry	Financial performance	Negative
Eiadat et al. (2008)	Jordan	Chemical industry	Business performance	Positive
Leal-Rodríguez et al. (2018)	Spain	Automotive component industry	Operational and financial performance	Positive
Lee et al. (2015)	Japan	Manufacturing industries	Financial performance	Positive
Raza (2020)	Europe	Sea shipping industry	Environmental and economic performance	Positive
Xie et al. (2019)	China	Heavily polluted manufacturing industries	Financial performance	Positive
Wijethilake et al. (2018)	Sri Lanka	Manufacturing and services industries	Operational and financial performance	N.S.
Wong et al. (2020)	Hong Kong (China)	Manufacturers and retail/trading industries	Cost performance	Positive

Note: N.S. = not significant

2.3 Green Innovation in the Supply Chain

Green innovation significantly impacts internal operations and performance within firms and plays an important role in the firms' supply chain networks. Melander and Pazirandeh (2019), through 11 case studies at high-technological global firms, observe that these organizations facilitate knowledge sharing on green innovation across industries via horizontal collaborations and extended networks, including interactions with suppliers and customers from disparate industries. This collaboration spans many green innovation projects for various objectives, culminating in improved resource efficiency.

A wealth of research has demonstrated how other supply chain members can catalyze a focal firm's commitment to green innovation. Firstly, considerable evidence indicates that customers' requirements and other characteristics can incite a focal firm to adopt more environmentally friendly innovations. Kesidou and Demirel (2012), utilizing a distinctive dataset of 1566 UK firms, argue that firms implement green innovations to fulfill the basic environmental expectations of customers and society. Huang et al. (2023) find that, among Chinese listed firms from 2006 to 2018, customer concentration positively impacted firms' green innovation, suggesting that firms are incentivized to engage in innovative green practices to maintain stable relationships with major customers. Additionally, Wei et al. (2023) observe that major customers committed to green development can enhance the green innovation of upstream suppliers by increasing purchases from green providers and providing resources to support suppliers' green innovation. Yang et al. (2024) analyze buyer-supplier dyadic relationships among Chinese listed manufacturing firms and discover that the tone of customers' annual reports promotes focal firms' green innovation. Wang et al. (2024)

identify that customer-driven voluntary environmental regulations lead to a contagion effect that significantly bolsters focal firms' green innovation. Secondly, the impact of industry peers on a firm's green innovation is documented. For instance, Kim and Springer (2008) report that the presence of foreign firms in the same industrial sector and locality augments the green innovation of local firms, corroborating the notion of environmental spillover effects. Yi et al. (2024) find that access to successful peers' green practices enables focal firms to engage in similar innovations. Lastly, the influence of supplier demands or characteristics on a focal firm's green innovation appears minimal. Yang and Jiang (2023) suggest that capacity slack and technology slack of suppliers indirectly reinforce the positive relationship between focal firms' environmental orientation and their green innovation.

Conversely, the green innovations of a focal firm can also impact its supply chain network and its members. Song et al. (2023) analyze 7104 firm-supplier-year observations for 183 unique focal firms and 407 suppliers over eight years in America, finding that higher emissions levels in a focal firm are associated with lower internal emissions levels in its customers. Crucially, focal firms' green innovation significantly contributes to this leakage effect. Wang et al. (2020) note that green innovation in focal firms has a positive effect on their relationship performance with customers—specifically, green innovation benefits relationships more significantly when customer participation and relational embeddedness are high. However, the volume of research exploring the inter-firm effects of green innovation remains relatively limited compared to studies focusing on intra-firm influences. Moreover, as LSPs are less science-based

(Meyer-Krahmer and Schmoch, 1998), their green innovations often require external technological support, which could influence the supply chain relationships and structure. Yet, this aspect lacks sufficient research attention.

Chapter 3 Study 1: Identifying Green Practices of Chinese Logistics Service Providers: Characteristics across Transportation Modes and Evolution Trend

3.1 Introduction

In alignment with the objectives set forth by the 2015 Paris Agreement, the logistics sector is identified as a significant contributor to GHG emissions, accounting for approximately 30% of the total emissions (USEPA, 2023). Beyond emissions, logistics activities also precipitate a wide range of environmental issues, including waste disposal, wastewater discharge, release of toxic substances, and noise pollution (Lin and Ho, 2011; Murphy and Poist, 2003). Regrettably, transportation emissions led to the premature deaths of 385,000 people in 2015, with an estimated health damage cost of up to 1 trillion dollars (ICCT, 2020). Given these alarming environmental impacts, the logistics sector must transition toward achieving net zero and embrace green development. This shift is not only necessary but also feasible, and our research aims to contribute to this transition by providing insights into the characteristics and evolution of green practices among LSPs.

Current research on green logistics predominantly focuses on the greening of logistics systems (Lai and Wong, 2012; Liu et al., 2020; McKinnon, 2010, 2018), with relatively less attention paid to stakeholders within these systems. Different stakeholders directly participate in logistics systems, including suppliers and customers of goods and LSPs, while other stakeholders influence or are impacted by logistics systems, such as governments and scientific institutions (Martinsen and Huge-Brodin, 2014). Notably, LSPs play a crucial role in connecting various components of logistics systems by offering services from basic transportation and warehousing to more complex logistics solutions (Centobelli et al., 2017; Lai, 2004; Liu and Lyons, 2011). As a result, environmental concerns are increasingly pressing for LSPs, as they directly confront major sources of environmental pollution within logistics systems (Perotti et al., 2012). Adopting green practices is becoming a viable strategy for LSPs to alleviate environmental degradation, particularly in handling the immense cargo flows from online sales (Kang et al., 2021). For example, to curb the excessive use of plastic bands and fossil fuels and the pollution caused, several Chinese LSPs, such as SF Express and ZTO Express, promote the use of dissolvable and recyclable packaging materials, reusable delivery containers, and electric vehicles and sustainable fuels (Cainiao, 2017).

Most research on the greening of LSPs has examined the drivers and barriers (Anderhofstadt and Spinler, 2019; Touratier-Muller et al., 2019) and performance effects (Layaoen et al., 2023) of green practices. While understanding these aspects is crucial, there is also an imminent need for a comprehensive framework of green practices that can serve as a vital reference for LSPs, considering their adoption and management of green practices. However, few studies have tried classifying LSPs' green practices (Centobelli et al., 2017). Figure 3.1 visualizes the relevant research streams in the current green logistics literature and pinpoints the research gaps this paper aims to address.

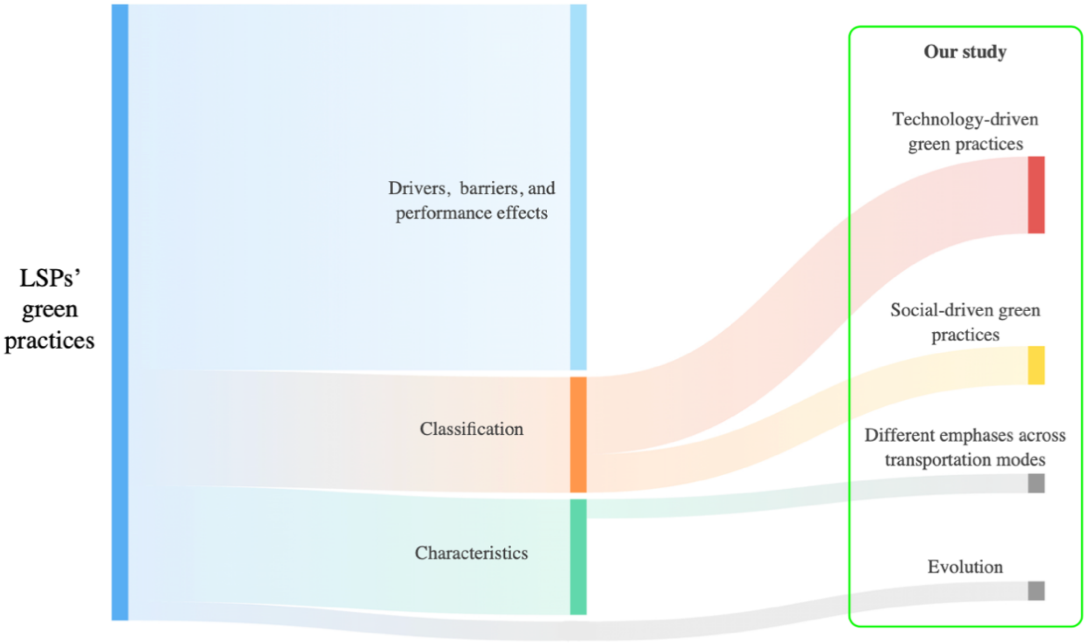


Figure 3.1 Research streams and gaps

First of all, prior studies on the classification of LSPs' green practices emphasize technical and operational practices during transportation and distribution processes (Martinsen and Huge-Brodin, 2014; Perotti et al., 2012; Sureeyatanapas et al., 2018), neglecting those associated with human behavior and social factors. Given the necessity for both technological advancement and societal adaptation for sustainable development, as emphasized by STS theory (Ruiz-Quintanilla and Freeman-Gallant, 1996), there is a compelling need for a more comprehensive framework that encompasses both social and technical dimensions of LSPs' green practices. Second, the current literature overlooks the differences in intensity or popularity between LSPs' green practices. Additionally, the unique characteristics of different transportation modes are rarely considered, leading to a significant gap in our understanding of how LSPs' emphasis on specific green practices might vary across these modes. Third, constrained by methodology and data, prior studies can only examine LSPs' green practices in a short period but not analyze these practices' evolution over time. Therefore, to narrow these gaps, we propose the following research questions:

RQ1 (Identification): What are the main green practices of LSPs in technical and social subsystems?

RQ2 (Characteristics): How does the emphasis on LSPs' green practices vary across transportation modes (including road, maritime, and aviation)?

RQ3 (Evolution): How and why do LSPs' green practices evolve?

To answer the above questions, China presents an ideal context for studying LSPs in developing countries, given its considerable efforts to modernize its logistics system. In addition, the total volume of Chinese freight has expanded almost sevenfold in the past two decades, reaching 15.25 million ton-kilometers in 2018, a figure that is nearly triple that of the United States (OECD, 2023). Examining the classification, characteristics, and evolution of Chinese LSPs' green practices is informative to academics and practitioners.

We conduct a probabilistic topic modeling method of the green practices of Chinese LSPs publicly listed on the Shanghai, Shenzhen, Hong Kong, and Taiwan Stock Exchanges from 2015 to 2021, covering three main transportation modes: road, maritime, and aviation freight. We employ the LDA topic model. This unsupervised machine learning method does not require predefined classification schemes to analyze "environmental" sections of LSPs' CSR reports. The LDA analysis yields 18 topics of green practices, including 10 technology-driven and 8 social-driven green practice topics. Furthermore, by comparing green practice topics in two periods, including the early (2015–2016) and later (2017–2021) periods, we elaborate on the evolution of these topics and identify emerging green practice topics. Finally, we complement these textual analytic-based observations with eight interviews to triangulate the LDA results and understand the factors affecting the priorities of different green practices across three transportation modes and the potential relationships between technology- and social-driven green practices.

This study makes several significant contributions to the green logistics literature. First, from the perspective of STS theory, it offers a holistic classification of green practices among Chinese LSPs. While previous studies are confined to technological approaches to address LSPs' environmental concerns (Centobelli et al., 2017), a classification of green practices considering both technical and social subsystems is lacking. Second, we conduct a quantitative analysis and identify the distinct emphasis on green practices adopted by LSPs in road, maritime, and aviation transportation modes, which remains underexplored in the relevant literature. Third, by analyzing topic evolution, we reveal a gradual shift in emphasis from cost-efficiency technologies to emerging green technologies and diverse social-driven green practices. Lastly, utilizing insights from interviews with eight LSPs, we validate and interpret the LDA results through industry experts' experience. We further portray the factors influencing green practices' adoption and relationships between technology- and social-driven green practices.

3.2. Literature Review

3.2.1. STS Theory and Green Practices

The STS theory is initially used to understand the complex interactions between social structure and technological content in the study of coal-getting mechanization (Trist and Bamforth, 1951). This theoretical framework proposes that organizations can be viewed as complex entities consisting of social and technical subsystems (Bostrom and Heinen, 1977). Specifically, the technical subsystem encompasses an organization's tools, devices, procedures, and technology. In contrast, the social subsystem comprises the human characteristics such as attitudes, behaviors, relationships, power, and norms of individuals and teams (Kull et al., 2013; Siawsh et al., 2021). Distinct from theories that isolate technological or social aspects, STS theory advocates for an integrated approach, emphasizing that optimal organizational outcomes are achieved when social and technical subsystems are developed concurrently (Ruiz-Quintanilla and Freeman-Gallant, 1996). Due to its comprehensive assessment of organizational dynamics, STS theory has been widely applied across various fields, such as operations management and information systems (Shou et al., 2021).

STS theory is also instrumental in environmental management. According to Ruiz-Quintanilla and Freeman-Gallant (1996), successfully addressing environmental issues involves technological solutions and necessitates considering organizational strategies and human factors. Liu et al. (2020) suggest that companies, especially in emerging markets, should prioritize behavioral approaches in their green supply chain practices before integrating technological practices to enhance economic, environmental, and operational performance.

The green practices of LSPs reflect their efforts to protect the environment by conserving natural resources and minimizing waste and pollution, which are achievable through various approaches such as efficient transportation and storage (Lai and Wong, 2012). From the perspective of STS theory, we categorize LSPs' green practices into two main types: social-driven and technology-driven. Social-driven green practices include individual, relational, behavioral, and other intangible actions taken to protect the environment within LSPs' operations, while technology-driven green practices involve technological, methodological, and other tangible measures.

3.2.2. Classification of LSPs' Green Practices

No single technology, software tool, or business practice currently exists or is foreseen that can comprehensively address the environmental challenges faced by the logistics industry (McKinnon, 2010, 2018). Therefore, McKinnon (2018) proposes a comprehensive green logistics framework consisting of five cornerstone strategies: (1) reducing the demand for freight movement; (2) shifting freight to transportation modes with lower carbon emissions; (3) enhancing asset utilization; (4) increasing energy efficiency; and (5) adopting lower-carbon energy sources. The foundational research by McKinnon (2010) and subsequent studies in green logistics (Lai and Wong, 2012; Liu et al., 2020b) has primarily concentrated on assessing and enhancing the environmental sustainability of regions and manufacturers' logistics systems.

Consequently, a notable absence of research focuses on specific stakeholders within the system that can implement the proposed environmental improvements. Particularly, LSPs, which perform a substantial portion of transportation and distribution activities, deserve more attention in the green logistics literature (Centobelli et al., 2017; Davarzani et al., 2016).

Through a systematic literature review on the environmental sustainability of LSPs, Centobelli et al. (2017) find that most of the existing studies focus on the factors influencing the adoption of green practices and the impact of green practices on LSPs' performance, and there are few papers concentrating on the classification of LSPs' green practices. Our analysis of the current literature, shown in Table 3.1, corroborates this observation, revealing a few studies exploring the classification of LSPs' green practices. For instance, Lieb and Lieb (2010), through a survey of 40 large LSPs across North America, Europe, and the Asia-Pacific region, delineate four types of green practices, encompassing administrative (e.g., establishing sustainability committees), analytical (e.g., environmental evaluation software), transportation-related (e.g., using alternative fuels, purchasing fuel-efficient vehicles, and promoting freight consolidation), and other practices (e.g., recycling office supplies and installing solar panels). Further, El Baz and Laguir (2017) interviewed 10 Moroccan LSPs, classifying four primary types of green practices according to LSPs' service phases: transportation and vehicle use (including fleet modernization, tour optimization, vehicle loading improvement, and alternative fuels), warehousing and handling (focusing on waste reduction and recycling), environmental training and control (e.g., eco-driving and environmental management system), and supply chain collaboration (e.g., supply chain reorganization). Later, Sureeyatanapas et al. (2018) conducted a survey targeting Thai LSPs operating in road transport. They categorize the green practices of LSPs into seven major classes based on the type of technology employed: vehicle routing optimization, eco-driving, alternative energy, modal shift, packaging reduction, reverse logistics, and green administration. Our comprehensive literature review highlights that technology-driven green practices related to transportation and distribution processes are widely adopted. In contrast, social-driven green practices are still neglected, which warrants further exploration.

3.2.3. Characteristics of Green Practices across Transportation Modes

Table 3.1 reports the current research on categorizing LSPs' green practices, which typically proposes a generalized classification framework. However, these classifications overlook the heterogeneity between transportation modes, such as variations in the types of goods transported, carbon intensity, and operational regions. First, the types of goods transported by different modes exhibit significant distinctions: road transportation primarily moves lighter manufactured and packaged goods; air freight is utilized for time-sensitive consignments with high-value density; waterborne modes handle heavy primary commodities such as coal, aggregates, cement, steel, oil, and chemicals (Rodrigues, 2018). Consequently, the average density of the freight moved varies significantly between modes, thereby leading to distinct carbon intensity across modes (McKinnon, 2018). Specifically, maritime transportation's carbon intensity is approximately one-tenth that of heavy-duty road vehicles and one-hundredth that of air transportation (ICCT, 2013).

Moreover, international freight's long-distance movement is overwhelmingly dominated by shipping, making maritime operations subject to a wide array of environmental regulations across different countries, as well as stringent international maritime guidelines from the International Maritime Organization (IMO), such as the Sulphur Cap and the Ballast Water Management Convention (Gollasch et al., 2007; Wan et al., 2016). Thus, LSPs operating maritime freight are under higher environmental regulatory pressure than their road and air freight peers. In summary, each transportation mode's unique characteristics create different environmental sustainability considerations for LSPs, leading to potentially differentiated focal points when implementing green practices.

Therefore, we have further summarized the green practices of LSPs in each transportation mode in Table 3.2. Consistent with the observations in Table 3.1, a substantial body of research focuses on technology-driven green practices, particularly those related to transportation equipment and operations. Meanwhile, although there are variations in green practices across road, maritime, and aviation freight, there remains a significant research gap in our understanding of the intensity of these practices within each mode. Therefore, this study aims to explore and quantitatively assess the intensity of green practices across each transportation mode to provide a holistic understanding of their implementation and effectiveness.

3.2.4. Research Gaps

The literature review concerning LSPs' green practices and classifications exposes several significant research gaps.

First, green logistics frameworks by McKinnon (2018) and prior studies on LSPs' green practice classifications emphasize technology-driven green practices, often focusing on transportation and distribution processes. Although some studies include categories like "internal management" and "others", the current classifications usually neglect social-driven green practices, highlighting a critical need for incorporating STS theory to understand both technological and social components of green practices.

Second, the existing studies often lack analyses of the intensity of different green practices adopted by LSPs. Additionally, there is insufficient examination of how the intensity of these practices differs across different transportation modes, each confronting unique environmental challenges.

Third, the evolution of green practices among LSPs is not instantaneous. The prevailing research methods, predominantly surveys and case studies, tend to examine only cross-sectional or short-term samples of LSPs, hampering the exploration of the evolutionary process in LSPs' green transformation. In addition, current studies collectively reveal a marked concentration on LSPs operating within the advanced logistics systems of Europe and North America. Given that China's logistics system has developed considerably over the past decade, it offers a valuable context for exploring the evolutionary process of greening LSPs in a developing country.

Table 3.1 Literature review on the classification of LSPs' green practices

Study	Classification of green practices	Classification criteria	Method	Country / Region	Transportation mode
Lieb and Lieb (2010)	Administrative; Analytical; Transportation-related; Other	Decision-making steps	Survey	North America, Europe, and the Asia-Pacific region	Not mentioned
Perotti et al. (2012)	Green supply; Distribution strategies and transportation; Warehousing and green building; Reverse logistics; Cooperation with customers; Investment recovery; Eco-design and packaging; Internal management	Phase of the service	Case study	Italy	Not mentioned
Pieters et al. (2012)	Internal approach; External approach; Innovation; Optimization	Firm strategies	Survey	Netherlands	Road
Martinsen and Huge-Brodin (2014)	Mode choice and intermodal transportation; Logistics system design; Transport management; Vehicle technology; Eco-driving; Alternative fuels; Environmental management systems; Choice of partners; Emission data; Efficient buildings; Other	Technology type	Case study	Europe	Not mentioned
El Baz and Laguir (2017)	Transport and vehicle use; Warehousing and handling; Environmental training and control; Supply chain collaboration	Phase of the service	Case study	Morocco	Road and maritime
Sureeyatanapas et al. (2018)	Vehicle routing optimization; Eco-driving; Alternative energy; Modal shift; Packaging reduction and reuse; Reverse logistics; Green administration	Technology type	Survey	Thailand	Road

Table 3.2 Literature review on LSPs' green practices across transportation modes

	LSPs' activities	Maritime freight		Road freight		Aviation freight	
		Practices	Studies	Practices	Studies	Practices	Studies
Tech-driven green practices	Transportation equipment	• Environment-friendly shipbuilding design (more efficient ship hulls, energy-saving engines, etc.) • Alternative fuels	(Lai et al., 2011; Psaraftis and Kontovas, 2010; Yang et al., 2013)3/26/25 6:03:00 PM	• Hydrogen and fuel-cell electric vehicles • Alternative fuels and vehicles	Kluschke et al. (2019); Li and Taghizadeh-Hesary (2022); Maas et al. (2014); Meyer (2020); Sureeyatanapas et al. (2018); Zhang and Fujimori (2020)	• New generation aircraft (improvement in engine, aerodynamics design, etc.) • Alternative fuels	Miyoshi and Mason, (2009); Sgouridis et al. (2011)
	Transportation operations	• Speed optimization (e.g., slow steaming) • Optimized routing • Improved fleet planning	Balcombe et al. (2019); Cariou (2011); Psaraftis and Kontovas (2013, 2010); Yang et al. (2013)	• Route optimizations • Last-mile solutions • Full vehicle loading • Eco-driving	Maas et al. (2014); Meyer (2020); Sureeyatanapas et al. (2018)	• Flight paths optimization • Green fleet planning • Lower flight altitudes • Loading optimization	Abdullah et al. (2016); Justin et al. (2022); Khoo and Teoh (2014); Miyoshi and Mason (2009); Ryerson et al. (2014); Scheelhaase et al. (2016); Sgouridis et al. (2011); Sobieralski (2023); Wen (2013)
	Logistics service	• Recycling of abandoned containers and waste • Eco-labeling of shipping crates	Lai et al. (2011); Yang et al. (2013)	• Packaging and material recycling • Reverse logistics	Maas et al. (2014); Sureeyatanapas et al. (2018)	• Onboard and ground waste recycling upcycling	Salesa et al. (2023)
	Company infrastructure	• Energy-efficient port	Lee and Nam (2017); Peris-Mora et al. (2005)	• Energy-efficient warehousing (e.g., solar panels in warehouses)	Maas et al. (2014)	• Ground operation optimization	Abdullah et al. (2016); Ryerson et al. (2014); Sgouridis et al. (2011)

Social-driven green practices	Company policy and management	• Clear environmental policy statement • Environmental management system • Cross-functional cooperation for green practices	Lai et al. (2011); Yang et al. (2013)	• Environmental management system • Employee training • Environmental advertising • Environmental performance measurement	Maas et al. (2014); Sureeyatanapas et al. (2018)	• Environmental management system	Abdullah et al. (2016)
	Supply chain management	• Green collaboration with suppliers, partners, and customer	Lai et al. (2011); Yang et al. (2013)	• Green collaboration with suppliers, partners, and customer	Maas et al. (2014)		
	Marketing					• Carbon pricing and emission trading	Anger (2010); Scheelhaase et al. (2016); Sgouridis et al. (2011)
	Compliance with regulation	• IMO regulations • Emission regulations for Sulphur oxides (SOx) and nitrogen oxides (NOx)	Chu Van et al. (2019); Lindstad and Eskeland (2016)				

3.3. Methodology

This study adopts a mixed-methods approach that combines quantitative topic modeling with qualitative interviews to comprehensively examine the green practices of Chinese publicly listed logistics enterprises from 2015 to 2021. The rationale for integrating these two methods is that LDA topic modeling offers a bottom-up, data-driven way to uncover hidden or emerging themes in corporate reports, while interviews provide deeper contextual insights into the underlying drivers and decision-making processes. By merging these quantitative and qualitative perspectives, the study gains both breadth (via large-scale text mining) and depth (through expert interviews), thus achieving a more holistic understanding of green practices.

First, Latent Dirichlet Allocation (LDA) topic modeling is applied to the "Environmental Protection" sections of corporate social responsibility reports published by listed LSPs. A key advantage of the LDA model is that it does not require predefined classification schemes. Instead, it leverages machine learning algorithms to automatically identify latent topics in the text data, thereby extracting core content related to green practices (Chae and Olson, 2021). This bottom-up analysis method allows researchers to uncover new and potentially unexpected topics related to green practices. Adopting such an approach, this study discovers critical green practice topics, explores topic characteristics and their evolution, and visualizes these results. However, because LDA is an unsupervised learning method, it cannot illuminate the motivations and logic behind these changes. Therefore, the study incorporates an in-depth qualitative component: semi-structured interviews with eight industry experts. By analyzing the interview data, the study elucidates how multiple factors collectively drive the green transformation of LSPs. Figure 3.2 depicts the flow of this LDA–interview approach.

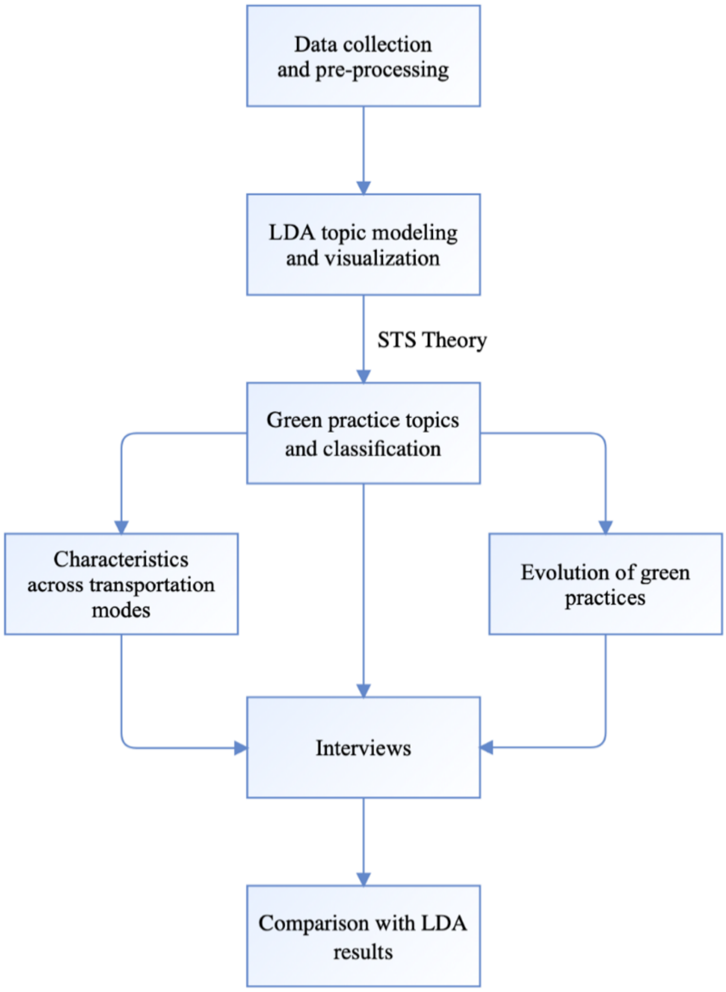


Figure 3.2 Flowchart of the LDA–interview method

3.3.1. Data Collection

A database of LSPs is compiled from the transportation or shipping sectors of the Shenzhen, Shanghai, Hong Kong, and Taiwan Stock Exchanges. As many of the firms listed under these sectors are engaged in transportation investment and infrastructure development, this paper restricts the selection of LSPs to those that must operate in at least one transportation mode: road, maritime, or aviation freight. Furthermore, duplicates (i.e., companies listed in more than one stock exchange) are removed, resulting in an initial sample of 92 listed LSPs.

Notably, almost no Chinese LSP released CSR reports before 2015. Then, the 2015 Paris Agreement spurred the development of environmental regulations and policies across the Chinese region (OECD, 2019). Therefore, we download the official CSR reports from the websites of the Stock Exchanges and the LSPs from 2015 to 2021. As Piecyk and Björklund (2015) find that only 13% of international LSPs had published CSR reports, we observe a similar scarcity among Chinese-listed LSPs. After further filtering out LSPs without published CSR reports or related reports lacking an environmental section, the sample retains 41 LSPs. Typically, an LSP issues no more than one official CSR report annually. To avoid duplicates, only the reports in Chinese version are considered, and reports written in other languages are dropped. Finally, the corpus encompasses 214 CSR reports, encapsulating over ten thousand pages, as summarized in Table 3.3.

Table 3.3 Sample overview

Report distribution by year	Frequency	%	Report distribution by region	Frequency	%
2015	14	6.54	Mainland	96	44.86
2016	23	10.75	Hong Kong	50	23.36
2017	27	12.62	Taiwan	68	31.78
2018	33	15.42	Total	214	100
2019	37	17.29			
2020	40	18.69			
2021	40	18.69			
Total	214	100			

3.3.2. Data Pre-processing

Before analyzing the contents of the CSR reports, it is necessary to perform various text pre-processing steps, as outlined by Goloshchapova et al. (2019). Pre-processing steps include removing non-linguistic elements such as photos and images and removing special symbols, numbers, dots, and space characters. In addition, we construct a list of "stop words" that will be dropped during textual analyses. This list encompasses commonly used Chinese stop words, company names, and geographic names. Some words (e.g., sustainability, social responsibility, green, etc.) are used too often by companies in CSR reports' environmental sections and therefore are also eliminated. Finally, some common words with no real meaning are removed in the iteration process.

Moreover, traditional LDA ignores some of the semantic features nestled within the complex structure of lengthy documents. The text chunk size is inversely proportional to the optimal number of inferred topics (Sbalchiero and Eder, 2020). The deconstruction of lengthy documents laden with diverse topics enhances LDA's precision in topic identification, thereby augmenting topic clarity and understanding (Guo et al., 2021). Considering the amalgamation of varied green practices within CSR reports, pinpointing these practice topics amidst voluminous text poses a significant analytical challenge. These CSR reports also comprise diverse sections, including corporate governance, employee welfare, environmental protection, etc.

Meanwhile, observing the 'Environment' sections reveals a structured delineation of diverse green practices by LSPs across subsections, each featuring specific green practices of substantial variation. For instance, SF Express, a leading LSP, divides its CSR report's 'Environment' section into three subsections: 'Climate Change Governance Strategy', 'Green Logistics', and 'Circular Economy'. Therefore, to effectively capture the characteristics of LSPs' green practices, we focus exclusively on the 'Environment' section of CSR reports and further partition the text by its chapter structure. The resultant corpus, which has 879 rows, with each representing a "green" section in a CSR report, is then compiled into a CSV file for the following LDA topic modeling analysis.

3.3.3. Topic Modeling

The LDA algorithm is a popular generative probability modeling method for identifying hidden topics from documents or corpora (Chae and Olson, 2021). Blei (2012) states that the documents and their constituent words are directly observable, and the topic distribution and each word's distribution within individual topics are viewed as hidden structures. Consequently, LDA's primary objective is to unearth this latent structure from the observed text.

Figure 3.3 shows LDA's graphical model, which describes its generative process. Each node is a random variable labeled according to its role in the generative process. The *D* plate denotes the total number of documents in the corpus; the *N* plate denotes the collection of words within documents; $W_{d,n}$ is the only observable variable representing the *n*th word in document d; α is the parameter of the Dirichlet before the topic distribution; θ_d is the topic proportion for the d-th document; $Z_{d,n}$ is the topic assignment for the nth word in document d; K is the specified number of topics; β_k is a distribution over the vocabulary; η is the parameter of the Dirichlet before the word distribution. Thus, LDA is a method for visually clustering words that often co-occur in the same document into one class.

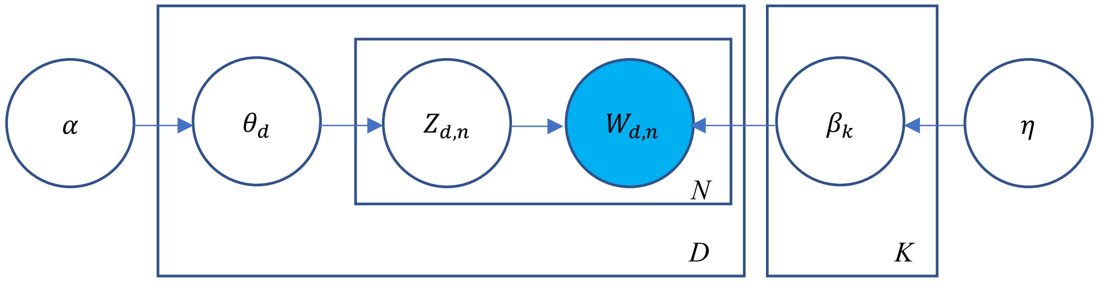


Figure 3.3 Graphical model of LDA

Moreover, this study utilizes perplexity to determine the optimal number of topics (Grün and Hornik, 2011), with lower perplexity suggesting superior LDA model performance (Y. Du et al., 2020). However, as the number of topics increases, the perplexity generally decreases. Figure 3.4 reveals a narrower fluctuation in perplexity between 16 and 20 topics, suggesting that this range is a suitable reference for the optimal number of topics. We broaden our exploration by adjusting the topic count from 10 to 25, observing the subsequent alterations in model performance and topic interpretability. This approach balances model fit (indicated by perplexity) and the interpretability and significance of the topics. Following this iterative procedure, an 18-topic model is identified as the most effective representation of the green practice diversity within Chinese LSPs. Finally, we apply *LDAvis* to fine-tune and visualize the results of the LDA model.

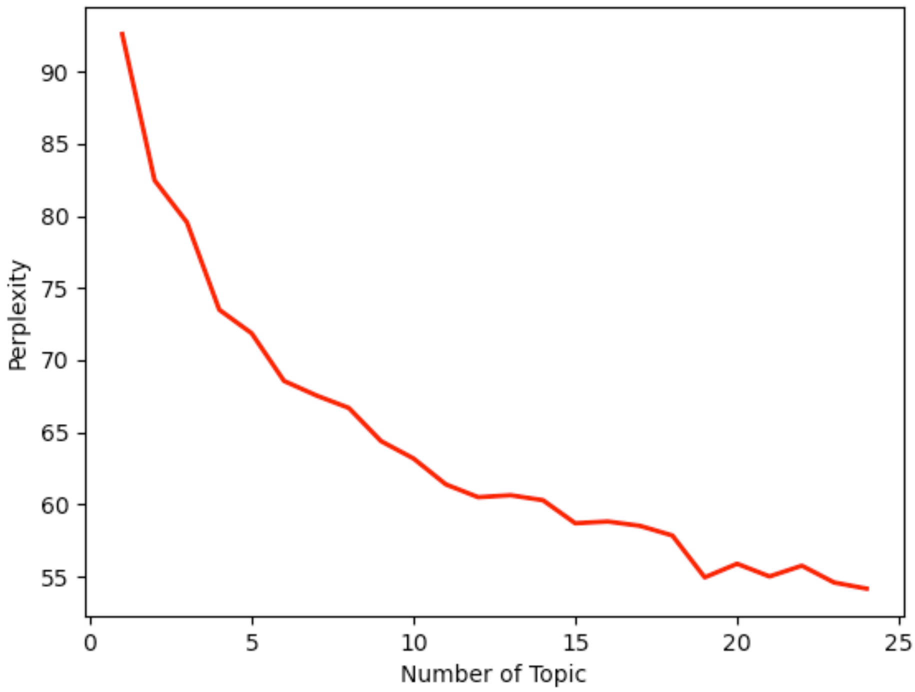


Figure 3.4 Perplexity with different topic numbers

3.3.4. Interviews for Triangulation

One potential limitation of the analyzed textual data from LSPs is that it may only partially reflect the actual green practices conducted, as it is based on what LSPs choose to convey to their stakeholders. This discrepancy could lead to a phenomenon known as “greenwashing”, where companies overstate their green practices to meet stakeholder expectations without substantiating their claims with concrete actions (Delmas and Blass, 2010; Piecyk and Björklund, 2015).

To address this concern, interviews were conducted with senior executives at eight Chinese LSPs to triangulate the LDA findings. These executives include top-level managers such as Chief Technology Officers and Vice Presidents/Directors. The LSPs represented in these interviews include three listed courier express companies involving aviation and road transportation, another three focusing on road transportation, and two liner-shipping companies. Initially, as a warm-up, background questions were asked about the executives' experiences and employment histories (Chuang et al., 2019), aiming to ensure the executives understood our study's objectives and encouraged frank responses to our inquiries.

The core questions of the interview aimed to identify the characteristics and evolution of these LSPs' green practices. Specifically, we did not disclose the LDA results initially to avoid biasing executives' responses (Chuang et al., 2019). Instead, we inquired about the green practices currently implemented by these LSPs. We then asked about the specifics of implementation and the challenges associated with the top green practice topics for different transportation modes identified by the LDA analysis. Additionally, the interviews aimed to identify the factors influencing these LSPs to adopt technology-driven and social-driven green practices. We further explored why adopting green practices may vary across various transportation modes.

3.3.5. Research Quality

In this research, the LDA topic modeling process selects listed LSPs operating exclusively within the Chinese regions. Several compelling reasons justify our selection of the Chinese region as a research context. First, the inland freight volume in China is currently the highest globally (OECD, 2023), and seven out of the top ten busiest container ports in the world are in the Chinese region, including Shanghai, Ningbo, and Hong Kong (World Shipping Council, 2024). This massive volume of freight transportation poses various environmental challenges that urgently need to be addressed, making the greening of LSPs in China crucial. Second, following the Paris Agreement, various regions in China have initiated environmental plans and strategies to combat these environmental challenges. Notable among these are Mainland China's 13th Five-Year Modern Comprehensive Transportation System Development Plan, Taiwan's Air Pollution Control Strategy, and Hong Kong's Climate Action Blueprint 2030, all of which were introduced in 2017. These strategies include specific measures for environmental protection within the logistics industry, providing a reference point for LSPs' green transformation.

Subsequently, our research utilizes semi-structured interviews to enhance the credibility of the LDA analysis results. In addition, the analytical work for this study is collaboratively conducted by all authors, and triangulation among these analysts further improves the research quality (Patton, 2014). Although this study focuses specifically on LSPs within the Chinese region, the findings are meaningful to LSPs in other regions.

3.4. Green practices of Chinese LSPs

3.4.1. LDA Analysis Results

As depicted in Figure 3.5, *LDAvis* provides a two-dimensional quadrant diagram, revealing a distinct structure in the distribution of the identified 18 topics. First, by observing the sizes of the circles representing different topics, we notice a significant difference in the intensity of various green practice topics. Specifically, the larger the circle, the greater the topic's intensity. Second, the less overlap between the circles implies that these topics are relatively distinct. This separation indicates a clear distinction between the various green practices undertaken by Chinese LSPs.

The LDA model is an unsupervised machine-learning method, so human involvement is necessary to label the topics. Two authors of this study label the topics based on the 20 most important words within each topic. As detailed in Table 3.4, each topic's green practice topics and relevant keywords are displayed following topic prevalence, aligning with the order presented in Figure 3.5. During the labeling process, several green practice topics pertain to a specific transportation mode; thus, these topics are initially classified into road, maritime, aviation, and general categories. Following the STS theory, these green practice topics are also subsequently categorized: eight social-driven green practices and ten technology-driven green practices.

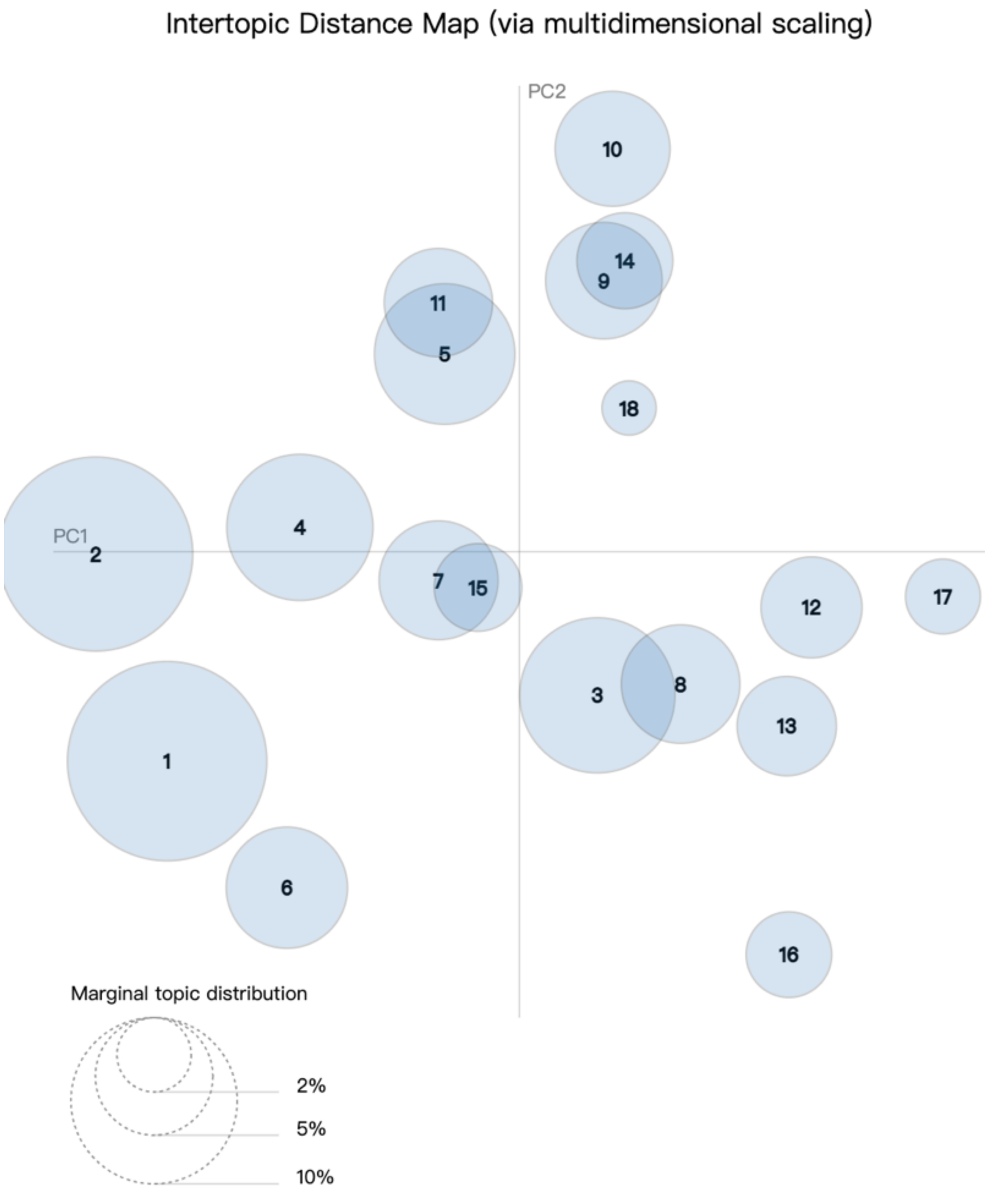


Figure 3.5 Visualization of topics

Table 3.4 Topic descriptions of green practices

	Topic	Transportation mode	STS category	High-frequency keywords
1	Energy efficiency improvements for ships	Maritime	Technology-driven	Ships, fleet, navigation, fuel, energy, efficiency, energy efficiency, ship type, ship speed, shipbuilding, power systems, fuel technology, etc.
2	Compliance with regulations	Maritime	Social-driven	Ships, garbage, ballast water, waste, regulations, legal rules, international conventions, standards, classification norms, marine creatures, IMO, etc.
3	Energy efficiency improvements for aircraft	Aviation	Technology-driven	Aircraft, fuel, energy, efficiency, engines, ground operations, fleet, aircraft types, winglets, retrofit, refinement, routes, weight reduction, taxiing, maintenance, etc.
4	Environmental performance assessment	General	Social-driven	Greenhouse gases, emission volume, calculations, carbon footprint, electricity, verification, energy consumption, office, volume, etc.
5	Environmental groups and committees	General	Social-driven	Environmental risk, management systems, teams, committees, meetings, policy, groups, employees, risk management, trends, etc.
6	Ship emissions	Maritime	Technology-driven	Ships, emissions, fuel oil, oxides, nitrogen oxides, emission volume, low sulfur, sulfur content, ozone layer, desulphurization, etc.
7	Fuel conservation for aircraft	Aviation	Technology-driven	Aviation, fuel, fuel conservation, aircraft, fuel efficiency, fleet, committees, groups, aircraft type, replacement, etc.
8	Vehicle technology	Road	Technology-driven	New energy, vehicles, electric vehicles, intelligent driving, truck models, logistics, automotive, electric, requirements, driver, etc.
9	Green supply chain cooperation	General	Social-driven	Suppliers, customers, waste, recycling, sourcing, materials, supply chain, solutions, commitments, etc.
10	Employee environmental training	General	Social-driven	Resources, employees, water conservation, paper, air conditioning, electricity consumption, paper use, recycling, warehouse, etc.

11	Three types of waste	General	Technology-driven	Waste, emissions, exhaust gases, disposal, noise, wastewater, reduction, greenhouse gases, collection, recycling, prevention laws, etc.
12	Green packaging	Road	Technology-driven	Packaging, express, recycling, environmentally friendly plastic, tape, reduction, usage, bags, etc.
13	Environmental certification	General	Social-driven	Management system, audit, emission reduction, certification, management procedures, improvement, lean, organization, environmental factors, responsible, evaluation, management center, subordinate, structure, etc.
14	Energy and consumables conservation	General	Technology-driven	Resource consumption, energy, packaging materials, reduction, consumption, indicator, fuel, electricity, effectiveness, efficiency, water, daily, electricity use, etc.
15	Alternative fuels	Aviation	Technology-driven	Biofuel, aviation, facilities, fuel, water, ecology, alternative, airbus, emissions, nature, conversion, etc.
16	Aviation carbon management and public engagement	Aviation	Social-driven	Carbon trading, aviation, carbon offsets, blue sky, flights, emission reduction, compliance, participation, aviation industry, green way, agreement, public interest, foundation, etc.
17	Environmental awareness promotion	General	Social-driven	Awareness, concept, advocacy, culture, office, topics, public, knowledge, promotion, communication, platforms, etc.
18	Arctic navigation	Maritime	Technology-driven	Arctic, natural resources, shipping lanes, fuel, synergy, cruising, etc.

3.4.1.1. Social-driven Green Practices

- *Legal compliance*

For social-driven green practices, our analysis first identifies Topic 2 as 'Compliance with regulations' in the maritime freight mode. Given the international nature of shipping operations, adhering to global and regional environmental regulations, such as the Ballast Water Convention and Sulphur Cap, is paramount. Primarily, these regulations mitigate the negative impact of maritime transportation activities on the environment. For example, the Ballast Water Convention helps prevent the spread of potentially harmful aquatic organisms and pathogens in ships' ballast water. Non-compliance with these regulations not only leads to severe environmental consequences but also gives rise to significant legal and reputational risks for shipping companies.

- *Internal social green practices*

Second, our analysis identifies multiple topics related to social green practices within LSPs. These topics reflect a comprehensive internal focus on environmental sustainability, encompassing assessment, committees, and training to enhance LSPs' environmental performance. Specifically, Topic 4 represents 'Environmental performance assessment'. This topic suggests that LSPs put considerable emphasis on monitoring and evaluating their environmental footprint, energy use, and waste volume, indicative of an intrinsic motivation to comprehend and minimize their environmental impact. Another internal social green practice is presented in Topic 5, labeled as 'Environmental committees and groups'. This topic signifies the existence of dedicated teams or groups within organizations devoted to promoting environmental sustainability. Topic 10, labeled as ‘Employee environmental training’, highlights the importance firms place on equipping their staff with knowledge and skills to adapt and propagate green practices in their daily duties.

Moreover, Topic 13, termed ‘Environmental certification’, emphasizes adopting standards such as ISO14001 and ISO50001. These certifications reflect a commitment to certain recognized environmental management standards. Specifically, they encompass policies, procedures, processes, and resources needed for implementing effective environmental management.

- *External social green practices*

Finally, some social green practice topics also pertain to relationships with external stakeholders. Topic 9, labeled as ‘Green supply chain cooperation’, sheds light on the significant efforts that LSPs devoted to collaborating with their suppliers and customers to establish green supply chains. This cooperation entails initiatives such as environmentally friendly sourcing, circular logistics practices, etc. These actions exemplify the shift toward more inclusive and collaborative green practices that extend beyond the organization’s boundaries, thus aligning the entire supply chain with environmental sustainability objectives. Topic 16, labeled ‘Aviation carbon management and public engagement’, implies the aviation sector’s efforts to manage the carbon footprint while engaging the public in their environmental initiatives. Topic 17, termed ‘Environmental awareness promotion’, hints at efforts by organizations to raise public consciousness about environmental issues and green practices. This topic mainly includes organizing public campaigns, educational seminars, and social media outreach to spread awareness and garner public support for environmental sustainability.

These topics focus on social-driven green practices that engage internal and external stakeholders, emphasizing the indispensability of internal initiatives, legal compliance, and collaborations in achieving comprehensive sustainability goals.

3.4.1.2. Technology-driven Green Practices

LSPs can develop green technologies to improve efficiency through logistics optimization, waste reduction, and energy-efficient transportation equipment modifications (Sureeyatanapas et al., 2018). Moreover, some emerging green technologies are essential for LSPs to achieve the objective of net zero carbon dioxide emissions for freight transport (Kang et al., 2021; Zhang and Fujimori, 2020). Our analysis also shows that LSPs in China are making strides in both harnessing operational efficiency and adopting emerging decarbonization technologies to carve a sustainable future for the logistics industry.

- *Efficiency improvement practices*

As for technology-driven green practices, our analysis unveils two main categories, one of which highlights efforts to reduce waste and enhance operational efficiency. The focus is predominantly on fuel and energy efficiency improvements, which are reflected in various topics. For example, Topic 1 pertains to ‘Energy efficiency improvements for ships’. This area involves measures like optimal speed management, adoption of energy-efficient ship types, optimization of power systems, and advanced fuel technologies. Similarly, Topic 3 represents 'Energy efficiency improvements for aircraft'. This area can be achieved through flight route optimization, implementing green flying practices, using lighter materials and advanced engine technologies, and retrofitting aircraft with energy-efficient technologies. Topic 6, labeled 'Ship emissions', concerns management and reduction of emissions generated by ships, indicating a keen interest in easing the environmental impact of shipping activities. Topic 7, labeled 'Fuel conservation for aircraft', emphasizes the methods and strategies used by the airlines to reduce fuel consumption, thereby lowering GHG emissions and boosting energy efficiency.

Moreover, another remarkable practice is evident in Topic 11, termed 'Three types of waste'. This topic highlights the efforts made by LSPs to manage different types of waste in an environmentally friendly manner, emphasizing the adoption of recycling and reuse practices. Topic 14, denoted as 'Energy and consumables conservation', reflects measures implemented by LSPs to conserve energy and materials, promoting sustainable resource use within the logistics industry. Topic 18, named 'Arctic navigation', hints at exploring new shipping lanes in the Arctic. This area reflects organizational efforts to identify shorter routes to improve maritime transportation efficiency. These technology-driven green practices collectively demonstrate how LSPs bolster operational efficiency while mitigating environmental damage.

- *Emerging decarbonization technologies*

Our analysis also draws attention to several emerging decarbonization technologies. Topic 8 focuses on the deployment of 'Vehicle technology'. This topic primarily focuses on two technologies: new energy vehicles (NEVs) or electric vehicles

(EVs) and autonomous driving technology. The penetration rate of EVs in China has increased rapidly, surpassing 20% by 2022. Compared to traditional fuel vehicles, EVs have a higher adoption rate of autonomous driving in China (McKinsey, 2023). Likewise, Topic 12, titled ‘Green packaging’, points to LSPs’ efforts to minimize material waste and enhance recyclability through advanced packaging solutions. In the same vein, Topic 15, labeled as ‘Alternative fuels’, sheds light on the use of alternative fuels. These renewable energy sources, often derived from organic materials, present a promising approach to reducing carbon emissions in logistics operations. These topics highlight LSPs’ proactive efforts to leverage innovative, technology-driven practices for decarbonization.

3.4.1.3. Different Emphases on Green Practices across Transportation Modes

Our analysis reveals that green practices across transportation modes have varied priorities and focal points. Green practices in maritime transportation are primarily centered around energy efficiency (Topic 1) and legal compliance (Topic 2). Given the huge energy demands of ships and the stringent regulatory landscape in maritime transportation, it is critical to adhere to laws while embarking on energy-efficient practices. In the aviation logistics sector, green practices focus on improving energy efficiency (Topic 3). The aviation industry, characterized by its highest carbon intensity, shows strong interest in adopting green practices that can boost fuel efficiency and reduce environmental damage.

In contrast, the road freight sector is prominently concerned with deploying new vehicle technologies (Topic 8) and green packaging (Topic 12). This focus likely reflects the sector's capabilities to adopt newer technologies rapidly and directly interact with end consumers, necessitating environmentally friendly packaging solutions. These differential foci of green practices across different transportation modes highlight each sector's unique characteristics and challenges in its journey toward environmental sustainability.

3.4.1.4 Green Practice Evolution

The 2015 Paris Agreement has spurred the development of environmental plans and policies across the Chinese region from 2015 to 2016. Consequently, a significant shift has also occurred in these two years as numerous LSPs began to disclose environmental content in their CSR reports. Therefore, as illustrated in Figures 3.6 and 3.7, our topic analysis of the textual data from 2015-2016 only yields eight green practice topics. We compare these findings with results from the entire sample to discern deviations. The topics already present during 2015-2016 are marked in blue, while the newly emerged topics in subsequent years are indicated in green. The period from 2015 to 2016 predominantly features technology-based green practices to reduce operating costs and enhance efficiency. The only identified social-driven green practices during this period are legal compliance for shipping companies and environmental certification. This area emphasizes ‘low-hanging fruit’ technologies to address environmental concerns.

The subsequent evolution of green practices is characterized by two main categories: emerging green technologies and social green practices. Emerging green technologies, such as advanced vehicle technology and alternative fuels, represent innovative technical solutions mitigating the environmental damage of logistics operations. In addition, the rise of social green practices indicates a shift toward a more inclusive approach to pursuing environmental sustainability.

Among various transportation modes, LSPs in the maritime sector are the earliest to stabilize their green practice categories. This early and persistent adoption is primarily due to the extensive regulatory landscape and the global nature of shipping operations, which necessitate a proactive approach to pursuing environmental sustainability. Following the maritime sector, the aviation sector has also made significant strides in green practices, likely driven by its considerable energy consumption and the increasing public and regulatory pressure to alleviate its caused environmental damage. The road transportation sector has been the latest to develop and stabilize its green practice categories. This delay may be attributed to the emergence of new vehicle technology and green packaging in recent years.

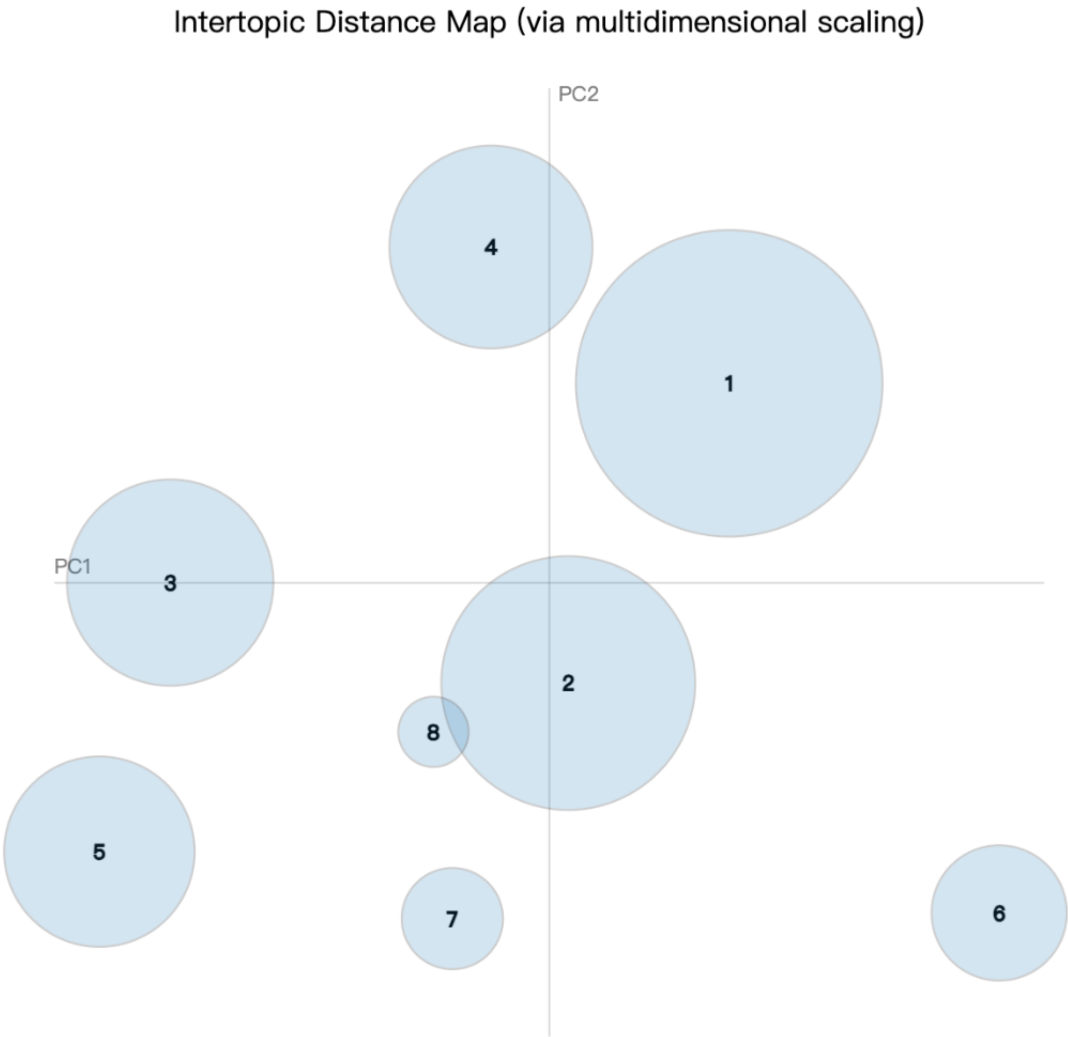


Figure 3.6 Topic distribution in 2015–2016

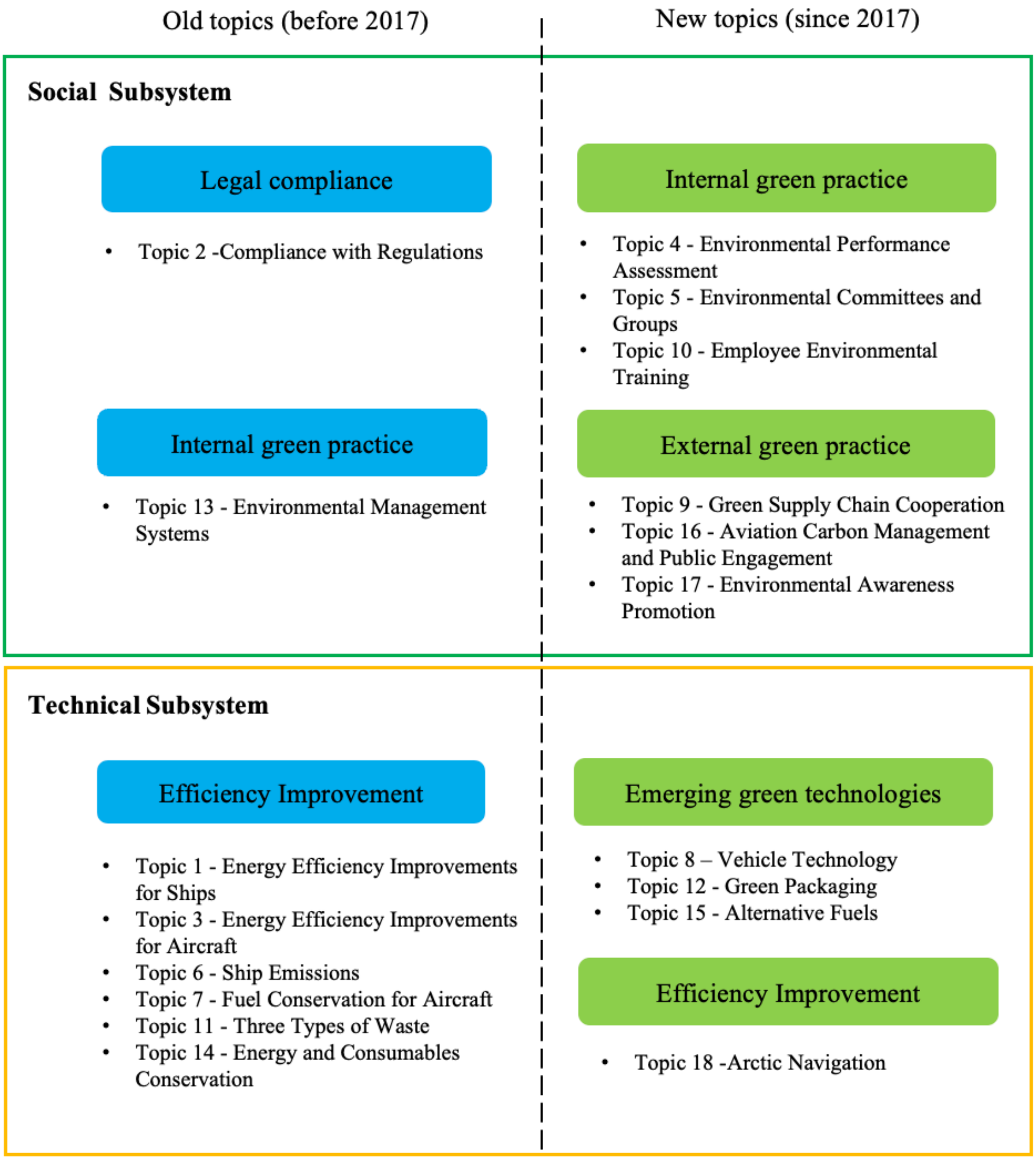


Figure 3.7 Evolution of Chinese LSPs' Green Practices

3.4.2. Interviews

3.4.2.1 Technology-driven Green Practices and their Influencing Factors

Our interviews showed that adopting technology-driven green practices exhibits variation based on different transportation modes. In the context of road freight, despite our prior findings highlighting Topic 8 'Vehicle technology', and Topic 11 'Green packaging', deploying these technologies has also encountered hurdles. For 'vehicle technology', particularly NEVs and EVs, the vice president of a listed express firm articulated, *"We have invested substantially to promote the use of hydrogen fuel cell vehicles, but insufficient hydrogen refueling stations outside designated test areas hinder its current application. Nevertheless, we deem electric light trucks to have achieved a satisfactory technological maturity, leading us to order 10,000 units, which resonated across the Chinese logistics and automotive industry."* This indicates that adopting electric light trucks in road freight is widespread yet confined to medium and short-haul transportation scenarios due to technological constraints.

Meanwhile, regarding autonomous driving technology within 'vehicle technology', a senior executive from a road freight LSP mentioned, *"It is often challenging to correct drivers' habits, so compared to traditional eco-driving training, we are more optimistic about the reduction in fuel consumption enabled by autonomous driving. However, autonomous driving technology is still immature and can only be used on a small scale in specific scenarios, such as port area transportation and designated autonomous driving lanes."* The immaturity of the technology is hindering the widespread adoption of autonomous driving.

Furthermore, regarding Topic 11 'Green packaging', the CTO of a road freight enterprise noted, *"In the field of green packaging, our focus is primarily on packaging reduction. The prospect of biodegradable packaging is not currently on our investment radar. We envision recyclable packaging as a future trend contingent on governmental endorsement and collaborative efforts from upstream and downstream entities."* The high cost of degradable materials impedes their application, with these LSPs primarily adopting packaging reduction strategies.

For maritime transportation, our analysis reveals that green practices are mainly centered on Topic 1 ‘Energy efficiency improvements for ships’. The general manager of a shipping firm commented on their efforts to reduce fuel consumption via energy-efficient ship modifications. However, the adherence to optimal speeds during voyages is compromised to avoid incurring demurrage charges, given the escalating pressure to fulfill cargo orders promptly. Meanwhile, the manager highlighted the financial burden of adhering to low-sulfur fuels, emphasizing that the current economic climate, exacerbated by the COVID-19 pandemic, has strained shipping companies. Consequently, this shipping company and many of its peers sought certificates of exemption for low-sulfur fuels.

For aviation, under Topic 15 ‘Alternative fuels’, the air transportation director at a major courier express company remarked, *“The sustainable aviation fuel market, in its current state, is characterized by limited availability and high costs, which deter its immediate utilization.”* However, as he continued, the company developed forward-looking plans, *“We are in the preliminary stages to work with biorefineries, eyeing collaborations to amplify sustainable aviation fuel production scales.”* Thus, sustainable aviation fuels, such as biofuels, are still in the pilot operation stage. Presently, the company’s green efforts in aviation center around Topic 3 ‘Energy efficiency improvements for aircraft’. The director explained, *“Our endeavors span refining flight trajectories to weight optimization initiatives and bolstering ground* *operation efficiency, each of which collectively contributes to minimizing fuel consumption."* He further provided an example: *"In synergy with air traffic control and other airlines, we have adopted Continuous Descent Approaches (CDA) across our operational hubs. The CDA technique, under its design, significantly reduces fuel burn, resultant emissions, and noise during an aircraft's descent phase."* These fuel-saving and efficiency-enhancing green technologies are mainstream green practices in the aviation industry.

Considering the existence of selection preferences of these LSPs for different green technologies, we further identify the key factors influencing the green technology selection of LSPs. Technology maturity is the critical consensus for these LSPs to invest in green technologies, and the ability of green technologies to reduce costs and increase efficiency is a crucial indicator of technology maturity. For instance, a courier express company's vice president noted, *"Our organization's decisions regarding green technologies are not typically driven by government policy. Instead, we lean toward green technologies based on their maturity. As a technology or product matures, related subsidies tend to decrease or vanish, resulting in a leveled marketplace. In this case, if the green technology continues to yield financial advantages, we can confidently advocate for increased investment in it."* These insights highlight that technological maturity influences LSPs' adoption of technology-driven green practices. Concurrently, the variation in green practice focuses on different transportation modes and is closely attributed to the levels of green technology maturity inherent to each transportation mode.

3.4.2.2 Social-driven Green Practices and their Influencing Factor

For social-driven green practices, the interview findings are congruent with the topics derived from our LDA analysis (e.g., Topic 2 'Compliance with regulations'; Topic 4 'Environmental performance assessment'; Topic 5 'Environmental groups and committees'), especially regarding larger listed firms. For instance, three listed LSPs have established environmental committees under their board of directors' purview. These committees oversee the holistic orchestration – formulation, execution, and monitoring – of the company's energy conservation and emission reduction initiatives. Furthermore, these companies have operationalized a 'green development' team. This unit consistently tracks the company's milestones in advocating the adoption of eco-friendly materials and vehicles and oversees carbon emission monitoring.

In contrast, the three non-listed LSPs lack a specialized structure for environmental management. A general manager from a listed LSP highlighted, *"The immediate impetus for the environmental committee's inception is our listing on the Shenzhen Stock Exchange, which reports periodically for CSR. Moreover, our foray into social-driven green practices is inextricably linked to our brand and corporate reputation."* These observations illustrate that listed LSPs exhibit a higher propensity for social-driven green practices than non-listed LSPs, driven by market imperatives and considerations for corporate reputation.

3.4.2.3 Relationships between Technology- and Social-driven Green Practices

Our interviews also probed LSPs regarding a distinct pecking order when instituting various green practices. A consensus emerged among several LSP executives concerning a systematic approach to green practice implementation. One vice president elucidated, *"Our approach to adopting green practices has three primary stages. Initially, we immerse ourselves in grasping the pertinent laws, regulations, standards, and other guiding documents to set the framework for our green practices. Subsequently, referencing the 'Measurement Methods of Greenhouse Gas Emissions from Express Services' published in 2014, we quantify the company's carbon emissions. This data becomes the bedrock upon which our green endeavors are anchored. Conclusively, we harness insights from the existing data assessments to pinpoint the emission reduction avenues and judiciously select our green practice interventions."* In other words, legal compliance and environmental performance assessments should precede other LSPs' green practices. This observation propounds that social- and technology-driven green practices are not separate but complementary. In addition, there is another example of the joint optimization of technology- and social-driven green practices. The CTO of an express company mentioned, *"To encourage packaging reuse, it is essential to establish recycling points at final outlets. Coupling this with targeted marketing and awareness campaigns can gradually guide consumers toward a reuse mindset. This behavioral shift among consumers can, in turn, diminish the costs associated with packaging recycling."* Therefore, the synergies between technology- and social-driven green practices are also pivotal for Chinese LSPs.

3.5. Discussion

3.5.1. Theoretical Contributions

This study makes several theoretical contributions. First, it classifies listed LSPs' green practices from the STS perspective. While previous classification studies have predominantly focused on technology-driven green practices (Centobelli et al., 2017), social-driven green practices are not given sufficient attention. Our study provides a spectrum of 18 green practice topics pertinent to Chinese LSPs. Notably, eight of these topics are social-driven, ten are technology-oriented, and some of these social topics are highly prevalent and discussed by LSPs. For example, Topic 2 'Compliance with regulations', and Topic 4 'Environmental performance assessment', are among the most intense green practice topics discussed. This classification highlights that the green transition of LSPs is not solely reliant on green technologies; it also hinges on the backing of the social subsystem.

Second, this study advances knowledge of adopting green practices in different transportation modes. Existing research often provides a generalized classification framework for categorizing LSPs' green practices (El Baz and Laguir, 2017; Lieb and Lieb, 2010). However, these classifications overlook the heterogeneity inherent among different transportation modes. Our findings indicate that maritime freight predominantly emphasizes legal compliance and energy efficiency, while aviation freight targets energy efficiency. In contrast, road freight prioritizes emerging green technologies, such as new vehicle technology and green packaging. These findings further extend the literature on green logistics.

Third, our study provides novel insights into how green practices in the logistics industry have evolved. Current research primarily focuses on the short-term green practices of LSPs (El Baz and Laguir, 2017; Lieb and Lieb, 2010; Sureeyatanapas et al., 2018), often overlooking the evolutionary aspect of these practices. Our study discovers an initial focus on technology-driven green initiatives to improve operational efficiency, which subsequently evolved to embrace innovative green technologies and a broader array of social-driven green practices.

Finally, our study explores different factors that steer LSPs toward adopting technology-driven and social-driven green practices and investigates the potential relationships between these two green practice categories. While past studies have broadly examined the determinants of LSPs' green practices (Anderhofstadt and Spinler, 2019; Touratier-Muller et al., 2019), scant research has delved into the possibility that diverse green practices may have unique driving forces. Our research finds that green technology adoption is primarily catalyzed by technological maturity. In contrast, social-driven green practices are propelled mainly by market requirements and the overarching quest for a fortified corporate reputation. Furthermore, the imperatives of legal compliance and environmental performance assessments should take precedence over other green practices. This situation indicates the technology and social subsystem's interplay during LSPs' green transitions.

3.5.2. Managerial Implications

Based on McKinnon (2018), which outlines logistics decision-making steps (i.e., strategic, commercial, operational, and functional), and our integrated LDA–interview results, we recommend that LSP managers adopt the following three steps to design their green journey. First, LSPs need a green foundation for social green practices, such as legal and standards compliance, green management, and staff education about environmental operations. LSPs should be more proactive in meeting multiple market and regulatory requirements to meet the green baseline at this stage. This is particularly crucial for LSPs in maritime freight, who operate across multiple global regions and are subject to extensive regulatory oversight. For these companies, legal compliance is not just a matter of policy but a critical factor for their survival and growth in the long run. In addition, LSPs need to evaluate their environmental performance, which is the starting point for choosing the appropriate environmental strategy.

Second, LSPs ought to start with efficiency-improvement practices. The green transition incurs operational costs, technical feasibility, and financial investment, which takes time to benefit LSPs. Profitable green practices can lessen resource consumption and emissions. Still, there is yet to be a universal approach due to the varying organizational size and financial strengths of LSPs to pursue their green transition. Practices involving lower capital investment such as waste, energy, and materials reduction and logistics optimization are favorable for smaller-sized LSPs to progress green transition.

Meanwhile, larger LSPs are more resourceful in leading the industry for intelligent, digital, visualized operations in their greening processes. For road transportation, the primary focus is on optimizing routing and load management to enhance fuel efficiency. For aviation, the emphasis might be on adopting more fuel-efficient flight paths and investing in newer, more environmentally friendly aircraft. For maritime transportation, the focus could be improving ship efficiency through better hull designs and slow steaming.

Finally, LSPs with adequate resources can invest in pilot projects of emerging green technologies. Success in green transition depends on whether countries can achieve the net-zero target in 2050. Emerging green technologies like alternative fuels are instrumental to this mission in the logistics industry. Our research indicates that the Chinese road freight sector has already begun to adopt electric light trucks on a large scale, suggesting that this could be a viable direction for further investment for most road freight LSPs. However, given that alternative fuels and new vehicle technologies are still immature for air and maritime transportation, LSPs should proceed cautiously in their investments and adoption strategies. Participation in pilot projects that harness these burgeoning technologies paves the way for LSPs to solidify their green commitment. Moreover, such proactive engagements can enable them to gain a competitive edge in the impending green-centric business landscape.

3.6. Conclusion

Drawing upon STS theory, this study investigates the classification, characteristics, and evolution of green practices within Chinese LSPs and different influencing factors of technology-driven and social-driven green practices. Analyzing CSR reports from Chinese LSPs from 2015 to 2021; we identify 18 green practice topics: eight social-driven green practices and ten technology-driven green practices. Further, we validate the LDA findings through interviews and investigate influencing factors behind social- and technology-driven green practices.

Although our research provides insights into the green practices of LSPs, it is subject to certain limitations when interpreting the results. First, our analysis is centered on the Chinese landscape. Although China presents a suitable and meaningful research setting, the focus on Chinese LSPs may limit the generalizability of our conclusions. Given China's distinct cultural, institutional, and economic environments, we should be cautious in generalizing our findings to other contexts. One promising direction for future research is gathering data from various countries to corroborate our findings, offering more implications. Second, our findings can be enriched with other methodologies, such as large-scale data analytics, enhancing our qualitative observations' statistical weight and rigor. Third, further studies could focus on quantifying the actual environmental performance of the green practices adopted by LSPs. Investigating whether technological and social green practices can support each other to yield higher environmental performance and other performance outcomes, such as logistics service quality and customer loyalty, presents an intriguing research opportunity. Lastly, beyond environmental technologies, future research could explore how emerging technologies, such as blockchain or artificial intelligence, are influencing green practices. This exploration could provide insights into the logistics industry's next generation of green strategies.

Chapter 4 Study 2: Does Green Innovation Contribute to Logistics Service Providers' Market Value? The Effects of Stakeholder Engagement and Public Attention

4.1 Introduction

LSPs are the linchpin of environmental sustainability because they are involved in business operations of all industries (Nwccindia, 2017) and contribute to a significant carbon footprint (e.g., 28% of total GHG emissions in 2021) (USEPA, 2023). Therefore, an increasing number of LSPs have engaged in green innovation to alleviate the adverse impact of their operations on the natural environment. For instance, SF Express, a leading Chinese LSPs, has devoted great efforts to undertaking green innovation. In 2021, SF Express purchased 8,000 new energy vehicles and achieved 20 green packaging-related patent grants, reducing GHG emissions by 279,000 tonnes (SF, 2023). Similarly, COSCO, the largest shipping company in China, launched a collaborative project with its supply chain partners to develop the liquefied natural gas (LNG) dual-fuel VLCC (very large crude carrier) in 2019, expecting to reduce CO_2 and NOx emissions by 20%-30% (COSCO, 2020).

While LSPs have recognized that green innovation is an important and viable means to mitigate environmental harms (Fernando and Wah, 2017; Y. Li, 2014), it remains to be recognized whether implementing green innovation can enhance their market value. There is an ongoing debate about the market value effect of green innovation, which is characterized by an unsolved dilemma. On the one hand, some researchers have pinpointed that the adoption of green innovation can help firms establish favorable relationships with their key stakeholders and acquire stakeholder-based resources (e.g., improved firm reputation, brand identity, and customer loyalty) (Chiou et al., 2011; Trumpp and Guenther, 2017; H. Wang et al., 2008), thereby contributing to their market value. On the other hand, the extant literature has also shown the potential downsides of green innovation adoption (e.g., substantial resource consumption, cost burden, and technology uncertainty) (Aguilera-Caracuel and Ortiz-de-Mandojana, 2013; Driessen et al., 2013), which could impair firms' market value.

Given this continuing controversy and the growing importance of green innovation, it is imperative to empirically unveil the impact of green innovation adoption on LSPs' market value to guide theory and practice development regarding green innovation in the logistics industry. Previous studies have primarily examined the impact of green innovation on firms' environmental performance (Rehman et al., 2021), financial performance (Lee et al., 2015; Xie et al., 2019), operational performance (Wijethilake et al., 2018), and stock returns (Ba et al., 2013). Nonetheless, more research is needed to disentangle how adopting green innovation influences firms' market value, particularly in the context of the logistics industry.

To bridge this knowledge gap, this study intends to investigate the impact of green innovation on LSPs' market value and the contingency conditions under which this impact may vary. Drawing upon the RBV (Barney, 1991) and stakeholder theory (Freeman et al., 2021), we theorize that green innovation yields diminishing marginal benefits for LSPs and imposes increasing costs on them, thus exerting an inverted U-shaped effect on their market value. Furthermore, given that many LSPs tend to engage external stakeholders in collaborative green innovation (Chen and Hung, 2014), we delve into how stakeholder engagement alters the efficacy of green innovation on LSPs' market value. Previous studies suggest that because of the varying levels of (in)compatibility between the focal firm and external stakeholders (Richey et al., 2012; Shou et al., 2018), engagements with different stakeholders may have distinct influences on green innovation. In this study, we particularly focus on two types of stakeholder engagement, i.e., supply chain partner engagement (SCPE) and scientific institution engagement (SIE), corresponding to the two major stakeholders when LSPs conduct collaborative green innovation (Zhou et al., 2021). Moreover, since green innovation generates positive societal externalities, non-engaged stakeholders in the broad scope (i.e., the public) may also influence the extent of market value derived from green innovation. Hence, we further explore the moderating effect of public attention on the green innovation–market value relationship.

We combine archival data from multiple databases to examine these hypotheses and construct a panel dataset of 53 Chinese-listed LSPs between 2011 and 2021. We find an inverted U-shaped relationship between green innovation and LSPs' market value. Furthermore, SCPE steepens this inverted U-shaped relationship, whereas SIE and public attention flatten this curvilinear relationship. In addition, we conducted post hoc interviews with senior managers from Chinese LSPs to comprehend our findings from the econometric analysis better. The *post hoc* interviews support the distinctive effects of different stakeholders' engagements on the green innovation–market value linkage from the executives' perspective.

This study makes several theoretical contributions. First, it extends the green innovation literature by providing sound empirical evidence on an inverted U-shaped association between green innovation and market value in the context of the Chinese logistics industry. Given the large carbon footprint of the logistics industry, our study offers new insights into green innovation in this important context. Second, this study expands the green innovation literature by disentangling the inverted U-shaped green innovation–market value relationship boundary conditions. Particularly, our study proffers a fine-grained understanding of how different types of stakeholder engagement (i.e., SCPE and SIE) and public attention modify the efficacy of green innovation on market value, which previous studies have not examined. Third, this study sheds light on the RBV and stakeholder theory literature by theoretically elucidating the inverted U-shaped green innovation–market value association and the contingency factors that moderate the underlying mechanisms of this association.

4.2. Research Background and Hypotheses Development

4.2.1. Green Innovation in the Logistics Industry

Compared with manufacturing industries, the fast-developing logistics industry is less environmentally regulated. However, this industry is pollution-intensive and poses serious environmental risks (e.g., severe environmental pollution and increased carbon footprint) (Lai and Wong, 2012). Recently, LSPs have increasingly implemented green innovation to alleviate the adverse environmental impact of their operations. For example, in 2017, Cainiao Green Alliance Foundation established a charity fund of 300 million RMB with some well-known Chinese LSPs (e.g., YTO Express and ZTO Express) to develop and promote green innovation, such as recyclable and bio-degradable packaging materials and energy-efficient material handling equipment (Cainiao, 2017).

Green innovation refers to adopting technologies to mitigate negative environmental impacts by enhancing resource utilization and reducing pollution emissions (Berrone et al., 2013; Karimi Takalo et al., 2021). In the logistics industry, there are significant differences in the extent of benefits and costs associated with green innovation. Following previous studies (Berrone et al., 2013; Centobelli et al., 2017), we consider two typical types of green innovation, including green technologies that help enhance efficiency and generate economic benefits and green technologies that are still not mature but may help reduce environmental impacts significantly in the long run.

Specifically, LSPs can develop green technologies to improve efficiency through logistics optimization, waste reduction, and energy-efficient transportation equipment modifications (e.g., engine upgrades, aerodynamic components, and lightweight design) (Centobelli et al., 2017; SRF, 2021). For example, numerous LSPs have developed technologies to leverage congestion and up-to-date traffic information, thus optimizing transportation routes and enhancing logistics efficiency (SRF, 2021). A recent report indicates that at the early stage of decarbonization, LSPs can implement net-present-value (NPV) positive activities (e.g., logistics optimization and waste reduction) to save money and reduce emissions simultaneously (McKinsey, 2021). Therefore, green innovation can improve resource utilization, reduce waste, boost logistics efficiency, yield significant economic benefits for LSPs, and serve as “low-hanging fruits” for their decarbonization.

At the same time, some emerging green technologies are essential for LSPs to achieve net zero carbon dioxide emissions for freight transport, including long-distance new energy trucks, alternative fuels, and bio-degradable packaging materials (El Baz and Laguir, 2017). However, these green technologies still need to be mature and need help if applied on a large scale, thus requiring firms to invest considerable resources and induce significant costs. For instance, the low availability and high costs of biofuels and infrastructure and compatibility issues have hindered the widespread adoption of biofuels in the logistics industry (McKinsey, 2020). In short, many emerging green technologies entail high uncertainty and costs, impeding LSPs from benefiting from such green technologies (Anderhofstadt and Spinler, 2019; Yan et al., 2021).

Previous studies have attempted to investigate the overall impact of green innovation on firms’ profitability or other market-based performance (e.g., Ba et al., 2013; Eiadat et al., 2008; Farooque et al., 2022; Xie et al., 2019). Nevertheless, the results of prior studies are largely inconclusive, and there is also a need for more research to unravel the relationship between green innovation and market value. Karimi Takalo et al. (2021) reviewed 178 articles on green innovation from 2007 to 2019 and found that 81% of the articles concentrated on the manufacturing or energy industries. Therefore, it is timely and essential to investigate the impact of green innovation on LSPs’ market value. This study can provide LSPs with a deeper understanding of the market value effect of green innovation, which can better motivate them to pursue technology-driven green innovation practices. Moreover, there needs to be more research investigating how stakeholder engagement and public attention modify the relationship between green innovation and market value, which will offer a nuanced understanding of the boundary conditions. Given these significant research gaps, our study aspires to advance the research on green innovation by disentangling whether and under which conditions green innovation can contribute to LSPs' market value.

4.2.2. Inverted U-shaped Impact of Green Innovation on Market Value

Previous inconsistent findings in green innovation literature imply that the relationship between green innovation and market value may be curvilinear rather than linear. To elucidate the non-linear curve, we analyze the benefit function (the positive mechanism) and the cost function (the negative mechanism) and integrate these opposing effects (Barnett and Salomon, 2006; Haans et al., 2016; Li et al., 2021). The fundamental logic is that if the marginal benefits of green innovation diminish gradually and the costs associated with green innovation increase continually, green innovation will have an inverted U-shaped relationship with market value.

The RBV and stakeholder theory can support the benefit function with declining marginal returns. From the RBV perspective, pollution can be considered a manifestation of economic waste, involving unnecessary and inadequate use of resources (Barney, 1991; Porter and Linde, 1995). This situation indicates that green innovation may improve LSPs' resource savings through optimization and waste reduction. These green technologies, which can bring short-term gains, are viable "low-hanging fruits" for LSPs to start their environmental journey. As the level of green innovation increases, LSPs may expand their R&D expenditures into developing long-distance electric trucks, alternative fuels, bio-degradable packaging materials, and other high-complexity decarbonization technologies, which currently have few resource-saving effects (Abbasi and Nilsson, 2016). Moreover, LSPs' operand resources, such as electricity, packages, and fuels, are limited and cannot be saved infinitely. Consequently, the marginal benefits of green innovation regarding resource savings and efficiency improvement will diminish.

Furthermore, from the perspective of stakeholder theory, green innovation enables LSPs to fulfill stakeholders' environmental expectations and requirements (de Medeiros et al., 2018), thus leading to enhanced reputations that can strengthen their relationships with critical stakeholders and yield additional benefits (Li et al., 2021; Trumpp and Guenther, 2017). For example, stakeholders such as customers, suppliers, and shareholders may be more willing to support greener LSPs (Trumpp and Guenther, 2017; H. Wang et al., 2008). Although green innovation could boost a firm's reputation, the marginal reputation improvement will decline gradually according to the law of diminishing marginal utility (Li et al., 2021; Pierce and Aguinis, 2013). Thus, moderate to high levels of green innovation can produce few marginal returns for LSPs because stakeholders have already formulated their environmental opinions (de Medeiros et al., 2018). In short, as green innovation increases, its benefits will flatten out gradually.

On the other hand, the cost function implies that the costs associated with green innovation for LSPs will continue increasing. To cover the related costs of pursuing a higher level of green innovation, LSPs need to spend extra expenditures on R&D investment and operational processes. As a result, green innovation diverts resources from firms' core businesses and ties up limited resources, increasing cost burdens on the firms (Li et al., 2021; Trumpp and Guenther, 2017).

Considering these countervailing forces simultaneously, we propose an inverted U-shaped linkage between green innovation and market value. As measured by Tobin's q, market value is influenced by shareholders' investment decisions in the stock market and depends on the perceived NPV of the monetary difference between benefits and costs (Lindenberg and Ross, 1981; Tian et al., 2022). Specifically, at low to moderate levels of green innovation, LSPs can improve efficiency, save resources through mature green technologies, and benefit from reputation improvements, which can outweigh the associated costs and generate positive NPV, thereby increasing market value. However, at moderate to high levels of green innovation, LSPs may shift their R&D focus to emerging green technologies, which incur considerable costs but generate few operational benefits in the short term. Meanwhile, the marginal reputational benefits brought by green innovation decrease gradually. As a result, in this situation, high investment ultimately erodes the NPV of green innovation, resulting in declining market value for LSPs.

H1. *An inverted U-shaped relationship exists between an LSP's green innovation and market value.*

4.2.3. Moderating Effects of Stakeholder Engagement

External stakeholder engagement is an important source of innovation for acquiring knowledge, markets, and technology and mitigating innovation-related uncertainties (Melander, 2017). The extant research has explored the benefits of collaborative innovation between firms and their external stakeholders in non-logistics industries (e.g., manufacturing, chemical, and electronics industries) (Liu et al., 2021; Shao et al., 2023), which inspires us to consider the potential merits of stakeholder engagement in green innovation for LSPs. Nevertheless, some studies posit that there may be downsides to stakeholder engagement in green innovation. Shou et al. (2018) point out that the incompatibility of organizations during stakeholder engagement may hurt their green innovation efforts. Therefore, the impact of stakeholder engagement on the relationship between green innovation and market value needs to be further explored. As mentioned above, this research focuses on the roles of two typical types of external stakeholders, i.e., supply chain partners (market-based partners) and scientific institutions (science-based partners), which are the two major sources from which Chinese LSPs attain knowledge (Du et al., 2014; Zhou et al., 2021).

Supply chain partners are closely linked to industry LSPs. Hence, SCPE may influence both the benefit and cost functions underlying the impact of green innovation on market value. First, customers are the decisive partners to drive LSPs to develop green innovation (Acebo et al., 2021). Through their purchasing decisions, customers can reward LSPs that meet their environmental requirements (Melander, 2017). In other words, LSPs may gain additional sales by working with their customers on green innovation. Second, SCPE can create value-added opportunities, direct green innovation to the mutual interests of logistic companies and supply chain partners, and help logistic companies achieve additional competitive advantages in terms of cost, technology, and time (Melander, 2017; Nieto and Santamaría, 2007). Third, supply chain partners can partially diversify the cost of making highly specific investments (e.g., green innovation) in a particular company (Barney, 2018). In short, we speculate that SCPE enhances the benefits and decreases the costs underlying the relationship between green innovation and market value, thereby steepening the inverted U-shaped green innovation–market value relationship.

H2a. *SCPE steepens the inverted U-shaped relationship between an LSP's green innovation and market value.*

However, as science-based partners of green innovation, scientific institutions exhibit a certain degree of divergence from LSPs in their missions and objectives. Specifically, scientific institutions focus on technologies that hold interest and value within the scientific community, potentially lacking precise commercial applications, whereas companies are often oriented toward the short-term success of commercialization and quick return on investment when undertaking green innovation (Ankrah and AL-Tabbaa, 2015; Meyer-Krahmer and Schmoch, 1998; Zhou et al., 2021). Furthermore, in the context of the logistics industry, this divergence between science institutions and companies may widen. Meyer-Krahmer and Schmoch (1998) pinpoint that the "transportation" technology field is less science-based than other technology fields, in which LSPs focus more on addressing current problems rather than basic science. Mission or objective divergence tends to be the most significant obstacle in green innovation collaboration; for example, slow academic bureaucracies may impede green innovation commercialization and suppress its benefits in the market (Ankrah and AL-Tabbaa, 2015; Zhou et al., 2021).

Additionally, because scientific institutions and LSPs belong to different social systems, there is a considerable gap in organizational structures and cultures that likely attenuate the efficacy of green innovation cooperation (Ankrah and AL-Tabbaa, 2015; Perkmann et al., 2021). For instance, staff at scientific institutions may need to be more theoretical, thus leading to impractical solutions (Ankrah and AL-Tabbaa, 2015). Consequently, LSPs need to develop specific management and administrative capabilities to collaborate with scientific institutions on green innovation, which is time-consuming and incurs increased administrative costs (Ankrah and AL-Tabbaa, 2015; Perkmann et al., 2021; Zhou et al., 2021). Thus, we conjecture that SIE weakens the benefits and aggravates the costs underlying the linkage between green innovation and market value, thereby flattening the inverted U-shaped green innovation–market value linkage.

H2b. *SIE flattens the inverted U-shaped relationship between an LSP's green innovation and market value.*

4.2.4. Moderating Effect of Public Attention

The public, including minority shareholders and investors, will also pay attention to the environmental efforts of LSPs as the public has been increasingly environmentally aware in recent years (Cheng and Liu, 2018; Wu and Ye, 2020). Firms with greater public attention are more visible and encounter greater environmental expectations and shareholder requirements (Cheng and Liu, 2018). As a result, when LSPs with greater public attention implement green innovation, the public and shareholders may not be surprised. Thus, the reputation improvement derived from green innovation is limited. This situation diminishes the shareholders' perceived NPV of green innovation, thereby weakening the efficacy of green innovation on LSPs' market value. By contrast, when LSPs with lower public attention adopt green innovation, they may be better positioned to satisfy the shareholders' lower environmental expectations and requirements. This situation boosts the shareholders' perceived NPV of green innovation, thus reinforcing the market value effect of green innovation. In short, we posit that high public attention attenuates the perceived NPV of green innovation, thereby flattening the inverted U-shaped green innovation–market value association.

H3. *Public attention flattens the inverted U-shaped relationship between a firm's green innovation and market value.*

4.3. Method

4.3.1. Sample and Data

We collect archival data of Chinese-listed LSPs from multiple sources to test our hypotheses. Our initial sample consists of all 132 companies listed on China's A-share stock market in the transport, storage, and postal industries (i.e., G53 to G60). Since the data on green innovation and public attention of the Chinese logistics industry are only available after 2010, we selected 2011–2021 for our study. The data on firms' green innovation are obtained from the Chinese Research Data Services (CNRDS) platform, which acquires patent information from the China National Intellectual Property Administration (CNIPA) and identifies green patents based on the Green Inventory category in the International Patent Classification (IPC) system developed by the World Intellectual Property Office (WIPO). We further verified the green patent data through the IncoPat Global Patent Database and used this database to code detailed information on green patents. The data of public attention are compiled from the Web Search Volume Index (WSVI) of Chinese listed companies, provided by the CNRDS database. Finally, financial data of LSPs are gathered from the China Stock Market and Accounting Research (CSMAR) database.

In the initial sample of 132 LSPs, 38 companies concentrated on non-logistics operations (e.g., passenger transport and transportation investment) and hence dropped from the sample. We exclude 41 companies with missing values on variables of interest, resulting in 53 LSPs in the final sample. Due to the listing or delisting of some LSPs during the sampling period, we obtain an unbalanced panel dataset. The final sample consists of 391 firm-year observations covering 53 LSPs from 2011 to 2021. We lag the dependent variable (i.e., market value) by one year to alleviate potential reverse causality. Therefore, the information on all explanatory variables comes from 2011 to 2020, and that on the dependent variable comes from 2012 to 2021. The sample overview is reported in Table 4.1.

Table 4.1 Sample overview

Sample distribution by year	Frequency	%	Sample distribution by industry	Frequency	%
2011	36	9.21	G53 Railway transport	30	7.67
2012	36	9.21	G54 Road transport	138	35.29
2013	36	9.21	G55 Water transport	132	33.76
2014	33	8.44	G56 Air transport	46	11.76
2015	36	9.21	G58 Stevedoring service	24	6.14
2016	39	9.97	G59 Storage service	3	0.78
2017	42	10.74	G60 Postal service	18	4.60
2018	43	11.00	Total	391	100
2019	44	11.25			
2020	46	11.76			
Total	391	100			

4.3.2. Measures

Dependent variable. Following previous studies (Nekhili et al., 2017), market value is measured by Tobin's *q*, calculated by dividing the sum of the firm's market capitalization by the book value of its total assets.

Independent variable. According to Cui et al. (2022) and Lin and Ma (2022), we utilize the number of green patent applications as a proxy for green innovation. We do not use the number of granted green patents to rule out the potential disturbance of the time lag since it normally takes a few years for a patent application to be granted in China (Cui et al., 2022; B. Lin and Ma, 2022). To mitigate the potential effects of variable skewness (Wu et al., 2022), we employ the natural logarithm of one plus the total number of green patent applications to operationalize *green innovation* (GTI).

Moderating variables. We use the IncoPat database to identify the applicants for green innovation by each LSP each year. In addition to green patents applied independently by LSPs, green patents are created through collaboration between LSPs and their external stakeholders. Based on previous literature (Acebo et al., 2021) and the results of our coding of applicant information, we identify two main categories of external stakeholders involved in the green innovation of LSPs: supply chain partners and scientific institutions. Therefore, we utilize two dummy variables as the proxies of *supply chain partner engagement* (SCPE) and *scientific institution engagement* (SIE). Specifically, the value of SCPE in a certain year is coded as 1 when the LSP has supply chain partners involved in green innovation that year; 0 otherwise. Similarly, SIE is coded as 1 when an LSP has scientific institutions involved in green innovation that year; 0 otherwise.

The WSVI database records internet users' search behavior in China. When searching for a particular company, users could search for its stock code or company name in abbreviations and full names. The WSVI database captures and reflects the intensity of each company's web searches (Cheng and Liu, 2018). A high volume of web searches indicates that the company attracts more public attention. To eliminate concerns about skewness, we measure a firm's *public attention* (PA) using the natural logarithm of one plus the median number of searches for the company in a year (Cheng and Liu, 2018).

Control variables. We control for factors that might affect firms' market value at both firm and industry levels (Nekhili et al., 2017; Trumpp and Guenther, 2017; Wang et al., 2008). First, we control for firm size and age since previous research has shown that larger or older firms are more likely to obtain more benefits than smaller or younger firms (Trumpp and Guenther, 2017; H. Wang et al., 2008). *Firm size* (Size) is measured by the natural logarithm of a firm's total assets. *Firm age* (Age) is calculated as the number of years since the establishment of the firm. Financial leverage can be described as a financing risk that may negatively impact market value (Trumpp and Guenther, 2017). *Financial leverage* (Lev) is the long-term debt divided by total assets. *R&D intensity* (RDI) is calculated as the ratio of R&D expenses to total sales, which may have a long-term impact on firms' implementation of green innovation and market value (Trumpp and Guenther, 2017; Wang et al., 2008).

We also control for several industry-level variables because the literature suggests that industry environments might affect companies' market value (Xue et al., 2012; Zhang et al., 2022). *Industry size* (Ind_Size) is operationalized as the natural logarithm of the sum of all firms' assets in the same two-digit CSRC industry (Xue et al., 2012). *Industry growth* (Ind_Growth) is computed as the growth rate of industry sales (Xue et al., 2012; Zhang et al., 2022). *Industry competition* (Ind_Comp) is measured by one minus Herfindahl index, which is calculated as the sum of the squares of the market shares of all companies in the same two-digit CSRC industry (Xue et al., 2012; Zhang et al., 2022). Finally, we include year dummies to account for unobserved time-specific heterogeneity.

4.3.3. Model Specification

We compare the differences between the random and fixed effects estimates based on the Hausman test. The results show that firm fixed-effect models are more suitable (χ^2 (25) =94.37, $p < 0.001$) for our data. We also perform the Wald test to ascertain whether heteroskedasticity exists (Chou and Bentler, 1990). The results show that our data suffer from heteroskedasticity. We estimate the firm fixed-effect regression models using robust standard errors to address this concern.

Given the time lag between green innovation and market value, we lag the dependent variable by one year. We employ the following equation to test our hypotheses:

$$Market\ Value_{i,t+1} = \beta_0 + \beta_1 GTI_{it} + \beta_2 GTI_{it}^2 + \beta_3 SCPE_{it} + \beta_4 SIE_{it} + \beta_5 PA_{it}$$
$$+\beta_6 GTI_{it} \times SCPE_{it} + \beta_7 GTI_{it}^2 \times SCPE_{it} + \beta_8 GTI_{it} \times SIE_{it} + \beta_9 GTI_{it}^2 \times SIE_{it}$$
$$+\beta_{10} GTI_{it} \times PA_{it} + \beta_{11} GTI_{it}^2 \times PA_{it} + \beta_i Control_{it} + \gamma_i + \eta_t + \varepsilon_{it}$$

where all variables are defined in Section 3.2; β_0 is the intercept, β_n represents a set of coefficients for the exploratory variables, γ_i is the firm fixed effect, η_t is the year fixed effect, and ε_{it} is the error term.

4.4. Analyses and Results

4.4.1. Main Results

The descriptive statistics of all variables are presented in Table 4.2. In our sample of 53 LSPs with 391 firm-year observations, 54 (13.8%) firm-year observations that cover 26 LSPs have collaborative green innovation with supply chain partners, and 28 (7.2%) firm-year observations that cover 12 LSPs have collaborative green innovation with scientific institutions. Table 4.3 shows the correlation matrix of all variables in this study. The variance inflation factor (VIF) values for all variables are less than the cutoff value of 10 (Menard, 2001), which suggests that multicollinearity is not a major concern in this study.

Table 4.4 reports the results of firm fixed-effects models. Model 1, which reports the test results for H1, includes GTI and its squared term (i.e., GTI^2), moderating variables, and all the control variables; Model 2 includes the SCPE- and SIE-related interaction terms to present the test results for H2a and H2b; Model 3 includes the public attention-related interaction terms to show the test results for H3; and Model 4 is the full model, which shows the test results for all the hypotheses.

Model 1 shows that both the estimated coefficients of GTI and GTI^2 are significant ($p<0.05$), with the linear term being positive ($\beta=0.256$) and the quadratic term being negative ($\beta=-0.067$). This finding indicates an inverted U-shaped effect of green innovation on market value.

We conducted a U test to examine further the inverted U-shaped relationship between green innovation and market value (Haans et al., 2016). The overall test of the presence of an inverted U-shape is significant (t-value=1.82, $p>|t|=0.037$). The turning point of the inverted U-shape is 1.823, within the green innovation data range (from 0 to 5.088). The slope at the lower bound of green innovation is significantly positive ($\beta=1.204$, $p<0.05$), and the slope at the upper bound of green innovation is significantly negative ($\beta=-2.156$, $p<0.05$). These results confirm the inverted U-shaped relationship between green innovation and market value, thus supporting H1.

The results in Model 2 demonstrate that the coefficient for the interaction term between SCPE and GTI^2 is significant and negative ($\beta=-0.098$, $p<0.01$). This finding indicates that SCPE sharpens the inverted U-shaped relationship between green innovation and market value, thereby supporting H2a. Moreover, the coefficient for the interaction term between SIE and GTI^2 is significant and positive ($\beta=0.122$, $p<0.01$), which implies that SIE flattens the inverted U-shaped curve, thus supporting H2b.

The changes in the inverted U-shape for models with and without SCPE and SIE are illustrated in Figure 4.1. The inverted U-shape curve between green innovation and market value is steeper for LSPs with SCPE, whereas this curve is flatter for LSPs with SIE. This finding further lends support to both H2a and H2b.

In Model 3, we discover that the coefficient for the interaction term between public attention and GTI^2 is significant and positive (β=0.044, p<0.05). The results suggest that public attention dampens the inverted U-shaped relationship between green innovation and market value, supporting H3. The changes in the inverted U-shape at low (mean – SD) and high (mean + SD) levels of public attention are depicted in Figure 4.2. The inverted U-shape curve is flatter for LSPs with greater public attention. This finding further demonstrates that public attention weakens the impact of green innovation on market value.

Table 4.2 Descriptive statistics

Sample distribution by year	Frequency	%	Sample distribution by industry	Frequency	%
2011	36	9.21	G53 Railway transport	30	7.67
2012	36	9.21	G54 Road transport	138	35.29
2013	36	9.21	G55 Water transport	132	33.76
2014	33	8.44	G56 Air transport	46	11.76
2015	36	9.21	G58 Stevedoring service	24	6.14
2016	39	9.97	G59 Storage service	3	0.78
2017	42	10.74	G60 Postal service	18	4.60
2018	43	11.00	Total	391	100
2019	44	11.25			
2020	46	11.76			
Total	391	100			

Table 4.3 Correlation matrix

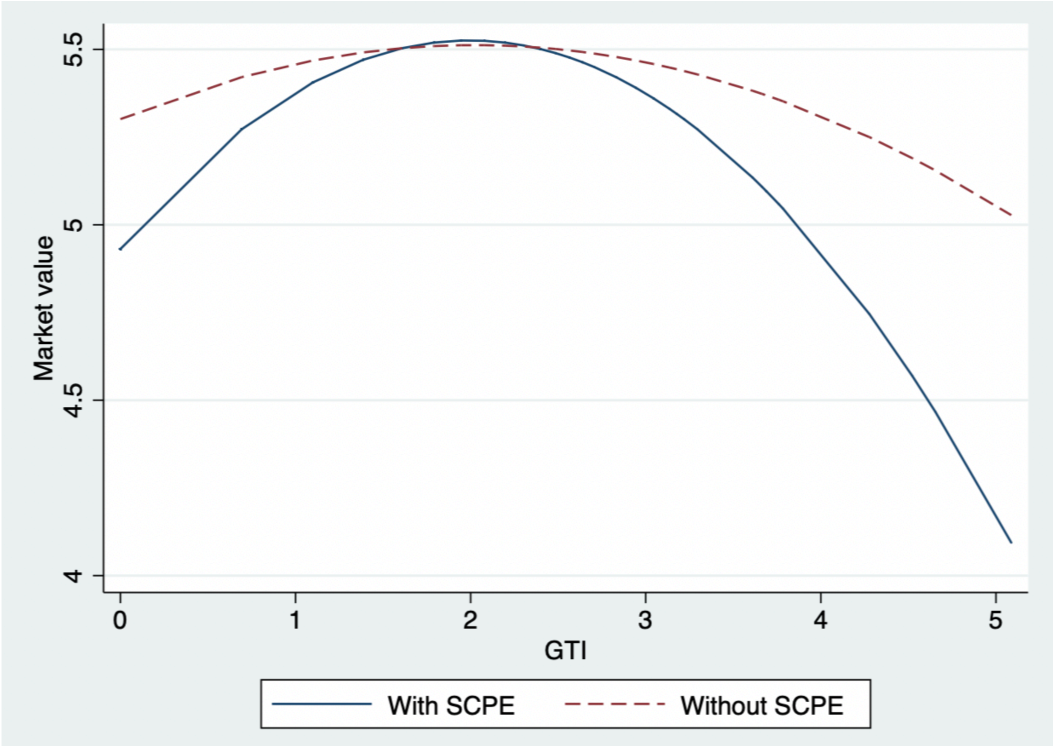
Variable	1	2	3	4	5	6	7	8	9	10	11	12
1. Market value	1											
2. GTI	-0.011	1										
3. SCPE	-0.069	0.554***	1									
4. SIE	-0.058	0.476***	0.320***	1								
5. PA	-0.135***	0.192***	0.005	0.047	1							
6. Size	-0.371***	0.393***	0.258***	0.199***	0.428***	1						
7. Age	0.006	0.003	-0.030	0.052	-0.062	0.064	1					
8. Lev	-0.248***	0.077	0.109**	0.073	0.096	0.377***	-0.114**	1				
9. RDI	0.034	0.221***	0.049	0.115**	-0.117**	0.100**	0.109**	-0.083	1			
10. Ind_Size	0.071	-0.021	0.011	-0.080	0.188***	-0.032	-0.189***	0.000	-0.036	1		
11. Ind_Growth	0.006	0.108**	0.050	0.033	-0.145***	-0.151***	-0.158***	-0.097	0.068	0.150***	1	
12. Ind_Comp	-0.063	-0.239***	-0.076	-0.070	-0.199***	-0.175***	0.026	0.273***	-0.135***	-0.060	-0.007	1

Notes: $N = 391$. ** $p < 0.05$, *** $p < 0.01$ (two-tailed test).

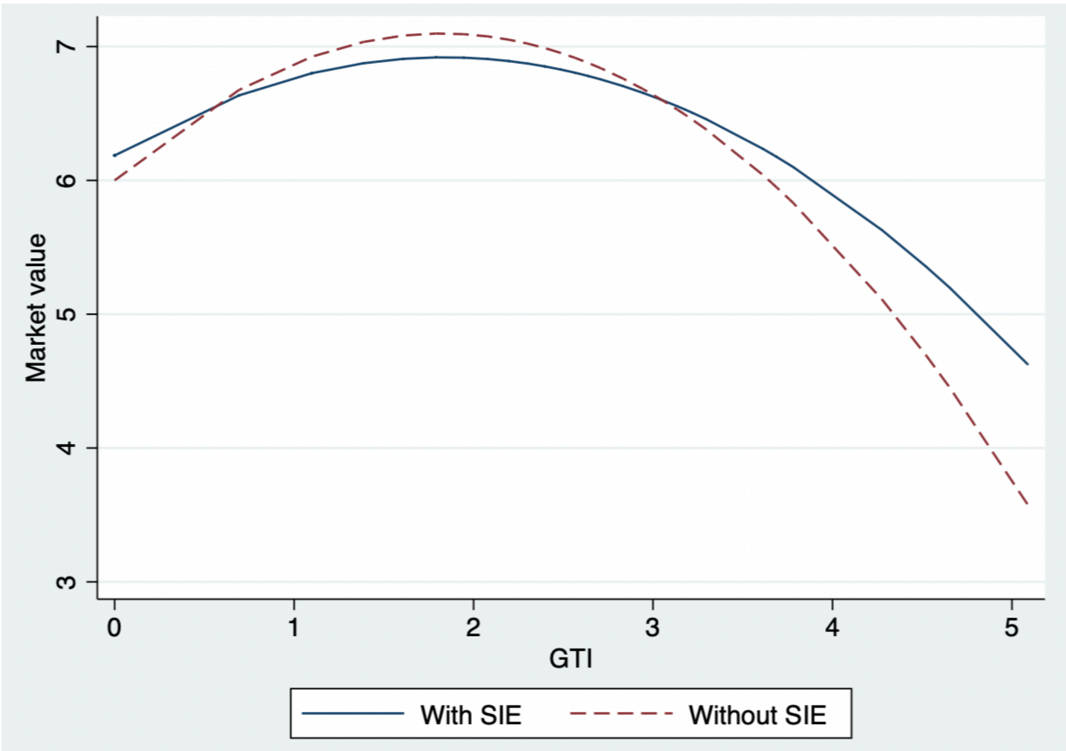
Table 4.4 Results of regression analyses

Variable	Model 1		Model 2		Model 3		Model 4	
SCPE	-0.096	(0.060)	-0.370**	(0.165)	-0.123*	(0.068)	-0.352**	(0.163)
SIE	-0.010	(0.044)	0.219	(0.147)	-0.041	(0.044)	0.186	(0.163)
PA	0.052	(0.062)	0.057	(0.062)	0.054	(0.067)	0.061	(0.066)
GTI	0.256**	(0.118)	0.209*	(0.106)	1.349*	(0.676)	1.204*	(0.661)
GTI^2	-0.066**	(0.034)	-0.051*	(0.026)	-0.379**	(0.173)	-0.330**	(0.160)
GTI × SCPE			0.388***	(0.141)			0 .332**	(0.145)
GTI^2 × SCPE			-0.098***	(0.032)			-0.085***	(0.030)
GTI × SIE			-0.434**	(0.171)			-0.406**	(0.182)
GTI^2 × SIE			0.122***	(0.041)			0.113***	(0.042)
GTI × PA					-0.151*	(0.081)	-0.136*	(0.080)
GTI^2 × PA					0.044**	(0.021)	0.039*	(0.020)
Size	-0.214*	(0.116)	-0.226*	(0.121)	-0.234*	(0.119)	-0.243*	(0.123)
Age	0.002	(0.033)	0.003	(0.033)	0.001	(0.033)	0.002	(0.032)
Lev	0.016	(0.036)	0.016	(0.035)	0.015	(0.036)	0.015	(0.036)
RDI	-8.043	(6.516)	-8.447	(6.321)	-10.472	(7.166)	-10.575	(7.040)
Ind_Size	0.019	(0.058)	0.017	(0.058)	0.002	(0.059)	0.003	(0.058)
Ind_Growth	0.228*	(0.123)	0.217*	(0.125)	0.290*	(0.133)	0.274*	(0.135)
Ind_Comp	0.189	(0.477)	0.193	(0.432)	0.287	(0.471)	0.276	(0.432)
Year FE	Yes		Yes		Yes		Yes	
Firm FE	Yes		Yes		Yes		Yes	
R^2	0.178		0.165		0.164		0.156	

Notes: N =391. *p < 0.1; **p < 0.05; ***p < 0.01 (two-tailed test). Robust standard errors are in parentheses.



(a)



(b)

Figure 4.1 Moderating effects of (a) SCPE and (b) SIE on the GTI–market value relationship

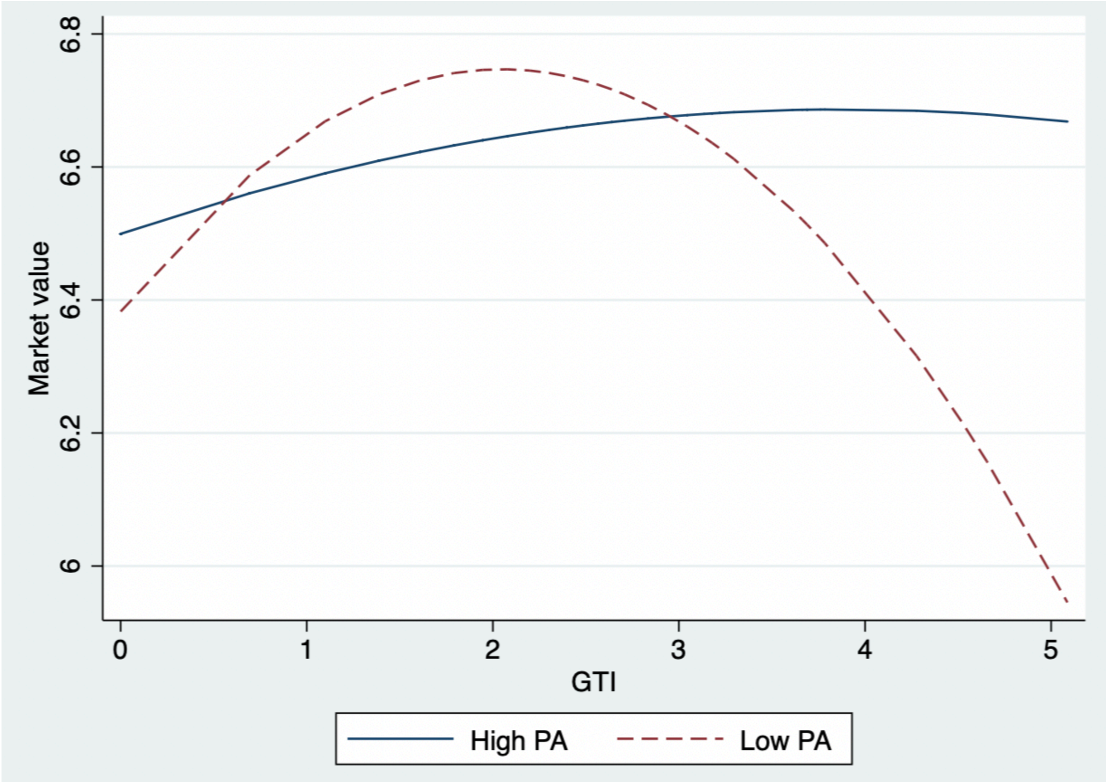


Figure 4.2 Moderating effect of public attention on the GTI–market value relationship

4.4.2. Endogeneity

We adopt multiple approaches to mitigate endogeneity concerns in our main models, such as a one-year lagged dependent variable, a series of control variables, and year-fixed effects. Moreover, we employ a two-stage least squares (2SLS) approach to address the potential endogeneity issue (Lu et al., 2018). We use the ratio of environmental protection expenditures to total expenditures of the provincial government (*GovEnvironment*) as an instrumental variable (IV). The data are collected from the CSMAR database. Environmental protection expenditures of the local government usually include investments in environmental protection projects, environmental pollution regulations, and research on environmental protection technologies. *GovEnvironment* reflects the local government's emphasis on environmental protection and represents the pressure on environmental protection encountered by LSPs. Scholars have found that governmental pressure is an important factor that drives a company to engage in green innovation (Berrone et al., 2013; Lin et al., 2014). Thus, *GovEnvironment* would be positively associated with LSPs' green innovation. Nevertheless, environmental protection expenditures at the provincial level are unlikely to be related to an individual LSP's market value. To validate our speculation, we further ran a regression (Li et al., 2021) and found no significant relationship between *GovEnvironment* and market value (β=2.0175, $p > 0.1$). Therefore, *GovEnvironment* is an appropriate IV for our study. Since our model includes an inverted U-shape relationship, we follow Haans et al. (2016) and create separate instruments for GTI (*GovEnvironment*) and GTI^2 ($GovEnvironment^2$). We discover that in the second stage of 2SLS, the coefficient of the GTI is significantly positive (β=1.7174, p<0.1), while that of the GTI^2 is significantly negative (β=-0.4152, p<0.1). This finding further supports the inverted U-shaped relationship between green innovation and market value. We also conduct an under-identification and weak instrument test (Lu et al., 2018). The Kleibergen-Paap rk LM statistic is 4.456 (p<0.05), which implies that the equations are well identified. The Cragg–Donald–Wald F statistic is 11.030, which rejects the weak instrument hypothesis. Based on these analyses, we conclude that endogeneity will not influence our results.

4.4.3. Robustness Checks

We conduct several additional tests to verify the robustness of our findings. We winsorize our sample by dropping the 3% and 97% tails of the dependent variable (i.e., market value) to eliminate the potential bias of outliers. The results remain consistent with those reported in Table 4.4, suggesting our findings are robust.

In addition, we employ an alternative measure of Tobin's q, which is calculated by dividing the sum of a firm's market capitalization, the book value of its long-term debt, and its net current liabilities by the book value of its total assets (Misani and Pogutz, 2015). The results are in line with those in Table 5. Moreover, we use an alternative measure of firm size, measured with the natural logarithm of a firm's total sales (Trumpp and Guenther, 2017; Wang et al., 2008). The results remain unchanged, demonstrating the robustness of our results. All the results of robustness tests are presented in Table 4.5.

Table 4.5 Results of robustness checks

Variable	Winsorization		Alternative measure of Tobin's *q*		Alternative measure of firm size	
SCPE	-0.364**	(0.159)	-0.558**	(0.246)	-0.380**	(0.166)
SIE	0.150	(0.159)	0.020	(0.467)	0.110	(0.174)
PA	0.053	(0.064)	0.020	(0.115)	0.060	(0.069)
GTI	1.283*	(0.658)	1.341	(0.872)	0.898*	(0.538)
GTI^2	-0.350**	(0.158)	-0.352*	(0.207)	-0.252*	(0.135)
GTI × SCPE	0 .339**	(0.142)	0 .468**	(0.219)	0 .382***	(0.137)
GTI^2 × SCPE	-0.087***	(0.029)	-0.107**	(0.047)	-0.104***	(0.028)
GTI × SIE	-0.351**	(0.175)	-0.400	(0.403)	-0.336*	(0.171)
GTI^2 × SIE	0.096**	(0.039)	0.140*	(0.085)	0.104***	(0.037)
GTI × PA	-0.150*	(0.080)	-0.146	(0.103)	-0.096	(0.067)
GTI^2 × PA	0.043**	(0.020)	0.041*	(0.026)	0.028*	(0.018)
Size	-0.211*	(0.124)	-0.209	(0.213)	-0.385	(0.252)
Age	0.007	(0.032)	-0.005	(0.047)	0.007	(0.037)
Lev	0.013	(0.038)	0.062	(0.498)	0.023	(0.030)
RDI	-6.080	(6.158)	-15.871	(13.346)	-13.283	(8.841)
Ind_Size	0.004	(0.059)	0.020	(0.071)	0.012	(0.052)
Ind_Growth	0.234*	(0.133)	0.581**	(0.265)	0.381*	(0.199)
Ind_Comp	0.236	(0.441)	0.213	(0.569)	0.011	(0.011)
Year FE	Yes		Yes		Yes	
Firm FE	Yes		Yes		Yes	
R^2	0.144		0.087		0.110	

Notes: *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$ (two-tailed test). Robust standard errors are in parentheses.

4.4.4. Post hoc Interviews

Six *post hoc* interviews are conducted to validate and enhance the interpretation of our findings. For rigor and authenticity, interviewees are chosen from senior executives of LSPs in our sample, including top-level managers (e.g., Chief Technology Officer [CTO] and Vice President) from five express companies and one shipping company, which focus on road, air, and maritime freight operations. Before formal interviews, a semi-structured questionnaire is provided for participants to familiarize them with the research's context and objectives. Each interview, lasting 40 to 60 minutes, is held either online or face-to-face.

Initial warm-up questions inquire about executives' backgrounds and employment histories. Questions pertinent to this study aim to identify these LSPs' green innovation investment strategies. Furthermore, we intend to unravel how these LSPs collaborate with supply chain partners and scientific institutions to conduct green innovation and the effectiveness of such collaborations. Throughout the interviews, we try not to impose unsolicited study results.

From the interviews, we find a consensus among these LSPs that efficiency improvement is the essential starting point for their green innovation choices. For example, a vice president of an express company points out that the company has about 300 million parcels to transport per day, and implementing green innovation to reduce costs and enhance efficiency would significantly impact economic performance. In addition, all interviewees stated that an optimal level of investment must be considered when making green innovation decisions. Some green technologies with long-term potential, like new energy trucks for long-distance transport, require further development, and the investment feasibility of such technologies depends on policy support.

When answering questions on collaboration with external stakeholders on green innovation, these executives say that SCPE and SIE exert differential effects on the efficacy of green innovation. A CTO states that "*the LSP is working more with supply chain partners for green innovation from the cost-reduction and efficiency-improvement perspective. For example, to promote green packaging, we need to work with supply chain members because the ownership of the goods, including packaging, belongs to suppliers and customers.*" By contrast, these executives state that scientific institutions are not favored partners for conducting collaborative green innovation. One vice president suggests that collaborating with scientific institutions for green innovation adoption does not generate benefits in the short run, as many of their green technologies are still experimental and take a long time to reach the application stage.

Moreover, one vice president states, "*Our previous green innovation collaborations with universities reveal that they struggle to grasp our business scenarios and require us to help them understand complex scenarios, thus resulting in high costs*". Nevertheless, these executives also note that scientific institutions are developing many cutting-edge green technologies, which are still in the pilot phase and require considerable investments. Thus, their LSPs hesitate to invest in these emerging green technologies because they focus on cost reduction and efficiency improvement.

In short, the Chinese logistics industry faces significant competitive pressure, so cost reduction and efficiency improvement are critical considerations for these LSPs when investing in green innovation. As a result, LSPs tend to collaborate with supply chain partners, focusing on quicker returns on investment and more economic benefits. The *post hoc* interviews further verify our research findings regarding the differential moderating effects of SCPE and SIE on the green innovation–market value relationship.

4.5. Discussion

4.5.1. Theoretical Contributions

This study makes multiple theoretical contributions. First, it expands the green innovation literature by empirically uncovering the inverted U-shaped impact of green innovation on market value in the Chinese logistics context. Previous studies have primarily concentrated on how green innovation affects manufacturing firms' environmental performance (Abu Seman et al., 2019; Rehman et al., 2021), operational performance (Wijethilake et al., 2018); financial performance (Lee et al., 2015; Xie et al., 2019), and stock returns (Ba et al., 2013). Although scholars have underscored that green innovation may yield both benefits and drawbacks for firms (Ba et al., 2013; Driessen et al., 2013), scant research has reconciled the existing controversial views and examined the non-linear effect of green innovation on firms' market value. More importantly, the extant research on green innovation has mainly centered on manufacturing industries, yet rare efforts have been devoted to logistics. Indeed, the logistics activities in China have grown dramatically and resulted in severe environmental damage, such as excess GHG emissions (Tian et al., 2022), which calls for more research investigating green innovation in the Chinese logistics industry (Chu et al., 2019). Accordingly, our study advances the green innovation literature by offering sound empirical evidence on the inverted U-shaped impact of green innovation on LSPs' market value.

Second, this study sheds light on the green innovation literature by providing a nuanced understanding of the boundary conditions of the inverted U-shaped green innovation–market value relationship. Our results indicate that SCPE steepens the inverted U-shaped linkage between green innovation and market value, whereas SIE flattens this linkage. This finding aligns with the notion that engagement with supply chain partners allows firms to acquire valuable and complementary resources from supply chain members and share costs with them (Acebo et al., 2021; Melander, 2017). Thus, SCPE enables LSPs to derive more value from green innovation. Conversely, engagement with scientific institutions may lead to misaligned environmental objectives between firms and scientific institutions (Zhou et al., 2021), weakening green innovation's market value effect. While previous studies have underlined that stakeholder engagement plays a crucial role in firms' implementation of green innovation (Acebo et al., 2021), little is known about how two different types of stakeholder engagement (i.e., SCPE and SIE) alter the efficacy of green innovation on firms' market value. In this sense, we extend this research stream by empirically unraveling the distinct moderating effects of SCPE and SIE on the inverted U-shaped association between green innovation and market value.

Moreover, our study verifies that public attention attenuates the efficacy of green innovation on market value, revealing its potential downside. Prior studies have primarily examined how public attention influences firms' environmental practices (Cheng and Liu, 2018; Du et al., 2019; El Ouadghiri et al., 2021), yet insufficient attention has been paid to untangling its moderating effect on green innovation–market value relationship. In this regard, our study broadens the extant green innovation literature by providing fine-grained insights into how public attention modifies the efficacy of green innovation on LSPs' market value.

Finally, this study enriches the RBV and stakeholder theory literature by demonstrating the interplay of green innovation, stakeholder engagement, and public attention in shaping the market value of LSPs. By integrating RBV (Barney, 1991) and stakeholder theory (Freeman et al., 2021), we theoretically verify that green innovation can help LSPs save resources and gain support from stakeholders (Abbasi and Nilsson, 2016). Nevertheless, the marginal benefits will diminish gradually, and beyond an optimal level, the associated costs will outweigh the benefits. This finding leads to an inverted U-shaped relationship between green innovation and market value, largely overlooked by previous studies. As such, our research contributes to the theoretical advancement of the RBV and stakeholder theory literature by attesting to the inverted U-shaped green innovation–market value association, particularly in the context of the logistics industry.

Furthermore, our study adds to the stakeholder theory by validating that different types of stakeholder engagement (i.e., SCPE and SIE) exert differing influences on the mechanisms underlying the green innovation–market value linkage. A more granular analysis of stakeholder engagement in the context of green innovation also enriches the RBV literature by illuminating how LSPs can better utilize external stakeholders' resources to adopt collaborative green innovation (Chen and Hung, 2014). Moreover, our research highlights the role of the public, as non-engaged stakeholders, in influencing the extent of market value brought by green innovation. Our study verifies that public attention is an essential contingency factor that alters the green innovation–market value relationship. This finding adds to the stakeholder theory literature by providing valuable insights for LSPs striving to balance their stakeholders' diverse expectations and requirements.

4.5.2. Managerial Implications

This study also offers insightful implications to managers. First, our findings highlight that the green innovation of LSPs has an inverted U-shaped effect on their market value. This finding indicates that intermediate green innovation levels can yield greater market value for LSPs than low or high green innovation levels. Therefore, we strongly recommend that LSPs with low degrees of green innovation proactively embark on technology-driven green innovation activities to fully reap the associated benefits (e.g., resource savings and reputation improvement) and thus enhance market value. For example, they can devote efforts to developing energy-efficient material handling equipment and new energy vehicles. Nonetheless, managers in listed LSPs should also be cautious that after passing an optimal level, extra investment in green innovation is detrimental to market value in the short term since this could incur substantial costs but create few benefits. Hence, managers need to be more wary of excessive investment in green innovation, under which the drawbacks of green innovation will outweigh the associated benefits, thereby leading to declining market value for LSPs.

Second, managers should know that SCPE steepens the inverted U-shaped green innovation–market value association, whereas SIE flattens this association. As such, it is highly advised that when embarking on green innovation, LSPs should prioritize the engagement with their supply chain members to reinforce the effectiveness of green innovation on market value. Supply chain partners are recommended to take an active role in collaborative technology-driven green innovation activities and exchange valuable knowledge and information with LSPs to facilitate the adoption of green innovation. Nevertheless, managers need to be mindful that considering the misalignment between the objectives of LSPs and those of scientific institutions, SIE attenuates the efficacy of green innovation on market value. Given this, it is advised that when implementing green innovation, LSPs should increase their efforts to reduce the divergence in objectives between them and scientific institutions to alleviate the potential downside of SIE. For example, LSPs can frequently communicate with scientific institutions to reach congruent objectives and carefully manage collaborative green innovation (Ankrah and AL-Tabbaa, 2015). Scientific institutions should also keep a close eye on divergent objectives and dedicate more efforts (e.g., extensive communication with LSPs) to resolve this issue arising from collaborative green innovation.

Third, our finding suggests that public attention attenuates the inverted U-shaped relationship between green innovation and market value. Hence, managers in listed LSPs should take heed of this attenuating effect and carefully oversee the level of public attention. It is recommended that LSPs in China keep a low profile when conducting green innovation, as more public attention is needed to enhance their market value. In short, a "greenhushing" strategy – to dedicate efforts to green innovation quietly – seems viable in the context of the Chinese logistics industry.

Finally, the logistics industry in China is still in its infancy, and many LSPs are hesitant to commit resources to green innovation. Hence, government bodies should enact preferential policies to motivate LSPs to engage more in green innovation. For example, they can provide financial subsidies and tax benefits for LSPs to help them offset costs and stimulate the implementation of emergent green technologies, such as alternative fuels and long-distance new energy trucks. Moreover, the government can establish supportive regulations, standards, and guidelines to drive LSPs to undertake green innovation proactively. In addition, considering the divergence in environmental objectives between LSPs and scientific institutions, the government could formulate some policies to facilitate knowledge sharing and collaboration to resolve this issue. For instance, the government can provide resources to support workshops, conferences, and the establishment of industry-scientific institution networks. By doing so, the government can help bridge the gap between LSPs and scientific institutions, enabling the exchange of ideas and speeding the diffusion of green innovation.

4.6. Conclusions, Limitations, and Future Research

Drawing upon RBV and stakeholder theory, this study investigates the relationship between green innovation and LSPs' market value and the moderating effects of stakeholder engagement and public attention. We find an inverted U-shaped linkage between green innovation and market value using panel data from 53 publicly listed Chinese LSPs from 2011 to 2021. Furthermore, SCPE steepens the inverted U-shaped linkage, while SIE and public attention flatten this linkage. In addition, we validate and interpret our research findings through *post hoc* interviews.

Although our research yields several key insights into the market value effect of green innovation, it has a few limitations that reveal future research directions. First, our study focuses on the Chinese context, which might constrain the generalizability of our findings. Due to China's unique cultural, institutional, and economic environments, caution is warranted in extending our findings to the context of other countries. A promising avenue for future research is to collect data from multiple countries to validate our results, which could proffer more implications regarding the effect of green innovation on market value. Second, we recognize the limitation of our study's small sample size, primarily attributed to the limited number of listed LSPs available for analysis. Future research is encouraged to expand the sample size, which could further improve our findings' robustness and provide a solid foundation for green innovation adoption in the logistics industry. Third, this research evaluates the pivotal roles of several moderators in altering the curvilinear green innovation–-market value relationship from the stakeholder theory perspective, yet other contingency factors (e.g., operational capabilities and industry environments) may also affect this relationship and deserve further attention. Thus, future studies could explore other potential contextual factors that may shape the association between green innovation and market value. Finally, we unpack the impact of green innovation on LSPs' market value. Future research is worthwhile in examining the spillover effect of green innovation on the market value of LSPs' suppliers and customers.

Chapter 5 Study 3: Incremental or Radical? The Effects of Green Innovation on the Supply Base Stability of Logistics Service Providers

5.1 Introduction

Over the past two decades in China, the total volume of inland freight has expanded almost sevenfold, reaching 15.25 million ton-kilometers in 2018 (OECD, 2023). This exponential growth in logistics activities has given rise to significant environmental challenges, including GHG emissions, toxic waste production, and noise and water pollution (Lin and Ho, 2011; Murphy and Poist, 2003). Consequently, many Chinese LSPs are actively plunging into green transformation. They predominantly pursue two principal avenues for developing green technologies (Shou et al., 2023). The first avenue focuses on optimizing and refining existing operational processes, such as employing intelligent transportation systems to cut mileage and increase operational efficiency, optimizing flight plans, and adopting slow steaming to lower GHG emissions. These practices are a form of incremental green innovation (IGI), concerned with environmental improvements that leverage existing resources and competencies (Cui et al., 2022; Dai et al., 2015; Zhang et al., 2020). For instance, by optimizing transport trunk routes, ZTO Express has reached a 99.93% utilization rate of its transport network, equivalent to averting the felling of approximately 520,000 fast-growing eucalyptus trees (ZTO, 2023). The second avenue involves embracing emerging environmental technologies for decarbonizing the logistics industry, including utilizing new energy vehicles, alternative and clean fuels, and recyclable packaging materials. This avenue represents a form of radical green innovation

(RGI), which significantly departs from LSPs' current knowledge base (Cui et al., 2022; Liao, 2020). For example, in 2021, China Eastern Airline, COSCO Shipping, and SINOPEC jointly completed the "Whole Life Cycle Carbon Neutral Oil" project, realizing carbon neutrality throughout the entire process of aviation fuel production and utilization (China Eastern, 2022).

In their quest for green innovation, LSPs can benefit from reevaluating and upgrading their relationships with upstream suppliers since suppliers are one of the most important external resources and knowledge (Sureeyatanapas et al., 2018). In the logistics industry, primary suppliers provide LSPs with critical components and services such as transportation outsourcing, vehicles, fuels, and various logistics equipment and materials (Bellingkrodt and Wallenburg, 2013). These inputs offer LSPs significant potential for environmental performance improvements, such as adopting green packaging, logistics optimization, clean fuels, and energy-efficient vehicles. At the same time, LSPs' pursuit of green innovation may affect their adjustment of supplier relationships. A notable example is DHL Express's purchase of 12 fully electric freighters from Eviation, an all-electric aircraft manufacturer, aiming to establish an electrified international express delivery network (DHL, 2021).

However, changes in supplier relationships and structures can also influence supply base stability (SBS), which refers to the continuity and consistency of upstream supply chain relationships and orders (Anderson et al., 2000; Kim and Springer, 2008). The instability in the supply base can lead to adverse outcomes like inconsistent material supply and reduced purchase discounts (Gu et al., 2022; Peng et al., 2020; Yang et al., 2023). For instance, shipping companies, which often outsource a portion of their capacity, have experienced shifts in cargo ships away from Asia toward the US, prompted by a pandemic-driven change from services to products in US consumption patterns. This instability in the supply base has resulted in a significant increase in shipping costs across the entire Asian region (DHL, 2021).

Therefore, LSPs encounter a potential trade-off between the environmental advantages of green innovation and the desire to maintain SBS, underscoring the imperative for further investigation. While current research on green innovation has predominantly focused on intra-firm performance (Rehman et al., 2021; Shou et al., 2023; Valero-Gil et al., 2023), there is a lack of research investigating how green innovation impacts LSPs' SBS. This is significant, given that stable suppliers enable LSPs to provide consistent and reliable services to fulfill customers' requirements (Gu et al., 2022; Peng et al., 2020; Yang et al., 2023). To narrow this knowledge gap, this study explores the effects of IGI and RGI on LSPs' SBS and the contingent factors influencing the direction and strength of the effects. Utilizing the recombinant search theory (RST) (Fleming, 2001; Jung and Lee, 2016), we posit that IGI, which involves recombining existing knowledge components within LSPs and their supply bases, is anticipated to stabilize supply bases. Conversely, RGI, characterized as a form of distant search, can induce significant shifts in the relationships and structures between LSPs and their suppliers, thereby impairing SBS. Moreover, the traits of the top management team (TMT) can significantly impact the implementation and outcomes of green innovation (He et al., 2021; Liao et al., 2022; Ma et al., 2021; Sun et al., 2023). Recognizing the TMT's importance in green innovation, our investigation extends knowledge on how TMT values and characteristics (e.g., growth orientation and board environmental expertise) alter the effects of different green innovations on SBS.

We compile archival data from multiple sources to examine the proposed hypotheses and obtain a dataset of 88 large LSPs in China, covering the years 2011 to 2019. Our analysis reveals that IGI increases LSPs' SBS while RGI decreases their SBS. Interestingly, we discover that both growth orientation and board environmental expertise help mitigate the negative impact of RGI on SBS. Still, they do not significantly alter the impact of IGI on SBS.

This study yields theoretical contributions on three fronts. First, this study explores the distinct impacts of IGI and RGI on SBS within the Chinese logistics industry, enriching the literature on green logistics beyond their conventional focus on environmental and financial performance to consider its implications for the broader upstream supply chain management. Second, this study unravels the roles of local and distant search processes in the green innovation of LSPs, extending RST's scope from the knowledge base to the supply base. Lastly, this research illuminates the critical yet neglected roles of growth orientation and board environmental expertise in shaping the impacts of green innovation on SBS. By examining how these managerial traits influence the effectiveness of green innovation, the study offers LSPs critical insights into managing SBS more effectively.

5.2. Theoretical Background and Hypotheses Development

5.2.1. Recombinant Search Theory and Green Innovation

Scholars have highlighted that recombination is the fundamental source of novelty, driving advancements and breakthroughs across various fields (Fleming, 2001; Jung and Lee, 2016; Kaplan and Vakili, 2015; Shi et al., 2020). RST holds that knowledge consists of different components: concepts, data, skills, and technologies (Fleming, 2001). Creating any novelty, whether in art, science, or practical applications, largely relies on recombining these existing knowledge components (Jung and Lee, 2016; Kaplan and Vakili, 2015). This knowledge recombinant mechanism applies to green innovation in the logistics industry. For LSPs, green innovation refers to adopting green technologies, products, or processes in logistics activities that mitigate adverse environmental impacts by improving resource efficiency and reducing environmental pollution (Lai and Wong, 2012; Shou et al., 2023). Following previous research on innovation management (Fleming, 2001; Kneeland et al., 2020; Schilling and Green, 2011), we further focus on two prevalent innovation approaches: local search and distant search.

"Local search" arises when inventors recombine components from a familiar knowledge base or refine a combination previously utilized (Fleming, 2001). Most inventors typically conduct exploitation within the "neighborhood" of their previous successful innovations, adhering closely to known and tested fields (Kneeland et al., 2020). Consequently, they can effectively sift out failed knowledge base areas and focus on areas with greater potential and lower uncertainty. In the realm of green innovation, IGI can be perceived as a form of local search, which involves the enhancement or utilization of existing technologies, products, and processes to address environmental concerns swiftly (Cui et al., 2022; Dai et al., 2015; Zhang et al., 2020). Specifically, for LSPs, IGI centers on optimizing and improving existing processes to enhance energy efficiency and reduce emissions, including route and loading optimization and energy-saving transportation equipment modifications (Shou et al., 2023). IGI is characterized as relatively stable and low-risky, given that it typically presents a lower threshold for breakthroughs (Zhang et al., 2022).

"Distant search" occurs in the opposite situation of local search, when inventors explore fresh ideas and new opportunities from distant or diverse knowledge bases (Fleming, 2001; Hou et al., 2023; Kaplan and Vakili, 2015). Such broad information searching and recombination of varied types of knowledge can break conventional bonds and inspire creativity, potentially leading to creations with high novelty and economic value (Kaplan and Vakili, 2015). However, this exploratory process introduces a heightened level of uncertainty as inventors navigate through unfamiliar components and combinations, culminating in a more complex knowledge base (Fleming, 2001; Kneeland et al., 2020). As a distant search approach to green innovation, RGI represents a firm's novel creations in green products or processes, achieved through the development or introduction of radical environmental technologies (Cui et al., 2022; Liao, 2020; Omri et al., 2024). For LSPs, RGI involves transformative changes and new inventions regarding green products or processes, such as developing new energy vehicles, utilizing alternative and clean fuels, and introducing recyclable packaging (Shou et al., 2023). Although RGI can potentially significantly lessen fuel consumption and emissions in logistics operations, it spans multiple knowledge and technological domains, thus inducing considerable complexities and uncertainties (Cui et al., 2022; Zhang et al., 2020).

5.2.2. Supply Base Stability

Extant SBS literature has underscored the importance of sustaining long-term and stable supplier relationships (Chatain, 2011; Kumar et al., 2020; Yang et al., 2008). A stable supply base enhances focal firms' competitiveness, which is attributed to the resultant benefits such as high-quality products and services, consistent material supply, purchase discounts, and efficient sharing of timely information (Gu et al., 2022; Peng et al., 2020; Yang et al., 2023). Conversely, volatility in a firm's supply base harms its operations, implying unreliability and potential disruptions in its supply chain (Kumar et al., 2020).

The instability in firms' upstream supply chains originates from multiple sources, with a notable cause being the volatility that results from the amplification effect, which refers to the phenomenon where fluctuations arising from the downstream firms intensify as they propagate upstream to their supply bases (Anderson et al., 2000; Kim and Springer, 2008). Specifically, such amplification can be driven by various factors within the focal firm, including unstable production processes, self-induced price variations, inaccurate forecasting, shifts in market strategies, or changes in production requirements (Nitsche and Durach, 2018). Green innovation will likely induce significant fluctuations in a firm's operational processes, thus affecting the upstream supply chain. In the logistics industry, major suppliers provide LSPs with essential components such as outsourced transportation, vehicles, fuels, and various logistics equipment and materials, which offers considerable scope for improving LSPs' environmental performance. These sourcing characteristics of LSPs may lead to more acute effects on the supply base when they strive for more environmentally friendly operational processes and technologies. However, a significant gap exists concerning the impact of green innovation on the supply base, which inhibits an in-depth understanding of the supply chain implications of green innovation. Consequently, this study aims to shed new light on the green innovation and green logistics literature by examining how the implementation of green innovation by LSPs, whether through more gradual, incremental improvements (i.e., IGI) or significant, transformative changes (i.e., RGI), affects the stability in their supply bases.

5.2.3. Green Innovation and SBS in the Logistics Industry

As illustrated before, the IGI of LSPs primarily denotes improving existing products, processes, or technologies to reduce their environmental harm (Cui et al., 2022; Liao, 2020). Based on RST, IGI involves recombining existing knowledge components from LSPs and their supply bases to foster environmental sustainability. During the local search for existing green knowledge components, the shared knowledge base between LSPs and their suppliers is further developed and refined, which enhances the mutual understanding of each party's respective knowledge and capabilities (Howard et al., 2016; Wang and Hu, 2020). Consequently, IGI facilitates increased communication and collaboration between LSPs and their suppliers regarding energy-saving and emission reduction, which is beneficial for LSPs in achieving environmental goals. Hence, we posit that IGI fosters the development of long-term, stable relationships between LSPs and their suppliers, leading to a more stable supply base.

H1. *Incremental green innovation increases LSPs' supply base stability.*

In contrast, RGI is more uncertain and complex as it involves searching multiple knowledge bases and technological domains (Cabigiosu, 2022; Zhang et al., 2022). In line with the observation of Meyer-Krahmer and Schmoch (1998), the “logistics” technology sector is relatively less grounded in scientific research than other more advanced technological domains. Consequently, the green knowledge components essential for RGI may not be readily accessible within an LSP’s existing knowledge base and supply base. Therefore, LSPs striving to integrate ground-breaking green components, such as alternative fuels, new energy vehicles, and recyclable packaging, must extend their search beyond their existing supply bases (Shou et al., 2023). Such a distant search may significantly modify the relationships and structures between LSPs and their suppliers, potentially compromising stability in the supply base.

H2. *Radical green innovation decreases the LSPs’ supply base stability.*

5.2.4. The Moderating Effect from the Top Management Team Perspective

TMT significantly influences organizational outcomes through strategic decisions, which are profoundly influenced by top managers’ experiences, preferences, and values (Hambrick, 2007). In other words, an organization’s strategic decision-making fundamentally reflects its TMT members (Mintzberg et al., 1976). Furthermore, the traits of TMT significantly influence organizational operations, innovation, and performance (Hambrick, 2007; Mintzberg et al., 1976). In the context of green innovation, various TMT values and characteristics, such as attention allocation and academic experience, can impact the implementation and outcomes of these green innovation initiatives (He et al., 2021; Liao et al., 2022; Ma et al., 2021). Therefore, we investigate how changes in LSPs' SBS, stemming from green innovation, are influenced by two TMT factors: growth orientation and board environmental expertise.

5.2.4.1 The Moderating Effect of Growth Orientation

Growth orientation, defined as a preference for prioritizing high growth over profits, reflects an outwardly focused development mode that seeks to expand a firm's size and operational scope (Zhou and Park, 2020). Growth is pivotal in attracting essential external resources, facilitating LSPs to secure competitive advantages within their markets (Chen et al., 2009). Therefore, as society gravitates toward sustainable development, executive boards with a growth mindset are increasingly inclined to channel investments into green innovation. Simultaneously, growth orientation increases external complexity as firms build many relationships, connecting with government entities, scientific institutions, and upstream and downstream firms (Sheng et al., 2011). This expanded relationship network enriches LSPs' existing knowledge base. It reduces the necessity for distant knowledge searches during the implementation of RGI, thereby alleviating the impact of RGI on supplier relationships.

Moreover, the extent of an LSP's growth, especially in emerging markets such as China, relies on efficient guanxi management (Sheng et al., 2011; Zhou and Park, 2020). Hence, growth-oriented LSPs are less motivated to engage in indiscriminate supplier switching during green innovation, as maintaining existing supplier partnerships can be integral to an LSP's steady growth. This preference can reinforce local search efforts within IGI while mitigating the extent of distant search within RGI.

H3a. *A growth orientation strategy strengthens the positive relationship between incremental green innovation and supply-base stability.*

H3b. *A growth orientation attenuates the negative relationship between radical green innovation and supply-base stability.*

5.2.4.2 The Moderating Effect of Board Environmental Expertise

We further explore the moderating effects of board environmental expertise. Many studies have demonstrated that the expertise of executives in specific fields considerably influences a company's development and innovation. In the context of green innovation, the environmental expertise of executives is a critical "green" knowledge component embedded in LSPs' knowledge base. Specifically, throughout the LSPs' development, including establishing their supply bases, these executives have built a certain level of environmental capability for LSPs. Consequently, the enriched knowledge base may reduce the imperative for the distant search of green components during RGI while strengthening the local search process within IGI.

Moreover, executives with an environmental background are often more adept at understanding and managing the integration of green innovation into established business models and supply chains (Meng et al., 2023; Zhu et al., 2023). Thus, LSPs possessing greater board environmental expertise demonstrate improved capability in conducting local searches for the development of IGI, thus enhancing SBS to a large extent. In addition, they can balance the need to pursue breakthrough green innovation and maintain a stable supply base. Therefore, board environmental expertise will alleviate the supplier changes brought by distant knowledge search, as executives are more proficient in adapting to environmentally conscious suppliers and tackling environmental challenges.

H4a: *Board environmental expertise strengthens the positive relationship between incremental green innovation and supply base stability.*

H4b. *Board environmental expertise attenuates the negative relationship between radical green innovation and supply-base stability.*

Figure 5.1 shows the conceptual model of this study.

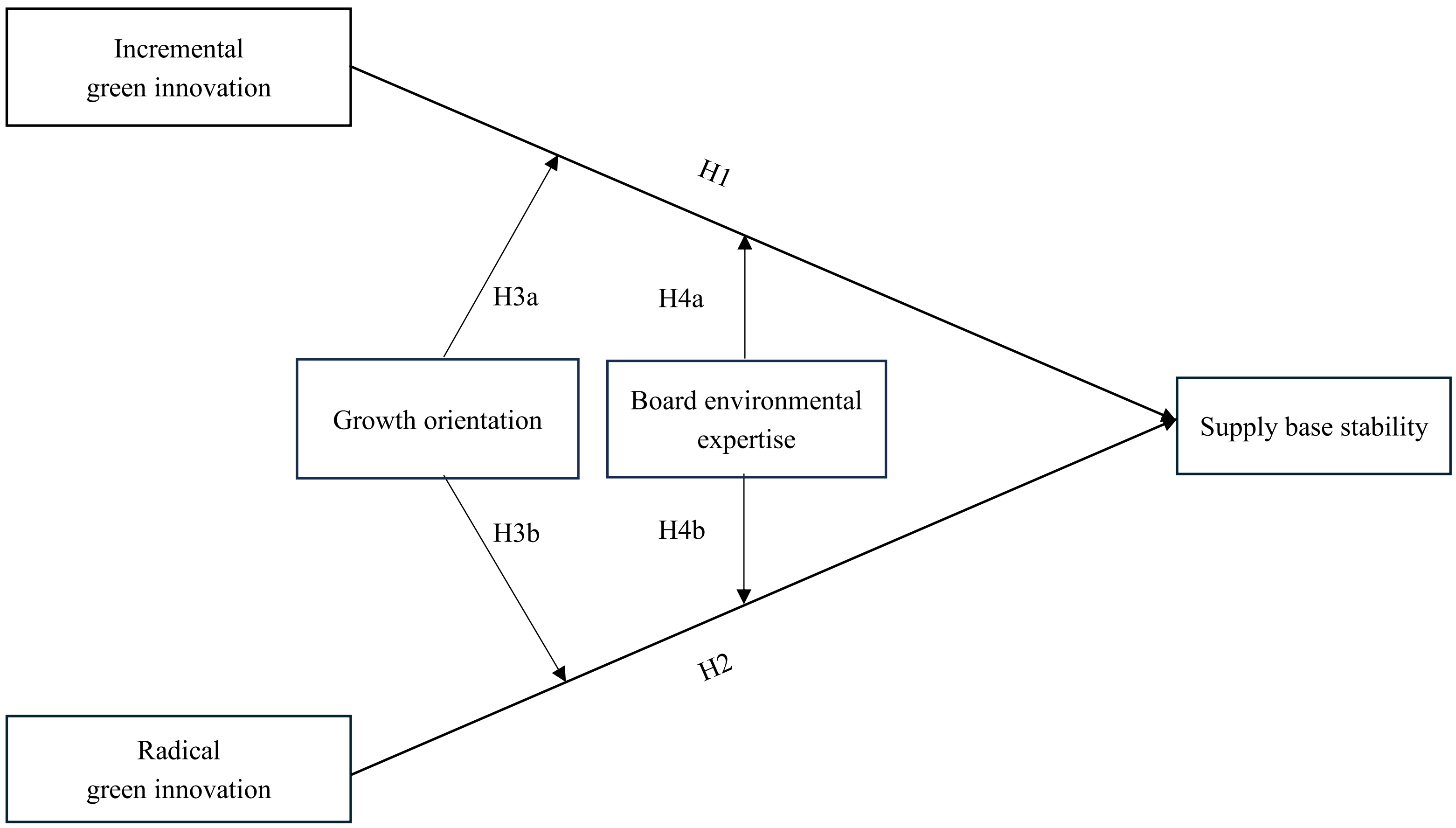


Figure 5.1 Conceptual model

5.3. Method

5.3.1. Sample and Data

Secondary data on Chinese-listed LSPs are collected through various sources to validate our hypotheses. The original dataset encompasses 132 firms listed on China's Shenzhen and Shanghai Stock Exchanges, specifically within the transportation, storage, and postal sectors. This study employs green patent data from the Chinese Research Data Services (CNRDS) database to measure green innovation (i.e., IGI and RGI). Since the data on green patents in the Chinese logistics industry are predominantly available from 2011, we select 2011–2019 as the timeframe for our analysis. Specifically, the "green list" in the International Patent Classification system, designed by the World Intellectual Property Organization, identifies green patents. Besides, data regarding the top five suppliers' purchase ratios and board member's resume text are sourced from the China Stock Market and Accounting Research (CSMAR) database. Other financial data for the LSPs are also gathered from the CSMAR database.

From the original set of 132 companies, we remove 38 firms concentrating on non-logistics operations. Additionally, six companies are excluded due to incomplete data on relevant variables, leaving 88 LSPs in our final sample. The measurement of SBS in our study utilizes purchase ratio data from the top five suppliers over three consecutive years. Consequently, the dependent variable, SBS, incorporates purchase ratio data from 2011 to 2021. Our final sample includes 360 firm-year observations of 88 LSPs from 2011 to 2019. Table 5.1 shows the sample distributions by year and industry.

Table 5.1 Sample overview

Sample distribution by year	Frequency	%	Sample distribution by industry	Frequency	%
2011	8	2.22	G53 Railway transport	15	4.17
2012	23	6.39	G54 Road transport	89	24.72
2013	14	3.89	G55 Water transport	129	35.83
2014	19	5.28	G56 Air transport	59	16.39
2015	25	6.94	G58 Stevedoring service	17	4.72
2016	52	14.44	G59 Storage service	37	10.28
2017	63	17.50	G60 Postal service	14	3.89
2018	75	20.83	Total	360	100
2019	81	22.50			
Total	360	100			

5.3.2. Measures

Dependent variable. Building on earlier research methods (Peng et al., 2020; Yang et al., 2023), this study quantifies supply base instability as the variation in supplier concentration over three continuous years. Since Chinese public firms are only required to disclose information about the top five suppliers, we calculate the firm's supplier concentration (SC) as the sum of the purchase ratio for the top five suppliers as follows:

$$SC_{i,t} = \sum_{j=1}^{5} Purchase\_ratio_{i,j,t}$$

where $Purchase\_ratio_{i,j,t}$ represents the purchase ratio of firm *i* from its *j*-th largest supplier in year *t*. Then, we compute the standard deviation of $SC_{i,t}$, $SC_{i,t+1}$, and $SC_{i,t+2}$ and denotes it as $SD_{i,(t,t+1,t+2)}$, using the following equation:

$$SD_{i,(t,t+1,t+2)} = \sqrt{\left(SC_{i,t} - \overline{SC}\right)^2 + \left(SC_{i,t+1} - \overline{SC}\right)^2 + \left(SC_{i,t+2} - \overline{SC}\right)^2}$$

where $\overline{SC}$ is the average of $SC_{i,t}$, $SC_{i,t+1}$, and $SC_{i,t+2}$. Finally, the measure of *supply* *base stability* (SBS) is given by:

$$SBS_{it} = -\frac{SD_{i,(t,t+1,t+2)}}{\overline{SC}}$$

Thus, SBS is estimated by the negative ratio of the standard deviation of supplier concentration for three continuous years to the average of supplier concentration in the same period. This method normalizes the variance in purchase amounts from the top five suppliers, ensuring comparability across different LSPs.

Independent variables. Following prior studies (Cui et al., 2022; Lin and Ma, 2022), the quantity of green patent applications is used to assess green innovation. Avoidance of granted green patents is due to time lag disruptions, as the approval process of patents in China can take several years. Moreover, China issues two principal types of patents: utility model patents, which address technical solutions concerning the configuration, structure, or materials of objects, and invention patents, which relate to new, inventive, and practical technical advancements. Following this classification, this study distinguishes between green utility model patents and green invention patents to represent IGI and RGI, respectively (Cui et al., 2022). Specifically, to address potential skewness in variables (Wu et al., 2022), we measure *incremental green innovation* (IGI) using the natural logarithm transformation of the sum of one and the count of green utility model patent applications. Similarly, *radical green innovation* (RGI) is measured by applying the same logarithmic transformation of green invention patent counts.

Moderating variables. First, following Zhou and Park (Zhou and Park, 2020), we employ the total asset growth rate and the return on assets (ROA) as indicators of firm growth and profitability, respectively. We calculate asset growth rate as the yearly percentage change in total assets, while ROA is computed based on the ratio of net income to total assets for each year (Cooper et al., 2008). Then, we define *growth orientation* (Growth) as a dummy variable, which is assigned the value of 1 for firms that exhibit a growth rate exceeding the industry average but profitability below the industry average throughout the observation period; otherwise, this variable is assigned the value of 0 (Zhou and Park, 2020).

Second, the original text data on board environmental expertise are derived from personal resume information collected in the CSMAR database. This study conducts a textual analysis of the resumes of board members from each listed LSP. The presence of keywords such as "eco-friendly," "environment-friendly", "sustainable," "renewable energy", "carbon reduction", and "green" within a resume qualifies the individual as having an environmental background (Meng et al., 2023; Zhu et al., 2023). Based on this method, the study counts board members with an environmental background. Hence, *board environmental expertise* (BEE) is quantified by the ratio of board members possessing environmental expertise to the overall board count.

Control variables. We control for several variables to mitigate factors that may impact firms' SBS. First, we consider firm size and age as control variables. Existing studies suggest that younger and smaller firms typically have access to a more diverse array of resources than their larger and older counterparts, potentially influencing their supply base management (Field and Meile, 2008; Hiebl and Pielsticker, 2023). *Firm size* (Size) is quantified using the natural logarithm of the firm's total assets, while *Firm age* (Age) is determined by the natural logarithm of the number of years since the firm's establishment.

Additionally, the financial conditions of customers, which can influence a major supplier's financial health, are considered (Lian, 2017). We, therefore, control for financial leverage, Tobin's *q*, and equity-to-debt ratio. Financial leverage reflects financing risk that may impact suppliers' capital structure (Oliveira et al., 2017). We quantify *financial leverage* (Lev) as the long-term debt ratio to total assets (Ghosh and Jain, 2000). Tobin's *q* (TobinQ) is calculated as the ratio of a firm's market capitalization to the book value of its total assets (Nekhili et al., 2017). *Equity-to-debt ratio* (ETD) is calculated as the proportion of shareholders' equity to total liabilities (Duke and Hunt, 1990). Moreover, this study considers instances where operational issues within a firm lead to upstream volatility (Anderson et al., 2000; Nitsche and Durach, 2018). Therefore, we control *inventory turnover* (Inventory), calculated by the ratio of the realized sales to the yearly finished goods inventory (Shan and Zhu, 2013). We also account for *labor productivity* (Productivity), computed as the ratio of the realized sales to the number of employees (Deng et al., 2020).

The study also incorporates various industry-level variables, as previous research indicates that industry contexts can influence firms' SBS (Nitsche and Durach, 2018). *Industry size* (In_size) is defined as the natural logarithm of the total assets of all firms within the same three-digit China Securities Regulatory Commission (CSRC) industry, following the approach of Xue et al. (Xue et al., 2012). *Industry growth* (In_grow) is determined by the sales growth rate within the same industry (Xue et al., 2012). To measure *Industry competition* (In_comp), we use a complement of the Herfindahl index, calculated as one minus the sum of the squares of the market shares of all firms in the same three-digit CSRC category (Xue et al., 2012). Lastly, year dummies are used to control for unobserved heterogeneity specific to different periods.

5.3.3. Model Specification

Due to the lagged impact of green innovation on SBS, we assess SBS for the three continuous years immediately following the implementation of green innovation. Additionally, we perform the Wald test, as suggested by Chou and Bentler (Chou and Bentler, 1990), to check for heteroskedasticity. Our findings confirm that this issue does affect our data. As such, we use robust standard errors to estimate the firm fixed-effect regression models, which help to mitigate this problem and control for unobservable time-invariant firm heterogeneity. We utilize the following equation to examine our hypotheses:

$$SBS_{it} = \beta_0 + \beta_1 IGI_{it} + \beta_2 RGI_{it}$$

$$+\beta_3 Growth_{it} + \beta_4 IGI_{it} \times Growth_{it} + \beta_5 RGI_{it} \times Growth_{it}$$

$$+\beta_6 BEE_{it} + \beta_7 IGI_{it} \times BEE_{it} + \beta_8 RGI_{it} \times BEE_{it} + \beta_i Control_{it} + \gamma_i + \eta_t + \varepsilon_{it}$$

where β_0 denotes the intercept, β_n signifies the coefficients for the explanatory variables, γ_i represents the firm fixed effect, η_t indicates the year fixed effect, and ε_{it} is the error term; all variables are described in the above section.

5.4. Analyses and Results

5.4.1. Main Results

Table 5.2 displays the descriptive statistics for all variables, while Table 5.3

presents their correlation matrix. Additionally, this study confirms that multicollinearity does not pose a significant issue by examining the variance inflation factor values for all variables and noting that they fall below the threshold of ten (Menard, 2001).

Table 5.4 presents the results of the firm fixed-effects regression analyses. Model 1 examines H1 by including IGI and all moderating and control variables. Model 2 assesses H2, incorporating RGI with the same set of variables. Model 3 introduces interaction terms related to growth orientation to test H3a and H3b. Model 4 evaluates H4a and H4b by including BEE-related interaction terms. Finally, Model 5 is the full model that combines the analyses of all hypotheses.

Model 1 reveals a significant, positive estimated coefficient for IGI (β=0.067, p<0.01), which validates the positive relationship between IGI and SBS, thereby supporting H1. Furthermore, Model 2 shows a significant negative coefficient for RGI (β=-0.034, p<0.05), which confirms the negative relationship between RGI and SBS. Hence, H2 is supported.

Model 3 reveals an insignificant coefficient of the interaction term between growth orientation and IGI, suggesting that growth orientation does not influence the positive relationship between IGI and SBS. Thus, H3a is not supported. Conversely, the interaction term between growth orientation and RGI is significantly positive (β=0.063, p<0.05), indicating growth orientation weakens the negative relationship between RGI and SBS, thereby supporting H3b. Figure 5.2(a) illustrates the difference in the RGI–SBS relationship at low and high levels of growth orientation, represented by the mean minus one standard deviation (S.D.) and the mean plus one S.D., respectively. It is shown that the negative RGI–SBS relationship is flatter for LSPs with high levels of growth orientation, which further corroborates H3b.

Model 4 shows that the interaction term between board environmental expertise and RGI has a significantly positive coefficient (β=0.271, p<0.05). This finding suggests that top managers with environmental expertise can mitigate the negative relationship between RGI and SBS, thus supporting H4b. Figure 5.2(b) illustrates the difference in the RGI–SBS relationship at low and high levels of board environmental expertise, represented by the mean minus S.D and the mean plus S.D., respectively. The negative RGI–SBS relationship turns positive for LSPs at high levels of board environmental expertise, indicating that board environmental expertise mitigates the negative impact of RGI on SBS. However, the interaction between board environmental expertise and IGI is insignificant. As such, H4a is not supported. Finally, the results from Model 5 align with those of the preceding models.

Table 5.2 Descriptive statistics

Variable	Mean	S.D.	Min	Max
SBS	-0.224	0.184	-0.957	-0.009
IGI	0.155	0.497	0	2.944
RGI	0.436	0.859	0	4.970
Growth	0.206	0.405	0	1
BEE	0.086	0.113	0	0.778
Size	22.217	1.566	18.828	25.762
Age	2.840	0.389	1.386	3.555
Lev	0.148	0.132	0	0.603
TobinQ	1.539	1.598	0.730	24.495
ETD	2.406	6.068	0.166	96.384
Inventory	3.697	1.788	-1.537	9.525
Productivity	13.945	0.914	11.847	17.087
In_size	25.752	1.949	21.883	28.226
In_growth	0.154	0.289	-0.130	4.230
In_comp	0.785	0.176	0.203	0.951

Table 5.3 Correlation matrix

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. SBS	1														
2. IGI	-0.103	1													
3. RGI	-0.079	0.421***	1												
4. Growth	0.025	-0.117**	-0.117**	1											
5. BEE	0.056	-0.046	-0.022	0.158***	1										
6. Size	0.059	0.320***	0.404***	0.019	-0.021	1									
7. Age	0.032	0.046	0.085	0.015	0.015	0.098	1								
8. Lev	-0.033	0.111**	0.086	0.155***	0.194***	0.355***	0.015	1							
9. TobinQ	-0.005	-0.089	-0.074	0.054	0.050	-0.231***	0.042	-0.237***	1						
10. ETD	-0.148***	-0.034	-0.083	-0.104**	-0.023	-0.197***	-0.101	-0.253***	0.045	1					
11. Inventory	0.082	-0.080	0.020	0.103**	0.066	0.089	-0.184***	-0.065	0.044	0.066	1				
12. Productivity	0.066	-0.035	0.073	-0.091	0.094	0.449***	0.048	0.291***	-0.003	-0.127**	-0.023	1			
13. In_size	0.001	0.007	0.001	-0.031	-0.014	-0.039	-0.074	-0.034	0.096	0.016	0.039	-0.001	1		
14. In_grow	-0.666	-0.008	0.023	-0.015	-0.007	-0.049	0.061	-0.174***	0.028	-0.044	-0.03	0.016	0.068	1	
15. In_comp	0.073	0.006	-0.072	0.006	-0.005	-0.031	0.071	0.253***	-0.012	-0.041	-0.145***	-0.105**	-0.103	-0.288***	1

Notes: sample size = 360. *** and ** are significant at the levels of 1% and 5%, respectively

Table 5.4 Results of regression analyses

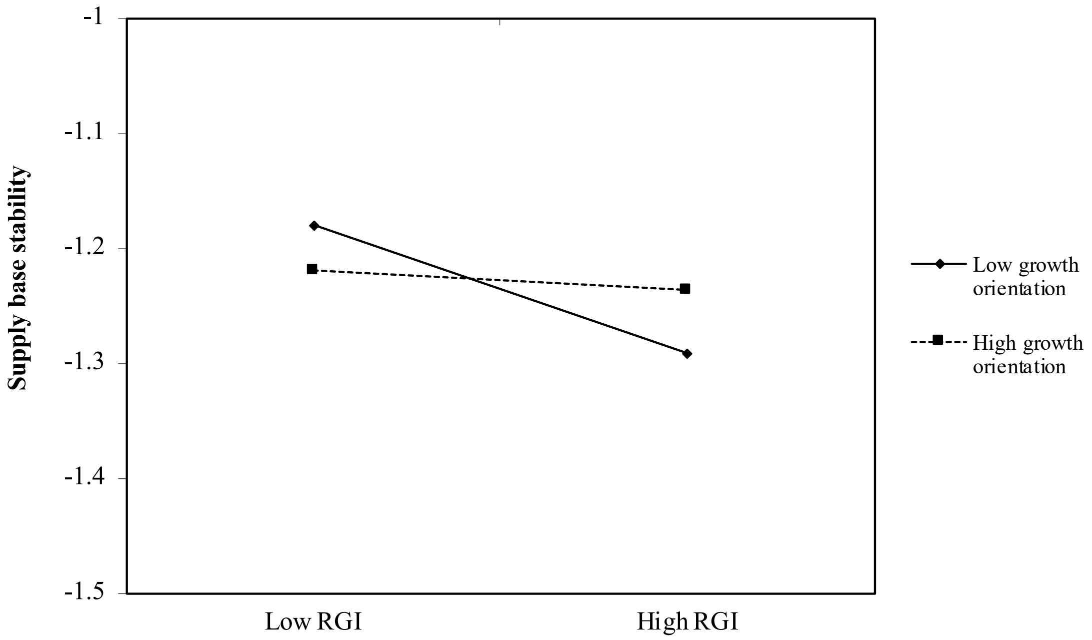
Variable	Model 1		Model 2		Model 3		Model 4		Model 5	
Growth	-0.011	(0.050)	-0.022	(0.052)	-0.021	(0.050)	-0.012	(0.050)	-0.017	(0.049)
BEE	-0.260	(0.213)	-0.262	(0.212)	-0.256	(0.210)	-0.331	(0.219)	-0.323	(0.221)
IGI	0.060**	(-0.028)			0.073**	(0.030)	0.068**	(0.040)	0.075*	(0.044)
RGI			-0.030**	(0.014)	-0.046***	(0.016)	-0.058***	(0.020)	-0.065***	(0.021)
IGI×Growth					-0.059	(0.083)			-0.050	(0.088)
RGI×Growth					0.063**	(0.026)			0.055**	(0.024)
IGI×BEE							-0.056	(0.190)	-0.067	(0.204)
RGI×BEE							0.271**	(0.118)	0.235**	(0.117)
Size	0.010	(0.046)	0.020	(0.048)	0.021	(0.046)	0.019	(0.048)	0.019	(0.046)
Age	0.030	(0.235)	0.040	(0.258)	0.014	(0.234)	0.017	(0.233)	0.014	(0.232)
Lev	-0.187	(0.206)	-0.196	(0.215)	-0.170	(0.205)	-0.218	(0.211)	-0.204	(0.207)
TobinQ	-0.011**	(0.005)	-0.011**	(0.005)	-0.011**	(0.005)	-0.011**	(0.005)	-0.011**	(0.005)
ETD	-0.004***	(0.001)	-0.004***	(0.001)	-0.004***	(0.001)	-0.004***	(0.001)	-0.004***	(0.001)
Inventory	-0.011	(0.016)	-0.012	(0.016)	-0.013	(0.016)	-0.015	(0.016)	-0.015	(0.016)
Productivity	0.035	(0.028)	0.034	(0.030)	0.031	(0.027)	0.036	(0.029)	0.034	(0.028)
In_size	-0.003	(0.007)	0.001	(0.007)	-0.003	(0.007)	-0.002	(0.007)	-0.002	(0.007)
In_growth	-0.069**	(0.026)	-0.063**	(0.025)	-0.065**	(0.025)	-0.066***	(0.025)	-0.066**	(0.025)
In_comp	0.190	(0.165)	0.141	(0.161)	0.233	(0.171)	0.172	(0.167)	0.209	(0.171)
Year FE	Yes		Yes		Yes		Yes		Yes	
Firm FE	Yes		Yes		Yes		Yes		Yes	
R^2	0.141		0.141		0.163		0.163		0.169	

Notes: sample size = 360. ***, **, and * are significant at the levels of 1%, 5%, and 10%, respectively. Robust standard errors are in parentheses

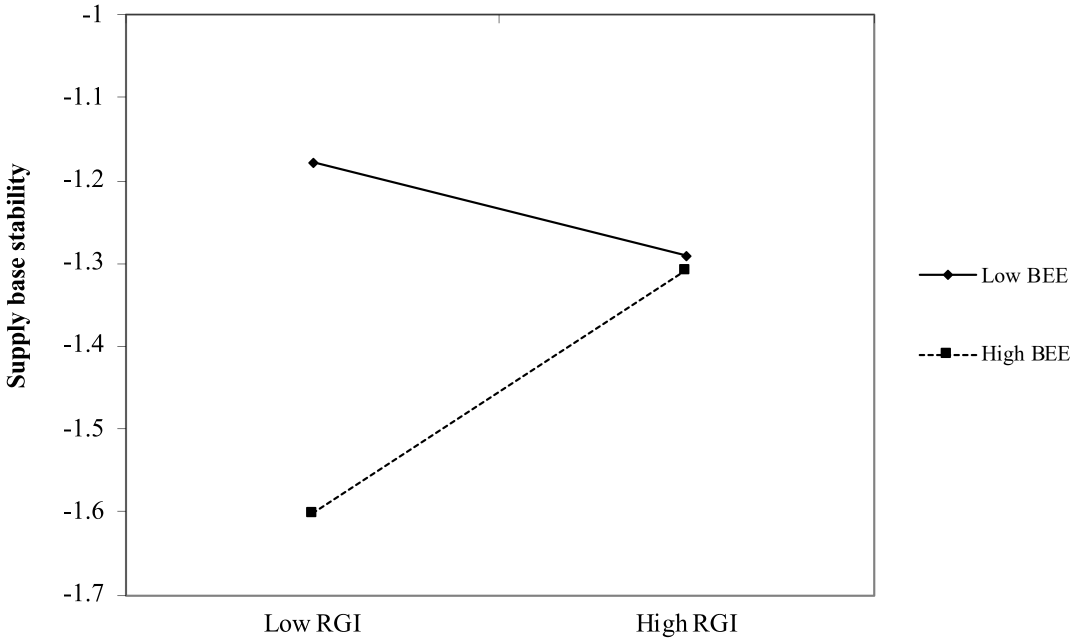
Table 5.5 Results of robustness checks

Variable	Model 1		Model 2		Model 3	
Growth	-0.019	(0.048)	-0.000	(0.053)	-0.017	(0.049)
BEE	-0.314	(0.216)	-0.350	(0.223)	-0.326	(0.222)
IGI	0.075^{*}	(0.044)	0.069^{*}	(0.041)	0.074^{*}	(0.044)
RGI	-0.065^{***}	(0.021)	-0.060^{***}	(0.022)	-0.064^{***}	(0.021)
IGI×Growth	-0.050	(0.088)	-0.058	(0.095)	-0.050	(0.088)
RGI×Growth	0.054^{**}	(0.023)	0.053^{**}	(0.026)	0.054^{**}	(0.024)
IGI×BEE	-0.070	(0.204)	-0.027	(0.207)	-0.057	(0.235)
RGI×BEE	0.233^{**}	(0.116)	0.246^{**}	(0.121)	0.235^{**}	(0.117)
Size	0.018	(0.046)	-0.112^{**}	(0.056)	0.020	(0.046)
Age	0.011	(0.231)	-0.012	(0.220)	0.016	(0.232)
Lev	-0.203	(0.207)	-0.146	(0.206)	-0.203	(0.207)
TobinQ	-0.011^{**}	(0.005)	-0.010^{**}	(0.004)	-0.012^{**}	(0.005)
ETD	-0.004^{***}	(0.001)	-0.004^{***}	(0.001)	-0.004^{***}	(0.001)
Inventory	-0.015	(0.016)	-0.019	(0.017)	-0.015	(0.016)
Productivity	0.034	(0.028)	0.043	(0.029)	0.034	(0.028)
In_size	-0.003	(0.007)	-0.003	(0.007)	-0.003	(0.007)
In_growth	-0.065^{**}	(0.025)	-0.064^{**}	(0.025)	-0.066^{***}	(0.025)
In_comp	0.210	(0.171)	0.225	(0.176)	0.210	(0.171)
Year FE	Yes		Yes		Yes	
Firm FE	Yes		Yes		Yes	
R^2	0.171		0.186		0.169	

Notes: ***, **, and * are significant at 1%, 5%, and 10%, respectively. Robust standard errors are in parentheses.



(a)



(b)

Figure 5.2 Moderating effects of (a) growth orientation and (b) BEE on the RGI–SBS association.

5.4.2. Endogeneity

To address endogeneity concerns in our primary models, we employ multiple strategies. One approach involves introducing a temporal lag between the independent and dependent variables, which helps mitigate the potential issues of reverse causality and simultaneity. We also incorporate a comprehensive set of control variables and firm- and year-fixed effects in our models, aiming to eliminate the potential influence of omitted variables. To further address potential endogeneity issues, we apply a two-stage least squares (2SLS) approach (Lu et al., 2018). We employ the industry average of green innovation as an instrumental variable (IV), calculated using the logarithm of the average number of green patents held by other LSPs within the same three-digit CSRC industry, excluding the LSP itself. When making green innovation decisions, LSPs encounter the influences of industry competitors, which make them learn from and imitate the green innovations of peer LSPs (Fan et al., 2022; Machokoto et al., 2021; Yi et al., 2024). This suggests a strong connection between the industry average of green innovation and firms' IGI and RGI. However, peers' green innovation is not likely to affect the supply base of an individual LSP. A regression analysis is conducted to corroborate this assumption, revealing no significant relationship between the industry average of green innovation and the SBS of LSPs (β=0.084, p>0.1), thereby confirming the appropriateness of using the industry average of green innovation as an IV. In the first stage of the 2SLS, when RGI serves as the dependent variable, the industry average of the green innovation coefficient is found to be significantly positive (β=0.728, p<0.01). However, when IGI is the dependent variable, the coefficient of the industry average of green innovation is insignificant. In the second stage, we find that the coefficient of estimated RGI is significant and negative (β=-0.076, p<0.05), reinforcing the negative relationship between RGI and SBS.

We also adopt government environmental attention as another IV for green innovation. Government environmental attention is measured by the proportion of environment-related terms (e.g., environmental protection, environmental quality, particulate matter, carbon dioxide, new energy) in the work reports of the municipal governments where LSPs are headquartered (Zhu et al., 2023). Governments with high environmental attention can stimulate green innovation in firms through various means, such as higher environmental subsidies and stringent regulations (Zhang et al., 2024; Zhu et al., 2023). However, it is unlikely to influence an LSP's SBS. We conduct a regression analysis to verify this assumption, finding no significant relationship between government environmental attention and SBS (β=10.311, p>0.1). Therefore, we consider government environmental attention to be an appropriate IV. Different from the previous IV, in the first stage of the 2SLS, when IGI is the dependent variable, the coefficient of government environmental attention is significantly positive (β=53.100, p<0.05); however, when RGI is the dependent variable, the coefficient of government environmental attention is not significant. In the second stage, we only find that the coefficient of estimated IGI is significant and positive (β=0.354, p<0.1), reinforcing the positive relationship between IGI and SBS. In conclusion, these findings demonstrate that endogeneity does not distort the results of our study.

5.4.3. Robustness Checks

To ensure the robustness of our findings, we conduct several supplementary tests. The comprehensive results from these robustness tests are compiled in Table 5.5. First, we mitigate potential biases from outliers by winsorizing the sample removing the top and bottom 1% of the dependent variable (SBS) in Model 1. The results, consistent with those in Table 5.4, confirm the reliability of our findings. Second, we use an alternative firm size measure, defined as the natural logarithm of a firm's revenue in Model 2 (Trumpp and Guenther, 2017; H. Wang et al., 2008), and find results consistent with our main analysis. In Model 3, we also adopt an alternative approach to calculate Tobin's q, which involves summing a company's market capitalization and the book value of total liabilities and then dividing this total by total assets (Erickson and Whited, 2012). There is consistency between the results obtained using this alternative measure and the results of the original model.

5.5. Discussion

5.5.1. Theoretical Contributions

Our research offers several notable theoretical insights. First, it broadens the scope of green logistics literature by offering sound empirical evidence demonstrating the distinct impacts of IGI and RGI on SBS within the Chinese logistics service sector. While earlier research focused on green innovation's effects on firms' financial and environmental performance (Rehman et al., 2021; Shou et al., 2023; Wong et al., 2020), there is a lack of exploration into its influence on the upstream supply chain. Given that upstream stability can significantly impact a company's operational and financial performance (Gu et al., 2022; Peng et al., 2020; Y. Yang et al., 2023), understanding this linkage is essential for comprehensively assessing the implementation of green innovation. More importantly, this research provides nuanced insights by uncovering that IGI increases the SBS of LSPs, whereas RGI decreases it. These distinct impacts of IGI and RGI are critical, as they highlight the multifaceted nature of implementing different green innovations, especially in industries closely associated with environmental pollution yet facing less stringent regulation and standards, such as the logistics industry (Lai et al., 2011; Shou et al., 2023). Thus, our research extends the green logistics literature by illuminating the distinct impacts that two types of green innovations have on the stability of the supply base in the logistics industry.

Second, our study enriches the RST literature by delineating the processes of local and distant searches within the context of LSPs' green innovation and illustrating their distinct impacts on SBS. We offer theoretical validation for the different nature of local search, associated with lower uncertainty and simplified knowledge complexity, against distant search, which entails higher uncertainty and leads to a more complex knowledge base (Fleming, 2001; Hou et al., 2023). Although previous research on RST has primarily focused on the impact of knowledge search strategies on a firm's knowledge base (Hou et al., 2023; Shi et al., 2020), our study advances this theoretical framework by empirically uncovering the differential effects of IGI and RGI on LSPs' SBS, thereby extending RST to the field of supply base management. This offers a fresh perspective on how knowledge search and recombination influence the supply chain, particularly in the context of environmental sustainability.

Finally, this study sheds light on the supply base management literature by elucidating the boundary conditions under which the effects of IGI and RGI on SBS may vary. The extant literature has offered few insights into the contingency factors that influence the effect of green innovation on firms' SBS. Our findings reveal that growth orientation and board environmental expertise weaken the effect of RGI on SBS. However, as the local search process within IGI does not demand a highly rich and complex knowledge base, neither growth orientation nor board environmental expertise moderates the IGI–SBS relationship. These findings expand research on supply base management (Gu et al., 2022; Peng et al., 2020; Yang et al., 2023), thus contributing to a more differentiated understanding of how TMT values and characteristics (i.e., growth orientation and board environmental expertise) play different roles in shaping the supply chain outcomes of IGI and RGI, particularly in the logistics industry where supply chain management is a critical component of operational success (Selviaridis and Spring, 2007).

5.5.2. Managerial Implications

This study provides essential managerial insights. First, it demonstrates that IGI increases LSPs' SBS while RGI decreases their SBS. This distinction highlights the need for strategic discernment in adopting different green innovations, given their varied impacts on the supply chain. This is especially relevant in the Chinese logistics industry, an emerging market characterized by rapid growth, an influx of start-ups, and increasing environmental awareness. Therefore, we strongly recommend that LSPs adopt a discerning approach toward green innovation, carefully weighing the potential trade-offs between green innovation-driven environmental benefits and SBS. Managers are advised to strategically integrate RGI within comprehensive supply chain management practices to mitigate potential disruptions. For example, firms can employ advanced forecasting techniques to anticipate and prepare for changes in demand and supply patterns, enhance supplier collaboration through shared sustainability goals, and diversify the supply base to reduce dependency on a single source. Concurrently, leveraging IGI can strengthen supply base stability by gradually improving processes, technologies, and materials in alignment with sustainability principles.

Second, our findings suggest that growth orientation dampens the negative relationship between RGI and SBS. Therefore, for LSPs employing RGI, growth orientation can serve as a valuable counterbalance. Hence, managers in LSPs should consider how growth-oriented strategies can align with their RGI efforts to manage and capitalize on the complexities of a volatile supply base. This alignment demonstrates that the drive for growth does not necessarily destabilize the supply chain but rather supports the LSPs' green innovation goals by enhancing the overall supply chain knowledge base.

Finally, our findings suggest that board environmental expertise alleviates the negative RGI–SBS relationship. Therefore, for LSPs implementing RGI, integrating executives with environmental expertise into their strategic planning could be crucial in reducing supply chain risk and uncertainty. The expertise that environmentally knowledgeable board members bring can help LSPs navigate the complexities of RGI, aligning it with supply chain practices. This approach can help alleviate volatility in the supply chain triggered by RGI. Thus, LSPs should ensure their boards include members with environmental expertise to oversee green innovation while effectively maintaining supply chain stability.

5.6. Conclusions, Limitations, and Future Research

Drawing on the RST, our research explores the effects of IGI and RGI on LSPs' SBS and the moderating effects of growth orientation and board environmental expertise. Analyzing data from 88 Chinese LSPs that are publicly traded, covering the period of 2011–2019, we identify a positive relationship between IGI and SBS and a negative relationship between RGI and SBS. Furthermore, growth orientation and board environmental expertise attenuate the negative RGI–SBS linkage.

Our study acknowledges limitations that suggest directions for future research. First, the limited number of publicly listed LSPs results in a small sample size, which restricts the scope of our analysis. Future research could broaden the sample size to enhance the robustness of our findings. Second, the focus on the Chinese context may limit the applicability of our results to other regions, given China's distinctive cultural, institutional, and economic characteristics. We encourage future studies to incorporate data from various nations to verify these findings. Third, while our research examines the roles of various moderators in the green innovation–SBS relationship, other potential contingency factors, such as industry environments, could also impact this relationship and warrant further exploration. Finally, our investigation into the impacts of IGI and RGI on LSPs' SBS paves the way for future research to explore the effects of green innovation on LSPs' customer bases.

Chapter 6 Conclusions

6.1 Summary of Study Findings

Grounded in an environmental sustainability perspective and employing theoretical frameworks such as STS and recombinant search theories, this thesis explores green practices' characteristics and evolution trends among LSPs across different transportation modes. It further examines how LSPs' green innovation influences inter- and intra-firm outcomes. The major findings and conclusions drawn from this study are as follows:

(1) Major findings and conclusions of Study 1

Drawing upon STS theory, Study 1 investigates publicly listed Chinese LSPs from 2015 to 2021 to identify their green practices' characteristics and evolution in different transportation modes (including road, maritime, and aviation). We combine probabilistic topic modeling and interviews to analyze the environmental text from LSPs' corporate social responsibility (CSR) reports and identify 18 unique social- or technology-driven green practice topics (i.e., eight social-driven green practices and ten technology-driven green practices). We also observe the differential priorities of green practices for each transportation mode, with maritime freight focusing on legal compliance and energy efficiency, aviation on energy efficiency, and road freight on emerging green technologies like new vehicle technologies and green packaging. Furthermore, LSPs' green practices have been experiencing a gradual shift in emphasis from cost-efficiency technologies to emerging green technologies and diverse social-driven green practices. Finally, we validate the LDA findings through interviews and investigate different influencing factors behind social- and technology-driven green practices.

(2) Major findings and conclusions of Study 2

Drawing upon RBV and stakeholder theory, Study 2 examines the relationship between green innovation and the market value of LSPs, along with the moderating effects of stakeholder engagement and public attention. Analyzing panel data from 53 publicly listed Chinese LSPs from 2011 to 2021, we observe an inverted U-shaped relationship between green innovation and market value, suggesting a complex interplay of benefits and costs associated with green innovation. Furthermore, SCPE steepens the inverted U-shaped linkage, while SIE and public attention flatten this linkage.

(3) Major findings and conclusions of Study 3

Guided by recombinant search theory, Study 3 assesses the differential impacts of IGI and RGI on the LSPs' SBS. Through data analysis of 88 publicly traded Chinese LSPs from 2011–2019, we find a positive association between IGI and SBS and a negative association between RGI and SBS, indicating the varied effects of green innovation types on supply chain relationships and structure. Moreover, growth orientation and board environmental expertise are found to mitigate the negative impacts of RGI on SBS.

6.2 Research Implications

6.2.1 Theoretical Implications

The theoretical contributions of the three studies are briefly summarized as follows:

Study 1 makes significant theoretical contributions by offering a nuanced classification of green practices from the STS perspective, distinguishing between 10 technology-driven and 8 social-driven practices among Chinese LSPs. This study challenges the prevailing emphasis on technological solutions in previous green logistics research (Centobelli et al., 2017), highlighting that the green transition in logistics relies equally on robust social practices. It details how green practices vary across transportation modes, highlighting sector-specific priorities and challenges. Additionally, it tracks the evolution of these practices from initial cost-efficiency measures toward broader adoption of innovative green technologies and social practices, mirroring broader industry trends toward deep integration of sustainability into business operations. This study reveals that adopting green practices is influenced by a mix of technological maturity and market demands, illustrating a complex interplay between technological and social factors in shaping green transitions within the logistics sector. These insights substantially enrich the green logistics literature by detailing the dynamics of green practice implementation and evolution in a critical industry.

Study 2 significantly advances the green logistics and innovation literature by empirically demonstrating an inverted U-shaped impact of green innovation on market value within the Chinese logistics industry, a sector previously underexplored in this context. By reconciling diverse viewpoints in existing literature, this study illustrates that green innovation yields benefits and costs, leading to a nonlinear impact on market valuation. Additionally, it explores the moderating effects of different types of stakeholder engagement. Specifically, supply chain partner engagement intensifies the positive impacts of green innovation on market value, while engagement with scientific institutions may dilute these benefits. Furthermore, the study highlights that public attention can negatively affect the relationship between green innovation and market value. Collectively, these findings enrich the RBV and stakeholder theory by integrating them to explain complex interactions in the logistics sector and expand our understanding of how stakeholder and public dynamics influence the economic outcomes of green innovation.

Study 3 also enriches the green logistics and innovation literature by empirically demonstrating how IGI enhances, while RGI diminishes, the SBS of LSPs. This distinction is crucial as it clarifies the varied impacts of green innovations on the upstream supply chain, a relatively neglected area compared to their effects on financial and environmental performance. Employing recombinant search theory, this study uniquely illustrates how local and distant searches differentially influence SBS, thereby expanding the application of recombinant search theory to supply base management. Additionally, it enriches the literature on top management by showing how characteristics such as growth orientation and environmental expertise act as moderating factors, differentiating the effects of IGI and RGI on SBS.

6.2.2 Managerial Implications

The managerial insights of the three studies are briefly summarized as follows:

Study 1 offers practical insights for LSP managers on structuring their green transition effectively. Initially, LSPs should establish a robust foundation in social green practices, focusing on compliance with legal standards and environmental performance assessments. This is especially critical in maritime freight due to stringent international regulations. Subsequently, LSPs should adopt efficiency-enhancing practices that align with their operational scale and financial capacity, such as optimizing resource use and adopting smarter logistics solutions. Smaller LSPs might focus on low-capital investments like waste and energy reduction, while larger ones could lead with advanced digital and intelligent operations. Finally, financially capable LSPs are encouraged to explore pilot projects in emerging green technologies like alternative fuels, particularly in road freight, where electric vehicles are gaining traction. This stepwise approach helps LSPs meet regulatory demands, innovate, and gain a competitive edge in a rapidly evolving green logistics landscape.

Study 2 offers valuable managerial insights by elucidating the inverted U-shaped relationship between green innovation and market value in the logistics industry. This finding suggests that LSPs should aim for a balanced level of green innovation to optimize market value, avoiding underinvestment and excessive expenditure. Engagement with supply chain partners is crucial to amplify the positive effects of green innovation, while alignment with scientific institutions needs careful management to mitigate potential misalignments in objectives. This balanced approach enables LSPs to optimize their green innovation strategies, ensuring investments enhance market value without triggering the detrimental costs associated with over-investment.

Study 3 offers several critical managerial insights for LSPs. First, our results indicate that IGI enhances SBS while RGI decreases it, necessitating a discerning approach to green innovation adoption. Managers should leverage IGI for gradual environmental improvements and strategically integrate RGI within supply chain management to lessen supply base instability brought about by RGI. Employing advanced forecasting, enhancing supplier collaboration, and diversifying the supply base are recommended practices. Second, the study finds that growth orientation can attenuate the negative RGI-SBS relationship. Managers are therefore advised to align growth-oriented strategies with RGI efforts to enhance LSPs' supply chain knowledge base. Finally, the study suggests that board environmental expertise alleviates the negative impact of RGI on SBS. Hence, managers should ensure that their boards include members with environmental expertise to navigate the complexities of RGI and maintain supply chain stability.

6.3 Limitations and Future Research Directions

While providing substantial insights into the green practices and innovation impacts of LSPs, this thesis acknowledges several limitations that pave the way for future research.

First, while the research provided substantial insights into LSPs' green practices, it primarily focused on the Chinese logistics industry. Given China's unique cultural, institutional, and economic contexts, the generalizability of these findings to other regions might be limited. Future research could enhance the robustness and applicability of the findings globally by gathering and analyzing data from multiple countries.

Second, the studies utilized primarily qualitative methods and a limited dataset from publicly listed LSPs, which may restrict the depth of statistical analysis and broad applicability of the findings. Future research could address this by employing a broader array of quantitative methods, such as large-scale data analytics, and expanding the sample size to improve the representativeness of the results.

Third, while the current thesis focuses on traditional green practices and technologies, emerging technologies like blockchain and artificial intelligence present new opportunities for enhancing green practices in logistics. Investigating the impact of these technologies could provide fresh insights into the next generation of green strategies within the logistics industry.

Fourth, there is a need for further studies to quantify the actual environmental performance and other related outcomes of the green practices adopted by LSPs. Future studies could explore whether technological and social green practices synergistically enhance environmental performance, providing deeper insights into effective green strategies.

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