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Enterprises' Green Growth Model and Value Chain Reconstruction

Theory and Method

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Preface

The tension between resources, environment, and population is becoming increasingly pronounced as environmental issues become a major challenge for global sustainable development. Ensuring environmental sustainability is one of the most important goals of the United Nations Millennium Development Goals. The balance between economic growth and environmental friendliness is the key to the economic growth model. The history of global development has proved that the "grow first, clean up later" strategy of pursuing economic growth at the expense of environmental friendliness is not sustainable, leading to environmental degradation and high governance costs. Green development is of great concern to governments, enterprises, individuals, and NGOs. Chinese president Xi Jinping has attached great importance to green development, recognizing that "clear waters and green mountains are as good as mountains of gold and silver," and announced that China would achieve a peak in carbon dioxide emissions before 2030 and carbon neutrality before 2060, signaling China's intention to increase the commitment it made under the Paris Agreement on climate change. Green development is the foundation for achieving the strategic goals of carbon peaking and carbon neutrality.

How to implement green development and ensure environmental sustainability has been a hot issue in academia and in industry. Enterprises are the basic unit of green development; implementation of the green growth model is critical to attain competitive advantages and obtain a win-win paradigm for business performance and environmental performance. Since 2000, our team has been engaged in the research of green/closed-loop supply chain and sustainable operation and management, mainly focusing on operational decision-making and optimization of green/closed-loop supply chain. Our achievements, and the reason we can persist in this field, can be attributed to various sources. We are grateful for the support of the National Natural Science Foundation of China (NSFC) and the Changjiang Scholar Program of the Ministry of Education of the PRC, which provided essential help to our team. We are also thankful for our academic predecessors and colleagues for their guidance on the theoretical frontier, research norms, and methods. In addition, we appreciate the support and participation of the enterprises. A special thanks to Everbright Environment Group Ltd. for providing us opportunities to understand enterprises' realistic needs and refine scientific issues. Due to substantial cooperation with Everbright, we were able to draft the People-First PPP Waste to Energy Guideline to disseminate China's green development program worldwide.

This monograph is the product of a research project funded by the Key Project of the National Natural Science Foundation of China "Research on Enterprises' Green Growth Model and Value Chain Reconstruction" under Grant 71732006 and the Major Project of the National Natural Science Foundation of China "Interface Connection and Logistics Optimization Management of the Manufacture-Circulation Industrial System" under Grant 72192830/72192834. It is the cumulation of our previous research. *Enterprises' Green Growth Model and Value Chain Reconstruction* systematically and comprehensively studies the concept, system model, implementation model, and operational environment of the green growth model for enterprises, facilitating the academic community and industry's understanding of the green growth model. *Optimization of Integrated Logistics Network Based on Remanufacturing: Theory and Method* and *Vehicle Routing Optimization for Hazardous Materials Transportation: Theory and Method*, which we have published in Chinese, are part of a series of monographs delving into the green growth model for enterprises from remanufacturing, sustainability, and safety perspectives. By providing specific operational decisions, such as logistics networks and vehicle routes, those two books provide methodological support and serve as decision-making references for enterprises to implement the green growth model.

This book could not have come into fruition without the guidance of Xiaoping Ouyang, Wei Huang, Qinghua Zhu, and Ada Che. Special thanks to the contributors of this book: Dandan Gao, Junling Han, Qidong He, Zhengwen He, Junchang Hu, Bin Jiang, Qi Jiang, Xuxin Lai, Xiaocui Li, Bo Liang, Rui Luo, Hesong Ren, Weixuan Shi, Shuyi Sun, Guwen Tang, Mengdan Wang, Bin Wei, Qunli Yuchi, and Meng Zhang.

This monograph can serve as a reference for researchers in the field of sustainable operations and management, as well as for enterprises to implement the green growth model. Given that we are exploring a relatively complete system of the green growth model for enterprises, and owing to limitations of our knowledge, there will inevitably be errors and omissions in this book. Any suggestions, remarks, and comments on the book's content are appreciated; they are invaluable to promoting academic research in the field of sustainable operation and management and implementing the green growth model for enterprises.

Xi'an China Prof. Nengmin Wang
April 2022

Introduction

The goal of this book is to improve the ability of enterprises to implement the green growth model and value chain reconstruction. China's environmental development strategies, such as carbon peak emission and carbon neutrality, have created new challenges and requirements for enterprises to "go green." In addition, anti-globalization and the complex dynamic uncertainty caused by COVID-19 have changed the operational environment that enterprises face. The application of new technologies, including the new generation of information technologies and the whole process management technology, provides solutions for the implementation of enterprises' green growth model and value chain reconstruction. Based on China's enterprise management cases, this book reveals the connotative features of enterprises' green growth model and their evolutionary regularities, the overall framework and decision optimization of value chain reconstruction under the green growth model, and the approach to implementing the green growth model and value chain reconstruction. The theoretical framework of the green growth model and value chain reconstruction established in this book has enriched and developed the research results in this field. Cases of enterprises implementing the green growth model can provide references for the green transformation of enterprises and help enterprises appreciate the synergy between sustainability and growth. This book can also serve as a research reference for scholars engaged in the field of sustainable operations, as well as decision-makers and managers of relevant government departments.

Contents

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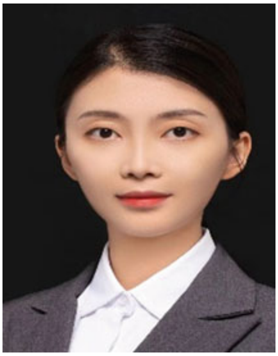
Nengmin Wang received the B.S. degree in investment economy from Central South University of Technology, Changsha, China, in 1997, the M.S. degree in management science and engineering from Central South University of Technology, Changsha, China, in 2000, and the Ph.D. degree in management science and engineering from Xi'an Jiaotong University, Xi'an, China, in 2003. He is currently a professor at Xi'an Jiaotong University and the President of Zhengzhou College of Finance and Economics. His research interests include sustainable operation management and green supply chain management. He has presided over seven national projects such as the National Natural Science Foundation of China, including one key project of the National Natural Science Foundation of China, and one major project of the National Natural Science Foundation of China. He has authored over 60 articles in refereed academic journals, including *Journal of Management Information Systems, IEEE Transactions on Engineering Management, European Journal of Operational Research, IEEE Transactions on Intelligent Transportation Systems, International Journal of Production Economics, Annals of Operations Research, International Journal of Production Research, Computers and Operations Research, Computers and Industrial Engineering.*



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Chapter 1
An Overview of Enterprises' Green Growth Model and Value Chain Reconstruction

Nengmin Wang, Qidong He, and Bin Jiang

Abstract Enterprises' green growth model is a coordinated development model of "growth" with economic performance goals and "green" with environmental performance goals. And value chain reconstruction is the activity aimed at maximizing strategic and main value-added activities, minimizing other activities, and improving core competitiveness and business performance. This chapter proposes concepts of enterprises' green growth model and value chain reconstruction. The features and operation models of the two topics are analyzed from the perspective of operational and business activities. This chapter is the foundation for later chapters in this book. First, this chapter analyzes the features of enterprises implementing various green growth models based on different product types, product structures, and environmental protection technologies. And on this basis, this chapter proposes a system model of enterprises' green growth model, and compares enterprises' green growth model and conventional growth model from the perspective of operational activities. Second, this chapter outlines the concepts of value chain and value chain reconstruction, analyzes their key features from the perspective of cooperation between value chain entities and collaboration of business activities. And on this basis, this chapter clarifies the specific activities carrying out value chain reconstruction. Finally, this chapter discusses the relationship between enterprises' green growth model and value chain reconstruction. The value chain reconstruction is the foundation and strategic approach for the enterprises to implement the green growth model, which is the path to achieve green transformation and green growth for enterprises.

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1.1 Enterprises' Green Growth Model

1.1.1 Concepts of Enterprises' Green Growth Model

(1) Green Growth and Enterprises' Green Growth Model

"Green Growth" is a development concept first proposed by the Organization for Economic Cooperation and Development to achieve the coordination between economic growth and environmental friendliness, and the goal is to ensure that the resources and environmental services that our future generations depend on for their survival can be sustainably managed [1]. Although different organizations define green growth differently based on their own developmental goals, the core is to simultaneously achieve economic growth and environmental friendliness. For example, South Korea, the first country to include green growth as a governmental policy goal, defines it as the "growth achieved by saving and using energy and resources efficiently to reduce climate change and damage to the environment, securing new growth engines through research and development of green technology, creating new job opportunities, and achieving harmony between the economy and environment [2]." According to the World Bank, green growth is the "growth that is efficient in its use of natural resources, clean in that it minimizes pollution and environmental impacts, and resilient in that it accounts for natural hazards and the role of environmental management and natural capital in preventing physical disasters, and this growth needs to be inclusive [3]." Based on previous views, the book argues that **green growth** is a development model that uses resources efficiently and circularly, transforms conventional growth motivations to new ones by green innovation, shifts extensive growth to intensive growth, and coordinates economic growth and environmental friendliness.

Enterprises' growth model refers to the way in which an enterprise grows through internal and external expansion to achieve its goals, including increasing sales, maximizing profits, and increasing market share [4]. **Enterprises' green growth model**, or EGGM for short, is a type of enterprise growth model, and the goal of which is to coordinate "growth" with economic performance goals and "green" with environmental performance goals. In addition to the growth models based on "scale boundary", "enterprise life cycle", and "external environment change", EGGM is a collaborative development model based on "green and growth" aimed at coordinating the economic performance and environmental performance of enterprises and achieving high-quality, efficient, and sustainable development. EGGM is the specific practice of green development concept at enterprise level, establishing innovation chain with different combinations of innovative production factors using new technologies and new form of industry with the help of cooperation of various entities in the value network [5]. It creates new business models to realize the coordination of business processes in value networks, and the coordination of "growth" and "green" which is "driven by innovation".

Contrary to EGGM, enterprises' conventional growth model refers to the growth model involving unbalanced "green" and "growth", which may manifest in two ways: first, to give up "growth" for "green" or the "reverence for nature" advocated by extreme environmentalism emphasizing only on environment or nature and ignoring the concept of people-first and giving up "growth"; second, to give up "green" for "growth", or the growth model emphasizing only economic performance, achieving high "growth" and causing serious environmental pollution and huge resource consumption. The contradiction among resources, population, and environment is becoming increasingly prominent. It is necessary for enterprises to implement the green growth model and achieve green transformation with the goal of coordinating green and growth.

(2) Features of Enterprises' Green Growth Model

In the process of green transformation of the growth model, various types of enterprises differ on the specific path of the growth model, value chain reconstruction, and integration of strategic direction. The first aspect that needs consideration is the environment protection technology required by enterprises to achieve green growth. Environmental protection technology can be divided into **end control** and **whole process management** according to the enterprise's management focus [6]; environment protection technology presents a trend of transformation from end control to whole process management, implying the transformation of end emission control management to whole life-cycle management from design and manufacturing to collection and recovery, including multi-entity environment management technology of value network. Different **environment protection technologies**, **product types**, and **product structures** jointly determine the features of EGGM:

(a) Features of EGGM under Different Product Types and Environment Protection Technologies

Products can be divided into **innovative** and **functional products** [7, 8]. Different types of products put forward different requirements for enterprises implementing EGGMs. Innovative products lay more emphasis on the agile response to market demand to obtain relatively high profit margins, rely on rapid technological innovation and update, and need to establish value chain network via outsourcing of activities in value chain. Functional products, in contrast, focus more on cost reduction via economies of scale to achieve cost savings, rely on relatively slow technological innovation and update, and need to establish value chain and reduce costs via integration.

Based on two product types, i.e., innovative product and functional product, and environment protection technologies, i.e., end control and whole process management, a two-dimensional matrix for four enterprise types is proposed here. Enterprises producing different product types have different ways to implement EGGM. See Fig. 1.1 for details.

For enterprises of type I and II, to improve innovation and product agility, core enterprise of value chain often achieves cooperation of all entities throughout the value network by outsourcing, resulting in more purchasing behaviors and

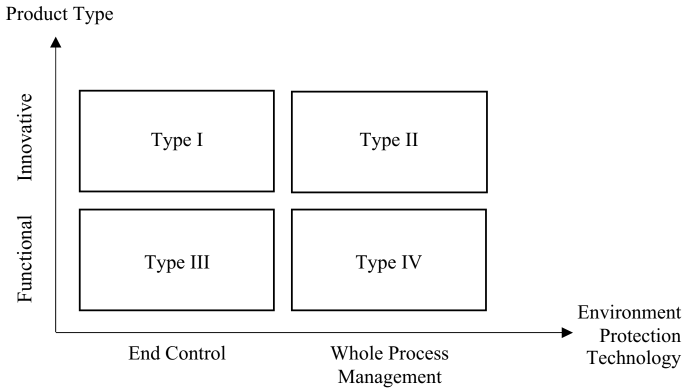

Fig. 1.1 Enterprise types of different product types and environmental protection technologies

outsourcing behaviors in both upstream and downstream, lower whole life process of environment management and control ability, higher environment management pressure, and greater regulation risk of environmental events. Therefore, in the short term, core enterprises often choose end control technologies to establish strict environmental monitoring procedures and standards to control the environmental risks caused by outsourcing. End control for Type I is easier for producing innovative products than whole process management for Type II.

However, in the long run, core enterprises invest additional capital and capacity to cooperate with upstream and downstream enterprises throughout the value chain to achieve green growth of whole process. When multiple entities in the value network establish trust relationships based on repeated transactions and tend to build and form stable value community, there occurs strategic cooperation between upstream and downstream entities and collaboration of business processes is an effective way to achieve green growth. That is, the whole process management of environment can be realized through deep cooperation in upstream and downstream, i.e., from Type I to Type II, like supplier participation in innovation. For example, Apple Inc. has established a long-term and stable value community with its suppliers, e.g., Foxconn, and relies on the mature value network. Apple Inc. has realized the whole process management of products, implemented green value chain management based on the environmental management technology of the whole life cycle, and achieved significant environmental, economic, and social benefits.

For enterprises of type III and IV, the strategic focus of functional products achieving growth goals is to achieve economies of scale and scope via integration to reduce costs. Compared to value chain network, an integrated organization can better realize the control and management of all activities in the whole life cycle, and the leading ability of core enterprises to control all levels is conducive to the implementation of environmental management technology in the whole process management of enterprises, so as to implement green growth for Type IV. Therefore, the whole process management under functional products is easier to achieve than that under innovative products, that is, compared with innovative products, functional products have greater advantages in realizing green design, green manufacturing, green marketing, green logistics, and green recycling. For example, China's Taiyuan Iron and Steel Group, or TISCO for short, established or bought upstream and downstream enterprises such as Shanxi Jinmei Tisco Energy Co., LTD and Taiyuan Iron and Steel Group Stainless Steel Industrial Park Co., LTD to achieve integration and reduce production costs, which helped TISCO focus on the whole process upgrade and improvement, carry out green transformation via the adoption of advanced waste gas, waste treatment, and solid waste utilization technology facilities, and obtain greater economic benefits.

(b) Features of EGGM under Different Product Structures and Environment Protection Technologies

Products can be divided into **integral products** and **modular products** according to whether its manufacture can be completed by an enterprise independently [9, 10]. To some extent, product structure affects the choice of the specific path for enterprises to implement EGGMs. Integral products are independently produced by one enterprise, and it has high requirements of the technology and production capacity that the enterprise relies on and requires the enterprise to have the knowledge and ability to produce such products. Modular products allow the enterprises lacking knowledge and ability to outsource value activities to other enterprises and those with the knowledge and ability to flexibly make outsourcing decision based on factors like product costs, profit, performance, and risk, and clarify the direction of integration and improvement of value chain.

Based on two product structures, i.e., modular products and integral products, and environmental protection technologies, i.e., end control and whole process management, this book establishes a two-dimensional matrix of four enterprise types. It is also necessary to analyze the particularity of modular products and integral products when choosing the integration of environmental protection technology, so as to provide decision-making support for different types of enterprises to choose the direction and path of EGGMs and value chain reconstruction and integration. See Fig. 1.2 for details:

Similar to the case of innovative and functional products, procurement and outsourcing decisions in the manufacturing process of modular and integral products determine the degree of integration with the upstream and downstream value chain, and ultimately determine the choice of environmental technologies of end control or whole process control.

For enterprises of type I and II, the modular advantage of products enables enterprises to outsource non-core value-added modules and processes to other value chain entities. In the beginning, outsourcing and procurement decisions of enterprises involve many entities, but the integration level of core enterprises and upstream and downstream value chain is not high, and so, the value community cannot be formed, and core enterprises adopt end control technology to achieve green growth for Type I. In the long run, enterprises establish long-term cooperation with upstream and downstream entities of the value chain by repeated transactions to achieve a highly

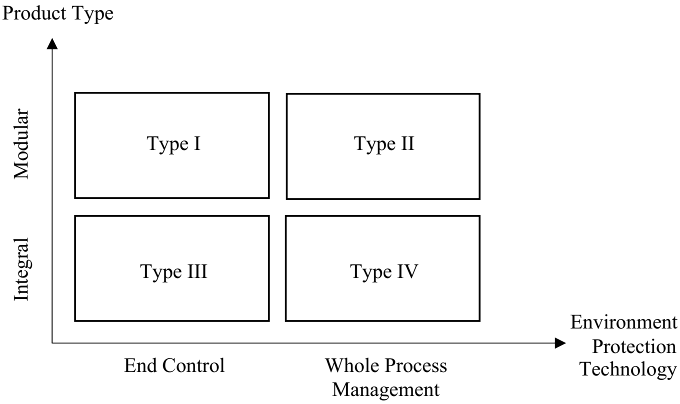

Fig. 1.2 Enterprise types of different product structures and environmental protection technologies

trusted value community and realize the green transformation of the whole value chain by the investment of capital and capacity, and environmental protection technology turns to whole process management for Type II from end control. For example, as a role model of global modular furniture producers, IKEA has established IWAY Department to evaluate the performance of suppliers and other stakeholders to realize environmental protection, forest resource protection, energy conservation, and other aspects, and the employees of IWAY Department constantly inspect the production and manufacturing workshops of suppliers with a third party to ensure whole process management of IKEA modular products under green growth model.

For enterprises of type III and IV, because there is no outsourcing in the manufacture of integral products and the business process is highly integrated, enterprises prefer to adopt whole process management technology to achieve green transformation for Type IV. Similarly, considering the transaction cost of the value chain, enterprises that manufacture integral products can realize the whole process more effectively than those manufacturing modular products, which requires modular product enterprises to continuously seek to build more stable and efficient value chain, coordinate value chain members, and reduce the transaction cost of modular product value chain. For example, as for the Chinese rocket manufacturer China Aerospace Science and Technology Corporation, or CASC for short, all parts of the products are made by CASC and its subsidiaries because of the particularity of rocket manufacturing and confidentiality requirements, resulting in a high level of completeness. Therefore, to ensure environmental protection, CASC has better ability in whole process management and can require all production links of its products to reconstruct and develop under the goal of green development, for example, sewage treatment, flue gas desulfurization and denitration, environmental protection equipment development and application, and environmental protection engineering construction. CASC is a typical enterprise applying whole process management to produce integral products.

(3) Strategic Direction and Management Point of Different Environmental Protection Technologies

The strategic direction and management point of the enterprises adopting whole process management or end control technologies are different. To produce innovative or modular products, enterprises need to procure and outsource in the short term to realize product design, manufacturing, selling, and service ability. The strategic direction of achieving EGGM at the beginning is to secure the green ability of core value-added process by end control, and the management point is to enhance green growth inside the enterprises. As long-term repeated trading under the trust relationship gradually forms, core enterprise can achieve the whole process management by deep cooperation mechanism of upstream and downstream value chain entities, and thus, realize the green growth of whole value chain. The strategic direction at this stage is to build up the value chain community, and the management point is to strengthen the coordination of entities along upstream and downstream value chain. For producing functional or integrated products, the features of the integrated production pattern are convenient for enterprises to strengthen the control and management of all activities in the whole life cycle to improve the green ability, strengthen the reconstruction of internal operation process, and realize the green upgrade of enterprises through the whole process control.

(4) Principles of Enterprises' Green Growth Model

There are two principles of EGGM: first, the implementation of EGGM requires the participation of all entities along the value chain, which is jointly achieved by the value community composed of governments, enterprises, consumers, and non-governmental organizations, or NGOs for short; second, the formation of value chain community needs to solve the Olson's Dilemma, that is, the different objectives resulting from individual rationality of different entities which may lead to global imbalance of the whole value chain, and non-realization of coordination of "green" and "growth" in value chain. The implementation of EGGM needs the coordination and cooperation of various entities in the value chain network.

Though different product types, i.e., innovative products or functional products, product structures, i.e., modular products or integral products, and environmental protection technologies, i.e., end control or whole process management, jointly influence enterprises' strategic direction and management point of implementing EGGMs, these two principles need to be considered for enterprises producing any type of products and owning any kind of technologies. The highest goals of decision-making for value community need to cover the overall economic benefits, environmental benefits, and social benefits of the whole value chain, realize overall optimization of the value chain through a series of coordination and cooperation mechanisms, and finally realize the EGGMs of the whole value chain.

(5) Practice of Enterprises' Green Growth Model: Huawei's Green Transformation

Since 2008, Huawei, a Chinese company, has released its fiscal-year sustainable development report to the public every year, revealing its sustainable development

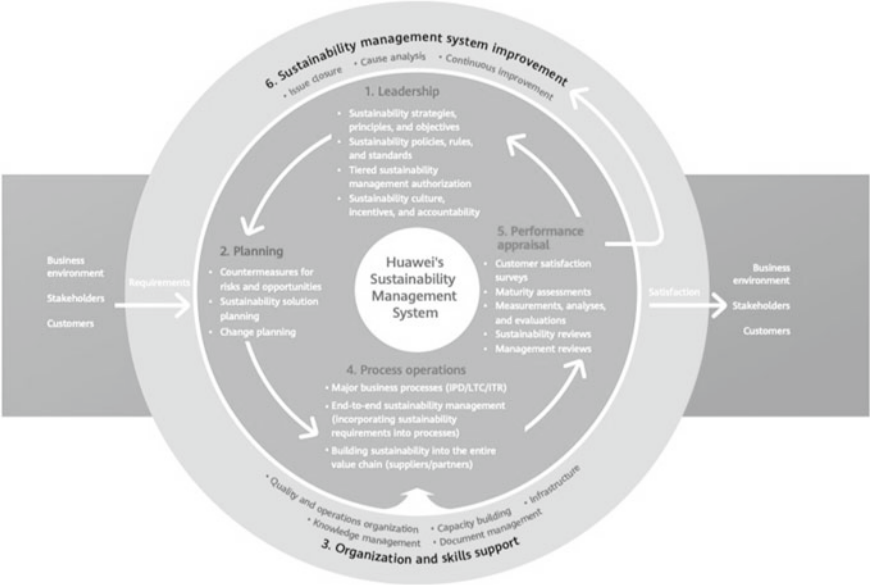

Fig. 1.3 Framework of Huawei's sustainability management system[1]

goals, actions implemented, and performance achieved. In the *Huawei Sustainable Development Report 2020* [11], Huawei simultaneously took environmental protection index "green" and profit/cost index "growth" as corporate development goals. As shown in Fig. 1.3, Huawei's sustainability management system covers all aspects of enterprise functions, including operation, marketing, and finance, and provides guidance for the whole process of leadership, planning, operation, and assessment. At the same time, Huawei's sustainability management system also considers all entities in the value chain and sets specific development directions for the realization of value community and global optimization. In 2020, Huawei's carbon emissions per unit sales revenue decreased by 33.2% compared to that in 2012, exceeding the emission reduction target set up in 2016. Huawei has already used 220 million KWH of renewable energy in China, which equivalently reduced carbon emissions by roughly 188,000 tons.

1.1.2 System Model of Enterprises' Green Growth Model

EGGM forms a value community by promoting the coordination and cooperation of various entities of a value chain. To support enterprises to make decisions to realize

[1] https://www-file.huawei.com/-/media/corp2020/pdf/sustainability/sustainability-report-2020-en.pdf.

the global optimization of value chain, this book proposes the **System Model of Enterprises' Green Growth Model** which mainly includes four aspects: the external environment of EGGM, triple bottom lines, entities, and the major activities. From the outside to the interior, the paper interprets various factors that enterprises need to consider when implementing the EGGM, as shown in Fig. 1.4.

(1) External Environment of Enterprises' Green Growth Model System

The external environment consists of the influence of macro politics, economics, society, and technological environment on the implementation of EGGMs. Governmental environment refers to the green policies and green regulations within the political subject and the influence of international gaming of green development on enterprises, for example, the WEEE fund systems of U.K. and China, as well as the EU carbon emissions trading system. Economic environment refers to the influence of economic development opportunities or pressure on enterprises, for example, the impact of low or even negative interest rates under the quantitative easing policy that has lasted for more than a decade since the 2008 financial crisis on corporate financing, and the impact of reduced global demand due to the COVID-19 pandemic since 2020. Social environment refers to the change of consumer behavior and perception and the influence of social activities on enterprises, for example, consumer's concern of environmental protection will increase the willingness of enterprises to carry out green marketing, and NGOs will exert pressure on enterprises. Technological environment refers to the impact of various green technologies, for example, environmentally friendly materials and processes for enterprises, mainly including the availability and low cost of technology.

(2) Triple Bottom Lines of Enterprises' Green Growth Model System

If implementing EGGMs, enterprises should not only consider economic goals, but also pay more attention to the impact of corporate behavior on society and environment and make systematic optimal global decisions relying on the triple bottom lines of society, environment, and finance [12]. The economic bottom line is mainly reflected in the enterprise's goals of increasing profits, tax liability, and dividends

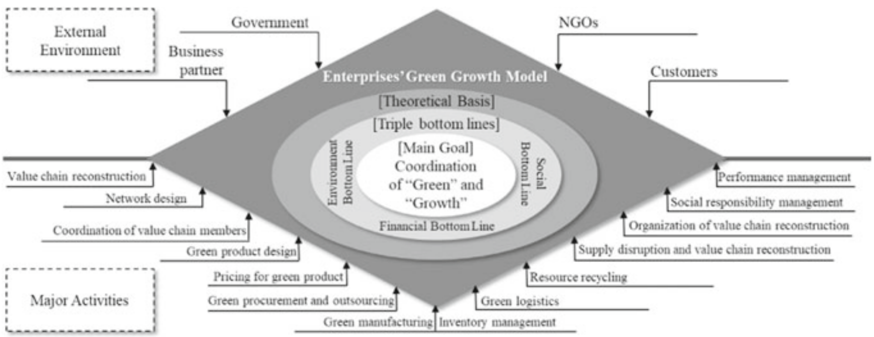

Fig. 1.4 System model of enterprises' green growth model

to shareholders and investors. The environmental bottom line is mainly reflected in the enterprise's commitment to protect the environment. The social bottom line is mainly reflected in the enterprise's responsibility to other stakeholders in the society. Enterprises must fulfill the objectives and responsibilities in the above three fields when carrying out CSR practices, which is the "triple bottom lines theory" related to corporate social responsibility. The main job of the business activities achieving the triple bottom lines is to get rid of the traditional public advertising in green development. Enterprises should figure out their goals of social performance, environmental performance, and economic performance within a reasonable period for consideration and control of the social, environmental, and economic performance of the state-owned enterprises to realize EGGMs based on the triple bottom lines.

(3) Entities of Enterprises' Green Growth Model System

Realizing value community is the main principle of EGGM, and enterprises need to consider the influence of different entities of EGGM. Among them, governments will make reasonable green development goals according to the economic and social development level of different regions and put forward different types of incentives or punishment measures. Obtaining business contacts and connections with cooperative enterprises is the main path for core enterprises to implement EGGM. Especially for enterprises that rely on value chain network, the green transformation of the whole process of production has a significant barrel effect, which requires the full cooperation of enterprises in all aspects. The environmental protection perception and consumption behavior of consumers directly determine the willingness of enterprises to implement EGGMs. The green marketing of enterprises and the green behavior of consumers promote the green growth of value chain mutually. Finally, NGOs supervise enterprise's activities and guide enterprises to implement EGGMs and achieve green transformation.

(4) Major Activities of Enterprises' Green Growth Model System

Enterprises need to consider the ways to achieve green growth in decision-making and implementation of almost all operational, financial, and marketing activities, which are reflected in both strategic development and operational management, presented in later chapters of this book. At strategic level, the activities of EGGM system mainly include value chain reconstruction and network design; while at operating level, mainly include coordination of value chain members, green product design, pricing for green product, green procurement and outsourcing, green manufacturing, inventory management, green logistics, resource recycling, supply disruption and value chain reconstruction, organization of value chain reconstruction, social responsibility management, and performance management. Main activities of EGGM system cover all aspects of traditional enterprise strategy and operation management. In each activity, the goal of "green" and "growth" should be fully coordinated, and the whole process of control and management should be realized under the principle of global optimization of "green" and "growth" coordination.

1.1.3 Differences Between Enterprises' Green Growth Model and Conventional Growth Model

EGGM enterprises and conventional growth model enterprises have different recognition of their core competence and key performance, which results in different attention and management models in various key activities for both, and ultimately affects the operation and transformation objectives of all enterprise activities including value chain reconstruction. For example, traditional environmental management emphasizes more on passive and end control while green growth emphasizes more on positive and whole process management. This is also the main difference between the two models (see Table 1.1).

For enterprises implementing traditional growth model, the core way to achieve growth is to improve performance and reduce costs, while most operating activities are profit oriented. The transformation of business processes entails improvement in the economic benefits and operating efficiency of enterprises. For example, enterprises implementing conventional growth model pay more attention to low-cost manufacturing and effective pricing strategies than to proper disposal of wasted products. Correspondingly, for enterprises implementing EGGM, both green and economic performance should be paid equal attention to, and the coordination of "green" and "growth" of all operational activities should be maintained in addition to operational efficiency. For example, activities related to green growth, such as green marketing, product remanufacturing, and green design will be regarded as strategic activities in the process of value chain reconstruction for enterprises implementing EGGMs, and will then result in long-term strategies and tactics for enterprises to improve related green development capabilities.

1.2 Value Chain and Value Chain Reconstruction

1.2.1 Concepts of Value Chain and Value Chain Reconstruction

(1) Value Chain and Supply Chain

Value creation for enterprise is the process of providing products and services to consumers in which production factors interact with each other. From the perspective of input–output, the process-based enterprise value creation mainly studies how enterprises transform production factors into output demanded by customers, and how to realize enterprise value. Value chain is developed from traditional value chain to virtual value chain, and to value network. Irrespective of how the concepts, forms, and structures of value chain evolve, value chain is essentially an organic system composed of a series of value creation activities.

Table 1.1 Comparison between enterprises' green growth model and conventional growth model under different activities

Activities	Different focus	
	Conventional growth model	Enterprises' green growth model
Value chain reconstruction	Economic efficiency and market competitiveness of enterprises	Coordination of economic and environmental benefits
Network design	Value chain network with low cost, low risk, high efficiency, and high stability	Low-cost value chain network that considers green goals such as wasted products collection and carbon emissions reduction
Coordination of value chain members	Achieve relationship coordination through profit sharing and other conventional mechanisms	Consider governmental environment protection policy, members' green ability, and willingness; and create green value
Product design	Balance of cost, production efficiency, and consumer preference; manufacturing-oriented design	Consider the green level of products and consumers' green preference, cost, and efficiency; ecology-oriented design
Product pricing	Cost leadership strategy	Differentiated pricing strategy considering consumers' green preference
Procurement and outsourcing	Procurement and outsourcing suppliers' capability to satisfy orders	Coordination of procurement and outsourcing suppliers' order-fulfillment capability and green capability
Manufacturing	Improvement of manufacturing efficiency and cost control	Coordination of improving manufacturing efficiency, reducing costs, and reducing environmental impact
Inventory management	Reduce inventory levels, maintenance costs, and waste of resources	Reducing inventory levels, maintenance costs, and environmental impact of inventory
Logistics and distribution	Minimize logistics and distribution costs	Coordination of minimizing logistics cost and environmental impact
Resource recycling	Less resource assumption	Coordination of "growth" and "green" through recycling and reuse
Supply disruption and value chain reconstruction	Minimize the impact of disruption on business continuity	Minimize the impact of disruption on business continuity and enterprise green capability

(continued)

Table 1.1 (continued)

Activities	Different focus	
	Conventional growth model	Enterprises' green growth model
Organization of value chain reconstruction	Reduce the organization size of non-core value-added processes	Improve the green capability of all the entities along value chain and reduce non-green organizations
Social responsibility management	Maximize consumer surplus	Coordination of maximization of consumer surplus and social environmental benefit
Performance management	Maximization of economic benefit	Attach equal importance to economic and green environmental benefits and seek coordination of "growth" and "green"

Porter proposed in his book *Competitive Advantage* that a series of value-creating activities produced by an enterprise can be regarded as a series of completed processes, which are indeed the value-added activities of the enterprise. In these value-added activities, the value created by the enterprise is greater than the cost of these activities. These value-added activities constitute a dynamic process, which form the value chain. Value chain emphasizes the importance of the position of an enterprise in the industry and its relationship with the outside, and names the larger industrial value chain which an enterprise's unit value chain belongs to as value system [13]. Michael Porter's value chain model is shown in Fig. 1.5.

Supply chain is initiated from Peter F. Drucker's "economic chain", developed by Michael Porter into "value chain" that eventually evolved into "supply chain", and Accenture has optimized the dissemination of the topic. The core work of supply chain centers on the core enterprise: through the control of information, material, and cash flows, supply chain starts from raw material purchasing, producing intermediate

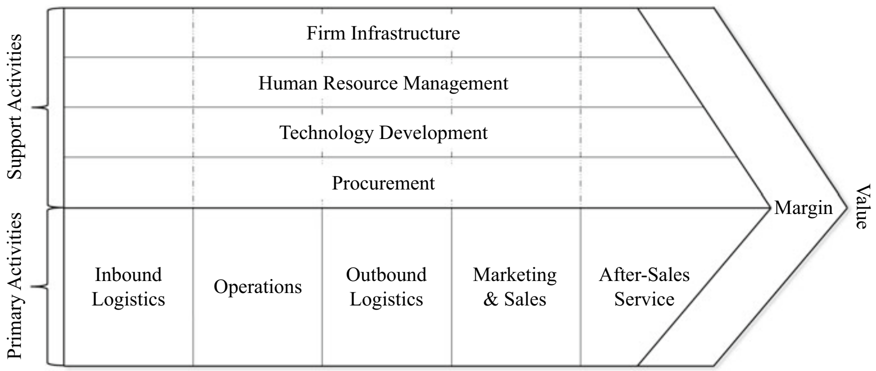

Fig. 1.5 Value chain model by Michael Porter

products and final products, and finally delivering the products to consumers through sales network. Supply chain is a network chain model that connects suppliers, e.g., raw material suppliers or spare parts suppliers, manufacturers, e.g., processing plants or assembly plants, distributors, e.g., agents or wholesalers, retailers, e.g., hypermarkets, department stores, supermarkets, specialty stores, convenience stores, and grocery stores, and end users into a whole function unit.

Supply chain is the development of the value chain, emphasizing network among enterprise. The focuses of value chain and supply chain are different: when first proposed, value chain is more of a single enterprise content, value chain perspective is more about the issues of value creation and distribution, and the target is to achieve maximum economic and financial value. Supply chain intends to solve the cooperation problem of multiple entities caused by outsourcing. Therefore, supply chain is more about the network among enterprises and the design and operation of efficient intra-company network [14].

(2) Value Chain Reconstruction

Value chain reconstruction refers to the process of maximizing strategic activities and main value-added processes and minimizing other activities by redefining the basic and auxiliary activities of the enterprise, thus improving the core competitiveness and business performance of the enterprise [15]. The reconstruction of value chain requires a review of enterprises' strategic activities, and a redefinition of which activities are of value and strategic significance. As the market environment of enterprises becomes complicated gradually, it is difficult for enterprises to optimize multiple activities in the value chain, leading to the decomposition of value chain. Enterprises need to choose the activities with advantages and retain them, and hand over the other activities with no competitive advantages to other value chain entities. This leads to the increase or decrease of some intermediate activities of the original value chain, and finally leads to reconstruction and merger of value chain. To choose the path of value chain reconstruction, enterprises should first apply value chain analysis, then modular decomposition of the internal activities, and finally determine which of the current activities of the enterprise should become strategic based on the requirements of the reconstruction for competitive advantages. The conditions for improvement and reconstruction are required.

For example, the COVID-19 global pandemic that started at the beginning of 2020 posed a challenge to all the value chains from all walks of life, which means enterprises' previous competitive advantages disappeared in this changing environment, and the original main value process of strategic activities also changed. Enterprises need to reconstruct the value chain in a timely manner to reshape competitive advantage and improve financial benefits. The garment manufacturing industry in Southeast Asia and South Asia is the most typical example [15]. Bangladesh's traditional competitive advantages in garment manufacturing are cheaper labor and higher proximity to raw material markets (China). Due to lock-down amid the pandemic, labor costs increased in Bangladesh and the country saw shortage of raw materials due to the suspension of international logistics. Previous competitive advantages of local garment companies are no longer significant. After the temporary and structural dynamics brought by COVID-19, garment manufacturers in Bangladesh have begun to break out of their traditional competitive advantages, reconstruct the value chain and reshape competitive advantages by optimizing raw material channels, new product development, positive marketing, and improving operational capabilities. At present, Bangladeshi garment enterprises can source 100% raw material from the local market, possess certain digital, risk resistance, and sustainable development ability, greatly improving the financial performance of enterprises.

Conventional value chain reconstruction activities usually take the existing assets and technical capabilities of the company as the research entry point, and expand the design, production, distribution, marketing, and other aspects of enterprise highlighting the existing core competitiveness of enterprise, while customers are usually the last to be paid attention to. However, this kind of analytical thinking pattern does not match current market environment. The market has changed from being driven by enterprise production to being driven by consumer demand. The core driving force of the enterprise structure upgrade should be to actively meet the changes in market demand, so as to consider ways to reconstruct the production process of the enterprise and determine the asset structure and core competitiveness of the enterprise [16]. Therefore, in the market environment where green products are gradually favored by consumers, enterprises should reconstruct their value chain to highlight the "green value" of products according to consumers' demand and from the perspective of green growth, so as to improve the competitiveness of products, economic benefits, social benefits, and environmental benefits of enterprise.

For enterprises seeking green growth, the reason for value chain reconstruction is that the upstream and downstream value chain cannot achieve the overall coordination of "green" and "growth" through cooperation and collaboration, which reflects two key points of value reconstruction under the green development of enterprise. First, it is necessary to realize the cooperation and coordination of value entities, requiring the core value chain enterprise to re-select the value chain cooperation partners that meet the goal of green growth, rebuild new value chain network according to the requirements of the whole process control, and finally realize the cooperation and coordination of various green entities on the value chain. Second, realizing the value chain process requires the coherence of the concepts of all businesses and activities, environmental management objectives, and environmental protection technology. Furthermore, with whole process control, enterprises should observe the value chain upstream and downstream processes, identify the most insignificant green value-added activities and minimize them, and finally achieve the coordination of green growth and value chain activities.

1.2.2 *Features of Value Chain and Value Chain Reconstruction*

(1) Features of Value Chain

The value chain achieving green growth of enterprise has two features:

First, value chain focuses on the cooperation of entities. Value chain helps enterprises build a value community including all stakeholders and realize global optimization. Value chain is an optimization idea of sorting out enterprise process, streamlining enterprise structure, concentrating enterprise core resources, and highlighting enterprise competitiveness in enterprise operation management [17]. Most previous research are based on the existing supply chain models and use the value chain idea of "value-added/non-value-added" to optimize the specific process of enterprises or conduct case studies of supply chain optimization [18]. Many enterprises exist in networks that include not only suppliers and consumers, but also competitors [19]. The value chain of an enterprise does not exist in isolation and the value chain of a single enterprise is embedded in a wider range of value networks. To obtain and maintain competitive advantages, an enterprise needs to understand not only its own value chain but also the value network in which the entire enterprise value chain is located.

Second, value chain also focuses on the collaboration of business processes and can be decomposed to achieve the optimization and management of each module, as well as to achieve a more transformative value chain reconstruction, but its core is to better coordinate various business processes to better achieve the goal of coordination of "green" and "growth". The value chain decomposition process is the modularization process that brings about the value chain nodes [20]. A value chain module is described as the vertical integration value chain structure of a specific industry, which gradually breaks into several independent value nodes. And through the horizontal concentration, integration, and enhancement of functions of each value node, a number of relatively independent value module manufacturers are formed. In order to ensure the effectiveness of the whole value creation system, the coupling between the modules becomes particularly important after some activities of the value chain are decomposed into value modules, leading to the interdependence between the modules. From the perspective of value creation, the essence of coupling between modules is an interactive process, in which modules exchange or jointly create value [21].

(2) Features of Value Chain Reconstruction

The essence of value chain reconstruction is to establish an innovation chain by innovating different combinations of production factors, provide enterprises with new competitive advantages, and improve economic benefits by realizing new products or processes [22, 23]. Value chain reconstruction involves a series of reform activities carried out by enterprises to meet the need of green transformation which cannot be realized by the existing value chain module. Value chain reconstruction has strategic influence on the development and future of enterprises and has the following features:

(a) Value Chain Reconstruction is the Process Where Enterprises Innovate Their Competitive Advantages

"Value proposition" is the core of the value chain, and value chain reconstruction can help enterprises to fully analyze and cognitively identify the processes which do not add value or perceived so by customers, to highlight the core value-added process through business process reengineering, to improve the existing core competitiveness and to obtain new competitive advantage. In the process of value chain reconstruction, the input of new technology, organizational structure, and technological process lead to a comprehensive innovation of the personnel, machine, technology, production model, and production environment of enterprises, which itself is an innovation process. Value chain reconstruction can achieve the purpose of breaking rigid organizational structure, updating production equipment and technology, improving production environment, providing enterprises with better development opportunities, providing the market with more satisfying products and services, and thus, improving or reshaping competitive advantages. Value chain reconstruction is also one of the effective ways to implement green development model which help enterprises innovate combination of value chain production factors in accordance with the requirements for coordination of "green" and "growth" from all production and operation activities, to avoid the possible mismatch of internal processes caused by partial innovation, and to achieve the coordination of "green" and "growth" of enterprises.

In the aforementioned case of Bangladesh's garment industry, some local garment enterprises shape new brand images and open domestic, European, and American markets through active value chain reconstruction. At the same time, the stability of the value chain is improved, and the risk of value chain interruption can be actively dealt with. After losing their original competitive advantages of cheap labor and proximity to raw materials due to the pandemic, enterprises built new competitive advantages through value chain reconstruction.

(b) Value Chain Reconstruction is the Process of Improving Enterprise's Financial Performance

Although certain risk exists in the process of value chain reconstruction, a successful value chain reconstruction can effectively improve enterprise operating efficiency and performance. First, by identifying basic and auxiliary activities, enterprises can carry out targeted business process optimization and transformation and reduce the production cost without affecting output. Second, by identifying strategic activities and market needs, enterprises can identify core business processes that need to be retained and continuously invested in, as well as non-core business processes that can be outsourced to reduce management and capital pressures. Third, by analyzing the first customer-oriented demand based on enterprise resources, enterprises can provide products and services that match different market demands as much as possible without massive investment, and improve competitiveness, market share, and performance of the enterprises. Therefore, the main purpose for enterprises to carry out value chain reconstruction is to improve their operational efficiency and financial performance, which is the most important guarantee for enterprises to voluntarily implement EGGMs through value chain reconstruction.

According to the US Department of Commerce, Bangladesh's apparel exports to the US totaled $5.92 billion in 2019 and fell to $5.22 billion in 2020 as a result of the pandemic. With the gradual recovery of the global economy, the reconstructed garment manufacturing value chain of Bangladesh fully responded to international demand, solved the problems of raw material price rise and supply disruptions, and achieved a total garment export of $7.14 billion to the United States in 2021. Bangladesh's apparel exports in 2021 reached $35.57 billion, up about 30% from $27.32 billion in 2020, according to data from Bangladesh's National Revenue Bureau.

(c) Value Chain Reconstruction is Multi-Entity Collaborative Process in Value Network

Coordination among the value chain entities is the prerequisite for the coordination of "green" and "growth". Interest-concerned entities generally do not take the initiative for the value chain reconstruction, and core enterprises need to coordinate the interests of different value chain entities in order to realize the whole control and global optimization of the value chain for effective value chain reconstruction. Instead of end control, EGGM is more about the green level of products and the requirement for terminal manufacturers to achieve green goals. Instead, EGGM is a type of whole process management that focuses on all activities in a value chain. All entities in the value chain need to achieve green growth, and any entity's lack of green ability or lack of financial-benefit sharing will fail to achieve green growth for the whole value chain. However, value chain reconstruction will completely change the traditional operation model, long-term partners, and classic products and services of enterprises, and thus, it also has certain risks. Therefore, all entities on the value chain should form a value community, and decision-makers of core enterprises should consider the maximization of the overall economic and environmental benefits of the whole value chain as the decision-making goal. They should realize the overall optimization of the value chain through coordination among various entities, and finally realize the coordination between "green" and "growth".

Therefore, value chain reconstruction is not only an internal decision-making process of enterprise, but also related to all external stakeholders, and it needs to make a comprehensive decision based on the internal and external environment. First, governments, consumers, and NGOs lay more emphasis on the influence of value chain reconstruction on social benefits, consumer surplus, and environmental benefits, and hope to guide the direction of the green transformation of enterprises through value chain reconstruction combined with national development strategies, to provide more innovative products through continuously exploring the potential demand of the consumers, and to improve the environmental protection level of enterprises by introducing new technologies and processes. Second, the upstream and downstream value chain entities also have different preferences towards value chain reconstruction. For the cooperative enterprise producing green products earlier, the value chain reconstruction can help them get better integrated into the production process and even get more outsourcing business from the core enterprise. For cooperative enterprises with no green power, value chain reconstruction means the loss of original business and profit, which requires the core enterprise to fully share the benefits of value chain reconstruction. For example, core enterprise can provide green technology sharing platform to enable green manufacturing for small enterprises, entrust retailers to upgrade product recycling service with the help of retail network, and provide additional compensation to ensure that upstream enterprises purchase green raw materials.

To achieve green transformation and upgradation and green growth of the whole value chain, Huawei established *Comprehensive Procurement CSR Management System* and *Supplier CSR Agreement* throughout the value chain, which would require all value chain enterprises to carry out green transformation activities, enable value chain enterprises to achieve green production models such as *Zero-Landfill Management System for Solid Waste*, and achieve green growth through value chain reconstruction. Huawei regularly reviews and evaluates the activities of value chain enterprises, establishes, regularly reviews, and updates the *Supplier CSR Audit Checklist*. Huawei has also established the value chain enterprise performance management mechanism to evaluate the green growth of enterprises, on-site audit results, and enterprises achieving improvement by value chain reconstruction, and provide more orders and cooperation opportunities to enterprises with excellent evaluation results. Obviously, in order to realize the value chain reconstruction of green growth, core enterprises of value chain need to coordinate different entities, strengthen the control of the whole value chain, enable entities of the whole value chain to achieve green transformation, and finally realize the coordination of "green" and "growth" for the whole value chain.

(d) Value Chain Reconstruction is the Process Where Enterprises Coordinate Different Business Processes

Value chain reconstruction of enterprises redefine all types of activities, maximize main value-added processes, and outsource other processes; and enterprises need to fully cooperate to maximize the benefits of reconstruction. Value chain reconstruction breaks the original business process and improves the core competitiveness of enterprises by selecting and reassembling. So, the possible problems of non-smooth links between entities and inefficient conflicts of operation and scheduling in reconstructed processes might influence the operation of enterprise and reduce the benefits brought by value chain reconstruction. Enterprises need to coordinate reconstructed processes again to ensure smooth connection among processes to realize smooth development of production and operation and ensure orderly and efficient scheduling to maximize the operation efficiency of the enterprise. Especially for the realization of EGGM, the adoption of new green technologies, new goals, new processes, and new environment requires enterprises to pay more attention to the coordination between green processes and original processes, so as to better realize the green performance and green competitiveness.

While enabling entities of the whole value chain to achieve green growth, Huawei has also reorganized the business processes of the enterprise according to the goal of green growth and realized the coordination of reconstructed processes. Recycling of waste products is a very representative one. Traditional wasted product recycling activities are often the result of governmental pressure, and recycling process leads to substantial cost and operational pressure for enterprises. Moreover, the recycled products are difficult to recover and cannot produce green income. Huawei integrates wasted product recycling into its existing sales business and collaborates it with new product sales to expand the business scope of network channels and reduce channel costs. At the same time, wasted products are used for product remanufacturing to improve resource utilization efficiency and reduce manufacturing costs by collaboration between new product manufacturing and waste product remanufacturing business. In 2020, Huawei recycled more than 4500 tons of electronic product waste through the "Four-Step Trade-In Process". More than 120 kg of gold and 87 tons of copper can be reused for new product manufacturing from every 10 million collected mobile phones. Huawei improves the efficiency of value chain reconstruction by coordinating different business processes, and gains new competitive advantages and significant financial benefits.

1.2.3 Steps of Value Chain Reconstruction

Figure 1.6 show eight steps of value chain reconstruction [24, 25]. First, enterprises should identify all internal and external value chain activities according to product type and structure and define primary or support activities to serve as the basis for subsequent reconstruction and optimization. Second, according to enterprises' own financial and technological advantages, as well as the ability of competitors in the market, enterprises should determine the strategic activities, those that competitors do

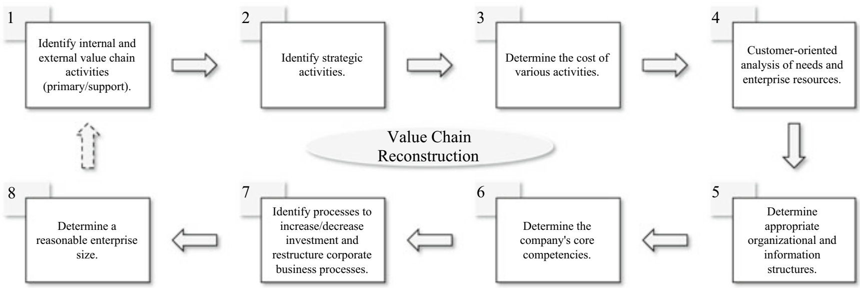

Fig. 1.6 Steps of value chain reconstruction

not possess. Third, enterprises should determine the cost of various activities based on historical operation data. Forth, customer-oriented analysis of market demand and enterprise resources and matching degree should be considered to identify the strengths and weaknesses of the enterprise, as well as opportunities and threats of the market environment. Fifth, enterprises should determine reasonable organization and information structure according to the analysis of enterprise resources, such as team system which is more suitable for innovative product, and linear function system which is more suitable for functional products. Sixth, enterprises should determine the core competence of the enterprise based on analysis results of strategic activities, activity costs, and organizational information structure. Seventh, to highlight the core capabilities, enterprises should determine the need to improve or reduce the investment process, that is, improve self-restraint ability or entrust outsourcing, to reconstruct the enterprise business. Eighth, enterprises should determine a reasonable enterprise scale according to the scale of the product and the complexity of the process.

The dotted arrows in above figure indicate that the enterprise's value chain reconstruction is not a permanent process, but a continuous cycle of development. Market environment is constantly changing, consumer demand is constantly being digging, and technology are constantly breaking through. Therefore, the effectiveness of the reconstructed value chain often decreases with changing internal and external environment, requiring enterprises to grasp the core of creating value for consumers, undertake self-innovation and value chain reconstruction, and enter the upward spiral process. Of course, each value chain reconstruction requires a period of time for the enterprise to adapt to and maximize the new value chain. Therefore, it is necessary to pay attention to the interval between two adjacent value chain reconstructions and determine the frequency of value chain reconstructions according to the situation of the enterprise.

1.3 Enterprises' Green Growth Model and Value Chain Reconstruction

1.3.1 Value Chain Reconstruction Based on Enterprises' Green Growth Model

The essence of value chain reconstruction is to establish an innovation chain through different combinations of production factors [22, 23]. Value chain reconstruction helps enterprises implement EGGMs and achieve green transformation, and provides a new direction, method, and combination model for value chain reconstruction. The concept of green growth puts forward new requirements and standards for traditional production factors, for example, the requirement to shift from polluting production technologies to zero-emission production technologies, change from the process flow that harms the health of personnel in the production process to the people-first process flow that ensures the physical and mental health of personnel, transform from rough mineral development to lean mineral development, and most importantly, shift from end control of environment protection technologies to whole process management that achieves green transformation and upgradation and green growth of the whole value chain. Therefore, enterprises need to innovate technology and management model on the basis of the traditional production model, and reorganize and re-allocate the original elements, that is, the reorganization and re-allocation of previous factors like technologies and management models. Enterprises should set up a new operating system to realize green growth by combining new green technologies, information technologies, and management models in Table 1.2. The research of various operating activities of enterprises in EGGMs will be gradually introduced in later chapters of this book.

1.3.2 Relationship Between Enterprises' Green Growth Model and Value Chain Reconstruction

EGGM put forward new green standards for production factors of enterprise, and in reverse, green production factors affect EGGM. Therefore, we propose the following relationship between EGGM and value chain reconstruction: the implementation of enterprises' green growth model requires value chain reconstruction which is the path for enterprises to achieve green transformation and green growth.

(1) The Implementation of Enterprises' Green Growth Model Requires Value Chain Reconstruction

Enterprises' green growth model puts forward a new requirement to the existing value chain network of enterprises, that is, the coordination of "green" and "growth", which requires enterprises to adopt value chain reconstruction to provide necessary environment, resources, and ability for enterprises to implement EGGM. EGGM demands all the aspects of existing value chain network, for example, technology, capital, and management, to achieve innovation and improvement in a green manner, which cannot be satisfied with the cost of lower financial growth. In this case, conventional enterprise green transformation, for example, adding filtering equipment fails to simultaneously meet the goals of "green" and "growth", cannot lead to total transformation in EGGM. Under this pressure, enterprises need to reform and reconstruct their value chain thoroughly, so that the new value chain can achieve the goal of green growth of enterprises. Therefore, the strategic decision of enterprises to implement EGGM can be one of the most effective driving forces for enterprises to implement the value chain reconstruction. EGGM requires enterprises to complete their own reformation and innovation, so as to continuously improve the market competitiveness and finally realize the growth of economic benefits, social benefits, and environmental benefits of enterprises.

Table 1.2 Different activities of value chain reconstruction in enterprises' green growth model

Activities	Contents
Network design	Workable and efficient networks should be designed for green operation activities and green objectives such as carbon emission reduction and collection of waste products; and optimization and game models should be constructed
Coordination of value chain member	The value chain should consider environmental policy pressure and consumers' green preference, and the coordination mechanism of value chain member relationship should be designed to realize the co-creation and sharing of green value and global optimization
Green product design	The internal and external realization paths of green product design and innovation should be determined, and the innovation models of green product design based on different perspectives of external new media or internal executives should be constructed
Pricing for green product	Considering the economic benefits, market competition, and policy pressure of green product pricing, the game models between enterprises and consumers, among value chain entities from the perspective of information asymmetry, and between enterprises and policy makers under the government regulation environment should be constructed
Green procurement and outsourcing	Based on the influence of green procurement and outsourcing on enterprises and considering the motivation and risk of outsourcing, the game model of strategic decision-making of green procurement and outsourcing should be constructed
Green manufacturing	Based on the introduction of new technologies like green technology and new business models like intelligent manufacturing and remanufacturing, an analysis model of enterprise remanufacturing under dual-channel strategy should be constructed to achieve green manufacturing
Inventory management	Considering the influence of inventory management on bullwhip effect under green development model, an analysis model of bullwhip effect and inventory management in closed-loop supply chain should be established
Green logistics	The path optimization analysis model of collaborative logistics and hazardous materials logistics should be constructed to analyze the specific implementation path of low-carbon logistics, collaborative logistics, and hazardous materials logistics

(continued)

Table 1.2 (continued)

Activities	Contents
Resource recycling	According to the new business model under the new technology and new policy, the game model of second-hand product recycling platform trading model in green manufacturing should be designed
Supply disruption and value chain reconstruction	According to new technology, new procurement strategy, and new manufacturing model, the supply disruption response plan considering the sustainable green growth goal of enterprises should be proposed, and the analysis model of cross-border supply disruption should be constructed
Organization of value chain reconstruction	According to the enterprise green growth goal, all the value chain entities should be evaluated and reselected to achieve better cooperation adopt novel activity elements like environmental management technology
Social responsibility management	The mechanism analysis model of the influence of employees and leaders on green growth model of enterprises should be constructed to analyze the ways to improve the social responsibility perception of internal members from inside and outside
Performance management	According to the design of green performance, data envelopment analysis, whole life cycle, and maturity green performance evaluation model based on various indicators, the analysis model of application of maturity evaluation model in practice should be constructed

(2) Value Chain Reconstruction is the Path for Enterprises to Achieve Green Transformation and Green Growth

Value chain reconstruction can effectively help enterprises to achieve green transformation and upgradation and realize the coordination between "green" and "growth" by reconstructing the core green value-added process internally and enabling the green value-added ability of the value chain externally. Different from the simple green production transformation model based on end control, which is difficult to achieve, the coordination between "green" and "growth", e.g., increasing purification equipment, and adopting environmentally friendly raw materials, green transformation and green growth are the results of the whole process management of value chain and cannot be achieved by simply optimizing and greening a specific partial production process. To realize green transformation, green growth, and the coordination between "green" and "growth", core enterprise needs to completely reconstruct internal processes, preserve, and highlight green-upgraded process, form competitive advantage to achieve growth, outsource processes to upstream and downstream value chain members with relatively higher green ability, and enable other value chain members to improve the green ability and green level of the value chain.

Therefore, value chain reconstruction is an effective way for enterprises to achieve green transformation and green growth.

1.3.3 Goal of Value Chain Reconstruction in Enterprises' Green Growth Model

Based on the above analysis of EGGM, value chain reconstruction, and their relationship, the book proposes the goal of value chain reconstruction in EGGM: considering the cost, environment, and security, to achieve the innovation-driven coordination of "green" and "growth" and global optimization of economic, social, and environmental benefits. First of all, EGGM driven by value chain reconstruction includes the protection and improvement of the environment under the premise of controllable cost, which is the guarantee of environmental benefits and the effective path to achieve green transformation. Second, EGGM should consider both green development and economic development, and drive enterprises to realize the coordination of "green" and "growth" through value chain reconstruction. It is necessary to avoid the emergence of the enterprise unsustainable model that sacrifices financial development for the sake of green, and the environment unsustainable model that sacrifices green for the sake of financial development. Finally, value chain reconstruction in EGGM should comprehensively consider all entities in value chain, improve the green ability and performance level of all members, promote the formation of value community through coordinated development goals, and achieve global optimization through the appropriate sharing mechanism of economic, social, and environmental benefits.

1.4 Summary

This chapter presented the overview of enterprises' green growth model and value chain reconstruction. First, this chapter presented important concepts of enterprises' green growth model, analyzed the features of different EGGM based on different product types, e.g., innovative products or functional products, product structures, e.g., integral products or modular products, and environmental protection technologies, e.g., end control or whole process management, proposed the system model of EGGM, and compared EGGM with conventional growth model. Second, this chapter introduced the concepts and features of value chain and value chain reconstruction regarding green growth and presented the steps of value chain reconstruction. Finally, this chapter analyzed how to reconstruct value chain on the basis of EGGM and proposed the relationship between EGGM and value chain reconstruction and the goal of Value Chain Reconstruction in EGGM.

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Chapter 2
The Logic of the Emergence of Enterprises' Green Growth Model

Nengmin Wang, Weixuan Shi, and Qi Jiang

Abstract The green transformation of enterprises is affected by multiple entities, including the government, NGOs, consumers, and upstream and downstream partners. The emergence of enterprises' green growth model is based on the integrated effects of internal and external factors of enterprises. First, the new trends, such as supply exceeds demand, green consumer preference, and tightening resource constraints, faced by enterprises' competition require them to adapt to the green development trend. Second, the green development concept and environmental management system proposed new requirements for enterprises to prompt them to implement green transformation. Finally, new technologies such as new generation of information technology, new forms of industry such as consumer Internet platforms and industrial Internet platforms, and new business models such as closed-loop supply chain, provide valuable support for the green transformation of enterprises. The overall goal of the green growth model is coordination between green and growth. Global optimization and overall coordination are important prerequisites for realizing the enterprises' green growth model. Value chain reconstruction and innovation is the key path to realize enterprises' green growth model. Value co-creation and sharing is the driving force to ensure the implementation of the green growth model. Environmental regulation provides institutional guarantee for enterprises to implement green growth model.

2.1 New Trends in Business Competition

2.1.1 Green Becomes an Important Component of the Core Competitiveness of Enterprises

With changes in the international competitive environment and the development of the concept of green consumption, green has become an important means for

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enterprises to improve their competitiveness. Progressively, enterprises realize that green does not mean high cost but can help them better adapt to new trends, new requirements, and changes brought about by new technologies. For instance, by meeting new trends in consumers' green preferences, enterprises can gain market competitiveness, and the implementation of whole process environmental management technologies enables enterprises to respond to new environmental regulatory requirements and reduce potential policy risks. The application of new technologies can realize the recycling of resources and reduce resource consumption for enterprises, thus reducing the operating costs of the value chain.

(1) Environmental Management System Becomes Increasingly Stringent

As energy and environmental problems become increasingly prominent, governments are becoming further aware of the fragility of the earth's ecological environment and the severe threat of environmental pollution to sustainable human development. They have developed a series of environmental management systems. Protecting the earth's environment and maintaining sustainable social development has become a concern for all countries worldwide. Greening is an essential strategy for achieving sustainable development globally [1]. Many countries, including China, the U.K., the U.S., Russia, Sweden, Denmark, New Zealand, Hungary, Spain, Chile, Japan, and South Korea, have set carbon-neutrality targets. In March 2020, the European Commission adopted a proposal for the European Climate Law to ensure carbon neutrality in Europe by 2050 in terms of legislation. On September 22, 2020, President Xi Jinping proposed at the 75th UN General Assembly that "China will scale up its Intended Nationally Determined Contributions by adopting more vigorous policies and measures. We aim to have CO_2 emissions peak before 2030 and achieve carbon neutrality before 2060." In his opening remarks at the Leaders Climate Summit on April 22, 2021, Biden announced that "the U.S. is expected to reduce its greenhouse gas emissions by 50% in 2030 compared to 2005 and achieve its carbon-neutrality goal by 2050." An increasingly stringent environmental management system requires enterprises to undergo a green transformation.

Simultaneously, green barriers have become an issue that enterprises must face to participate in international competition. Enterprises participating in the international competition face a series of environmental management systems. For example, the United States introduced the "2021 Trade Policy Agenda and 2020 Annual Report," clearly indicating that it will consider the carbon border adjustment tax in the trade agenda on March 1, 2021. The EU has set carbon footprint limits for imported auto parts and vehicles. It is expected that, from 2024 onward, power battery manufacturers and suppliers entering the European market must provide carbon footprint statements, and from 2025 onward, each car exported to the EU should account for the release of its life-cycle carbon dioxide emissions. China's agricultural exports are concentrated in developed countries with a better "green" legal foundation, led by the U.S., Japan, and the EU. Green barriers to international agricultural trade have seriously impacted China, with bans on imports, returns, and claims increased. The rise of green barriers requires enterprises to participate in the international competition to achieve green transformation.

(2) Supply Capacity is Greater Than Market Demand

The current economic characteristics are as follows: supply capacity is higher than market demand, and economic growth is slowing. From the perspective of consumer demand, green, personalized, and diversified consumption is becoming mainstream. From the investment demand perspective, traditional industries are relatively saturated, while investment opportunities for new products, new forms of industry and new business models generated by new technologies are emerging in large numbers. From production capacity and industrial organization viewpoint, supply capacity exceeds demand greatly. The industrial structure must be optimized and upgraded. From the viewpoint of the relative advantages of production factors, the advantage of low labor cost no longer exists. The "growth" will rely more on the quality of human capital and technological progress, which requires the transformation of old and new motivations for growth through innovation. From the perspective of the characteristics of market competition, the past has mainly involved quantitative expansion and price competition, and the market is gradually shifting to quality-oriented, differentiation-based competition. From the resources and environmental constraints perspective, the current environmental carrying capacity has reached or is close to the upper limit, indicating the need to implement a green growth model and form a new model of green low-carbon cycle growth. The economic development model is shifting from extensive growth to intensive growth, from "green" in opposition to "growth" to green and growth coordinated. Therefore, the coordination of green and growth is the basic logic behind enterprises' current growth.

In addition, the long-term high-input, high-consumption growth model has led to severe environmental pollution and high resource consumption. Consider China as an example; the total industrial wastewater emissions in China in 2019 were approximately 25.2 billion tons, and industrial waste production was about 3.543 billion tons. In addition to polluting the environment, Chinese enterprises also have a high level of resource consumption, with a total energy consumption of 4.98 billion tons of standard coal in 2020, an increase of 2.2% over the previous year.[1] Enterprises are constrained by their resource environment when choosing a green growth model.

(3) Consumers Frequently Pay Attention to Green

While government regulations are becoming increasingly stringent, the consumer demand for green products is growing. Green consumption considers the rights of consumers and environmental impact. It is a win–win consumption model for both consumers and the natural environment. With the concept of environmental protection gradually gaining popularity, an increasing number of consumers favor green products with features such as health, energy-saving, and pollution-free [2]. Ali Research Institute report shows that the number of consumers who bought green goods in Tmall and Taobao in 2018 exceeded 380 million. The "2019 Green Consumption Trends Development Report" released by JD Big Data Research Institute mentions that the variety of green goods has exceeded 100 million. TrendForce Tibco's research shows that the total sales of new energy vehicles will reach 6.473

[1] http://www.cinic.org.cn/xw/tjsj/1045932.html.

million units in 2021, with an annual growth rate of 122%, the highest growth rate since the development of vehicle electrification. The growing demand for green products on the demand side is driving the rapid emergence of green industries.

The matching of demand and supply is key to the effectiveness of the enterprises' growth model. With the improvement of consumers' bargaining power, the intensification of competition due to supply capacity becomes greater than market demand. The range of choices and transparency in the market has also increased because of the consumer Internet platform triggered by new generation of information technology. Therefore, green has become an important criterion for consumers' decision-making. If enterprises do not adapt to this demand trend, their supply will be ineffective, and their growth will not be achieved.

2.1.2 Technological Innovation Provides the Possibility of Green Transformation for Enterprises

Information technology has given rise to new forms of industry and new business models. The integration of environmental technology and information technology provides important support for the green transformation of enterprises' growth models.

(1) New Generation of Information Technology Has Given Rise to New forms of industry and New Business Models

The rapid development and popularity of new generation of information technology have brought revolutionary changes to the operations and development of enterprises. New generation of information technology reduces the cost of information exchange between enterprises, thus triggering a significant reduction in transaction costs. The communication of entities in the value chain is closer to seamless, and the organizational structure is flatter. These changes give rise to a series of new forms of industry and new business models, including consumer Internet platforms and industrial Internet platforms. The emergence of new forms of industry requires enterprises to respond to technological trends and reconstruct their growth models and value chains [3].

Consumer Internet platforms integrate massive amounts of fragmented supply and demand information based on new generation of information technology. This can reduce transaction costs, and improve the effective matching of supply and demand. Consumer Internet platforms have greatly facilitated e-commerce development. In China's "11.11," the online transaction volume in 2021 was 965.12 billion CNY, with a 12.22% year-on-year increase.[2] Amazon's net sales in the fiscal year 2021 were $469.8 billion, with a 22% year-on-year increase.[3] The total merchandise transactions of Russian e-commerce Ozon reached 445 billion rubles in 2021, with an increase of

[2] https://baijiahao.baidu.com/s?id=1716187305417857981&wfr=spider&for=pc.

[3] http://www.spb.gov.cn/gjyzj/c200007/202202/6a15f2da4e404d7bafc9fca60aff8836.shtml.

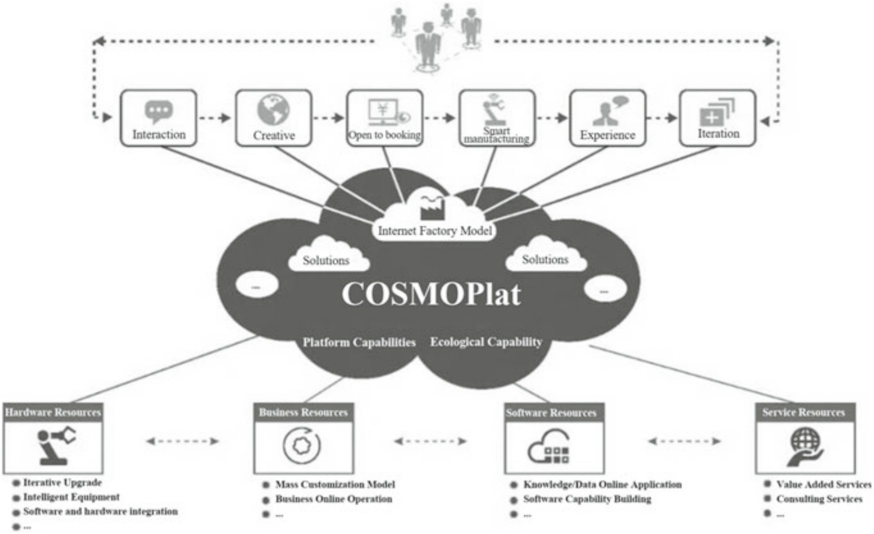

Fig. 2.1 Haier's COSMOPlat industrial internet platform

more than 125%. For eight consecutive quarters, its order volume rose by more than 100%, and the order volume rose to as high as 500% on Black Friday.[4] E-tailing has gradually become a prime channel of global consumption.

The industrial Internet platform realizes the evolution of demand from fragmentation to scale and reduces the cost of operational activities, such as design, production, and logistics. It provides system service solutions for the demand side in a platform-based manner to reduce transaction costs and space for value-added actors in the value network through value co-creation and sharing. For example, Haier's COSMOPlat platform is based on data-driven mass customization, which provides a platform and conditions to improve customer experience with the help of the Internet of Things, new generation of information technology to gain an accurate insight into demand (Fig. 2.1). It can merge fragmented and independent demand into scenario demand through the platform. It also can integrate supply-side capabilities, knowledge, and resources. This enables enterprises to provide agile, low-cost, and accurate responses to users' personalized demands and gain competitive advantages. At present, COSMOPlat has bred 15 industrial ecosystems, including pottery, textiles, molds, machine tools, and food processing, and has established seven centers nationwide, replicated in 20 countries through continuous empowerment of enterprises.[5]

(2) Development of Environmental Management Technology Evolves from End Control to Whole Process Management

Globally, environmental management techniques and tools have evolved from end control to whole process management, that is, environmental management of the

4 https://www.dsb.cn/news-flash/88803.html.

5 https://baijiahao.baidu.com/s?id=1667659310959557190&wfr=spider&for=pc.

Table 2.1 Evolution of environmental management

Stages of the environmental management	Main features	Era
Risk management	Waste management	1970s to mid-1980s
Pollution prevention	To reduce resource consumption, minimize waste, and increase efficiency through process improvement	Mid-1980s to early 1990s
Whole process management and eco-industry	To maximize environmental quality and profitability through systematic management of the whole environmental impact process	Mid-1990s to present

entire life cycle of the enterprise value chain [4]. The evolution of environmental management has gone through the following stages: from the 1970s to the mid-1980s, environmental management has been mainly risk management with waste management as the main feature; from the mid-1980s to the early 1990s, its main focus was pollution prevention to reduce resource consumption, minimize waste, and increase efficiency by process improvement; from the mid-1990s to the present day, it transformed into the whole process management and eco-industry stage, which ensures environmental quality and profit maximization through systematic management of the whole process of environmental impact (Table 2.1).

The whole environmental management process profoundly impacts enterprises' growth models. An imbalance between greenery and growth is prominent in the short term. The promotion and application of new environmental management technologies will increase the costs. It will also change the existing decision-making and operational models of value activities of enterprises. Therefore, it is necessary to reconstruct the value chain of an enterprise, which means greening value activities such as green design, green logistics, and green manufacturing. It is inadequate to reconstruct the internal value chain of the enterprise, but the overall optimization and reconstruction of the internal and external enterprises are needed to ensure the implementation of whole environmental management technology. The decision of each entity in the value chain is based on local optimization, making it difficult to achieve the overall global optimization of the value chain. It is necessary to innovate the value co-creation and sharing mechanism to realize the overall optimization of each entity in the value chain, from the local to the global decision.

(3) The Integration of New Generation of Information Technology and Environmental Protection Technology

Integration of new generation of information technology and environmental protection technology provides strong technical support for the green transformation of enterprises' growth models and reconstruction of their value chains. In enterprises' growth model and value chain reconstruction, the integration of new generation of information technology and environmental protection technology can effectively

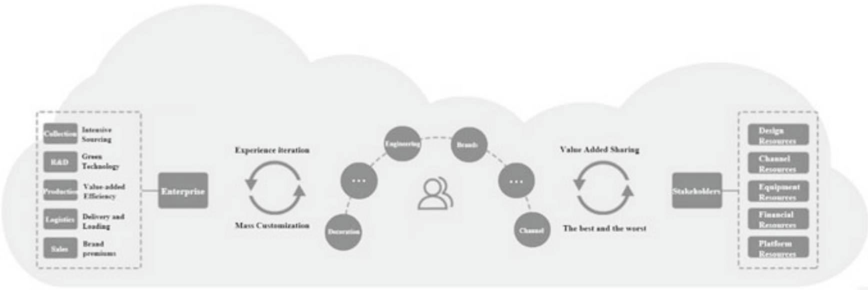

Fig. 2.2 Haixiangtao industrial Internet of Things platform

balance green and growth. Through new generation of information technology, we analyze the contribution of entities in the value chain involved in value discovery, value creation, and value transmission activities. Simultaneously, we analyzed the impact of each value activity on the environment using environmental protection technologies and tools such as material flow analysis, life cycle analysis, and carbon footprint analysis. By combining these two technologies, we can establish a framework for reconstructing and deciding the value chain in the enterprises' green growth model. For example, a value analysis database based on the integration of business and environmental performance can be established for typical industries to provide a reference for enterprises to reconstruct their value chains [5].

The Beijing Mulianneng Software Technology Company developed a series of industry public service platforms and engineering software such as Renewable Energy Information Network, Renewable Energy Information Resource Database, CFD wind power, and CGD photovoltaic.[6] The company can provide decision support for renewable energy enterprises to implement the whole process of environmental management. Haier's COSMO ceramic industrial park builds the HaiXiangTao industrial Internet of Things platform to provide a set of integrated solutions, including intelligent manufacturing, logistics and distribution, enterprise marketing, investment, and incubation. Enterprises in the park unify the use of natural gas, waste treatment, plant standards, and online environmental monitoring. Thus, the park enterprises transform from high energy consumption and high pollution to energy saving, emission reduction, and green.[7] In addition, it also meets the needs of user scenarios through the RenDanHeYi model, helps transform and upgrade ceramics. Thus, the enterprises in the park can transform from labor-intensive to data-driven intelligence and realize coordination between environmental and economic profits (Fig. 2.2).

[6] http://www.mlnsoft.net/index.jsp.

[7] https://baijiahao.baidu.com/s?id=1610928763682705116&wfr=spider&for=pc.

2.2 Enterprises' Conventional Growth Model Cannot Adapt to the New Competitive Trends

2.2.1 Enterprises' Conventional Growth Model

Penrose originally proposed the theory of enterprises' growth. Since then, enterprises' growth has been of interest to scholars and three different theories of enterprises' growth have been developed. The first is the scale boundary-based theory of enterprises' growth, which holds that enterprises' growth is reflected in the enterprise profits growth caused by changes in the production scale [6]. The second is the lifecycle-based theory of enterprises' growth, which suggests that enterprises undergo the same life cycle of germination, growth, maturity, and aging [7]. The third is the environment-based enterprises' growth theory, which states that enterprises' growth is the process of transforming a business in response to changes in its environment, thus enabling it to grow [8]. Enterprises' growth models can be divided into two types: internal growth and external growth. The growth in revenue and profit by relying on additional investment is called external growth. Conversely, growth achieved through the effective use of an enterprises' capital is called internal growth.

Generally, the enterprises' conventional growth model is external, and this extensive and external growth characterized by the expansion of production factors is particularly prominent in the industrial sector. Consider China as an example: China's incremental capital-output rate was around 2 in the early 1990s, rose sharply after 1995, and increased to 5–7 after 2000; that is, it took 5–7 CNY of additional investment to increase GDP output by 1 CNY. According to a World Bank report, China's investment rate was 42% in 2002, which means that 42% of national income was spent on investment to maintain an 8% GDP growth rate. However, this growth model is less efficient and hardly sustainable.

2.2.2 Limitations of the Conventional Growth Model

(1) Difficulty in Sustaining Resource Investment in the Long Term

In general, growth is sustained by input factors alone, which in the long term cannot be sustained due to scarce and limited resources. Since January 2021, major European economies have experienced significant increases in electricity prices. As of July 2021, electricity prices in Italy, Spain, Germany, and France have reached 10.5, 9.2, 8.1, and 7.8%/kWh, respectively, a significant increase of 166%, 167%, 170%, and 134%, respectively, from 1 year ago. The average retail price of electricity in the U.S. reached 11.3 cents/kWh, higher than that in the same period in the past three years.[8] With soaring electricity prices, enterprises are experiencing steep increases in production costs. The highest British fertilizer producer CF Industries Holdings Inc. closed two plants, and the Norwegian ammonia producer Yara International ASA limited its production in Europe. Nyrstar cut production at its European refineries by 50% due to soaring electricity prices, a reduction expected to average close to 30,000 tons per month, affecting 2.5% of the global zinc supply.

Although input factors can cause rapid economic development, some industries face overcapacity, an imbalance between supply and demand, rising costs, falling prices, and other issues. The extensive, conventional growth caused by these problems is further highlighted. First, enterprise technology innovation capacity needs to be improved, including low labor productivity, the lack of core technology, and independent brands need to be resolved. Second, long-standing economic growth has resulted in a large amount of energy and raw material consumption. Today's enterprises face resource constraints and simultaneously increase their investment burdens.

Therefore, to cope with limited resources, environmental regulations, and other environmental constraints, to enhance sustainable development capacity, brand image and other competitiveness on their own, enterprises can no longer be high pollution or high energy consumption. Enterprises cannot be at the expense of environmental resources and public profit as the development price. They need to achieve a comprehensive transformation from pollution, extensive, and external to green, intensive, and internal growth.

(2) Difficulty in Achieving Coordination between Green and Growth

The narrow connotation of green includes environment-friendly, reduced energy and material consumption, ecological security, and low-carbon development. The broad connotation includes balanced, economical, low-carbon, clean, circular, and safe. An enterprises' conventional growth model is a growth model in which green and growth are in a state of imbalance. As mentioned in Chap. 1, the imbalance may manifest in two ways: giving up growth for green, or green for growth, with giving up green for growth being more common than growth for green.

Enterprises using the conventional growth model create massive wealth by providing products and services to people, but at the same time, they also cause huge environmental pollution and resource consumption [9]. In this model, green and growth are in a state of imbalance, that is, green is given up for growth. The result is that the contradiction between population, resources, and the environment is becoming increasingly prominent, threatening the air, land, and water resources on which human beings depend, such as the frequent occurrence of air pollution typified by haze. Developed countries and emerging economies have experienced similar situations. The growth model that prioritizes growth over green or even sacrifices green, that is, polluting first, treating later has induced major environmental pollution events such as air haze. This model is not conducive to the coordinated and sustainable development of the economy, society, and the environment. The increasing

[8] https://baijiahao.baidu.com/s?id=1712199258354651317&wfr=spider&for=pc.

contradiction between the economy, society, and environment requires rethinking the economic development model and enterprises' growth model. It also requires choosing the green growth model to achieve economy, societal, and environmental coordination.

2.3 The Evolution of Enterprises' Green Transformation

2.3.1 From the End Control to the Whole Process Environmental Management

Environmental management technologies include production equipment, methods, activities, product design, and delivery systems to constrain and reduce the negative impact of products or services on the natural environment. Typical environmental management techniques include emission control, selection of alternative materials for rare resource processing, improvement of environmental practices and innovation, and modification of product functions. The environmental management model of enterprises can be divided into two models in terms of friendliness with nature, combined with their environmental management objectives and methods: one is the end control with end-of-pipe management as the core; the other is the whole process management with whole process control and circular economy as the core.

With changes in the environment and the need for competition, the environmental management model of enterprises has changed from end control to whole process management. The basic reasons for environmental management in enterprises are resource recycling, waste elimination, and environmental friendliness. As the business environment changes, the reason for environmental management is not only to improve the environmental impact but, more importantly, to establish a competitive advantage in products, processes, and services innovation, and operations through environmental management [10].

(1) End Control and Its Shortcomings

From the 1970s to the early 1980s, with the rapid development of manufacturing industries and technological innovation, the range of resources and products that human beings depend on has expanded. Synthetic chemical substances are continuously produced and manufactured, and these chemicals cannot be quickly absorbed and recycled by natural systems, causing serious environmental pollution problems. Concurrently, the manufacturing process consumes a large amount of energy and resources. It also causes tremendous waste that the environment cannot accommodate and recycle, resulting in increasingly prominent environmental problems.

Based on this background, governments of various countries are becoming increasingly aware of the fragility of the earth's ecological environment and the increasingly serious threat posed by environmental pollution to the sustainable development of human beings. Governments have formulated a series of environmental protection policies and emission standards to limit the maximum allowable amount of industrial waste entering the environment. The behavior of enterprises in polluting and damaging the environment is also restricted and controlled. With the introduction of the "polluter pays" principle, the laws of all countries stipulate that enterprises must bear the economic responsibility for their pollutant emissions, and any pollutant emissions exceeding the prescribed emission standards must pay excessive emission fees. If they cause environmental damage, they must bear the cost of pollution control and compensate for corresponding losses. For operating within the scope of institutional constraints, enterprises' environmental means are often in the final manufacturing process of their manufacturing or outfalls to establish a variety of environmental pollution prevention facilities to deal with pollution, such as building sewage treatment stations, installing dust removal, and desulfurization devices, for meeting the discharge of waste and emission standards demanded by regulations. This environmental management model is based on the idea of "pipeline pollution control" and emphasizes the end-of-pipe management of emissions.

The environmental management model of end control has the basic characteristics of a linear economic model, which is an open-loop system consisting of a unidirectional process of "resources-products-waste discharge" (Fig. 2.3). When controlling the waste treatment and pollution, the emphasis is on the waste control from the manufacturing process of the enterprise itself. The waste from the distribution process and consumer use are not considered and controlled. The goal of environmental management is to control waste and pollution in the manufacturing process to meet the requirements of emission standards and avoid the risks arising from environmental regulations.

This environmental management model requires several basic prerequisites to achieve the harmonious development of man and nature in the overall economic system. The first prerequisite is the sustainability and infinity of natural resources; that is, the manufacturing industry can continue to obtain resources and energy from the ecological system. The distribution and use of products do not produce waste that threatens the natural system. The natural ecosystem can dissolve, absorb, and eliminate waste disposed of enterprises through end control. These three assumptions do not exist. Natural resources are limited. A large amount of waste is generated during the distribution and use of products, such as electronic waste, which has become a growing concern and has put enormous pressure on the natural environment. Natural

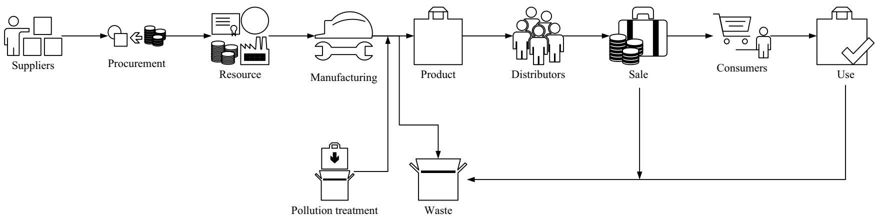

Fig. 2.3 End control model

systems have a limited ability to degrade, absorb, and eliminate waste. The end control model with pipeline control as the core cannot achieve the harmonious development of humans and nature.

(2) Whole Process Management

In the 1970s, enterprises emphasized applying the end control by emphasizing the treatment of pollutants after they were produced. However, after more than 10 years of application, scholars and entrepreneurs found that end control could not fundamentally solve the problem of the negative impact of manufacturing on the environment. In the 1990s, people began to emphasize the prevention of pollution from the source of production and consumption. Environmental management from a single part of a single enterprise cannot achieve manufacturing and environment friendliness. Achieving environmental friendliness requires adopting preventive measures as a whole, that is, the need to adopt a whole process environmental management model emphasizing the cooperation of multiple individuals based on the theory of circular economy. The whole process management of the product in a prevention-oriented control model is inevitable for the current enterprise environment [11].

The theoretical basis of the whole process management model is the concept of a circular economy. The circular economy is a linear economy with high consumption and emissions from industrialization. It is the economic embodiment of a sustainable development strategy, which means using resources and developing the economy in an environment-friendly way. It also means gradually realizing the reduction, resourcization, and harmlessness of pollution emissions with minimum cost and higher efficiency. In production activities, we control the waste generation, establish a cyclical mechanism for the repeated use of nature, incorporate human production activities into the natural cycle, and maintain the natural ecological balance. It is also necessary to reconstruct the economic system according to the laws of the material cycle and energy flow of the natural ecological system so that the economic system is harmoniously incorporated into the material cycle process of the natural ecological system. The feedback process of economic activities must be organized as "natural resources—products and services—renewable resources" (Fig. 2.4).

Under the whole process management model, we need to comprehensively use various environmental management tools taking preventive and control measures from the procurement of resources to recycling and waste disposal. It is also necessary to improve each activity of the entire ecological cycle of products according to the general law of material circulation and energy flow of the ecosystem and replace the open-loop linear economic model with the closed-loop economic model. We can realize waste-free production, waste reduction, and waste utilization in procurement, production, sales, and consumption so that the whole company's cooperation chain can achieve environmental friendliness. The whole process management model has several apparent characteristics: first, environmental management involves all activities and links in the overall process of the enterprise, from procurement, design, and manufacturing, to sales. They all need to take effective prevention and control measures. Second, the whole process management model emphasizes cooperation

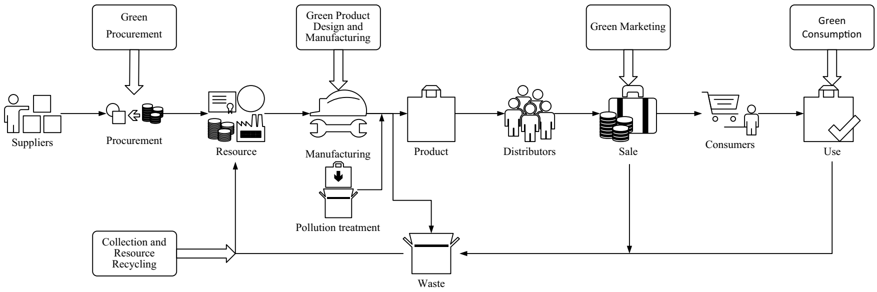

Fig. 2.4 Whole process management

with relevant individuals. In this model, it is necessary to take effective environmental prevention and control measures in each activity of the enterprise process; the enterprise should maintain effective coordination with other entities, such as suppliers, distributors, and users of products. Therefore, cooperation between entities is a prerequisite for the whole process management implementation. Third, the whole process of management is the integration of various environmental management tools. These environmental management tools include green procurement, eco-design, green manufacturing, end-of-emission control, green marketing, and remanufacturing.

To cope with increasing environmental pressure, enterprises are adopting increasingly systematic and integrated strategies, and their attitude toward environmental management is changing from passive adaptation to severe environmental regulations to active environmental management. The objective of environmental management is no longer to prevent risk arising from environmental pollution disclosure but to achieve value-added in the whole value chain through recycling, reuse, and resource reduction. The entities involved in environmental management have changed from the operational level of a department within the enterprise to the strategic level of the enterprise, from a single functional department to multiple functional departments, and from a single enterprise to collaboration among members of the value chain. The focus of environmental management technology has changed from end control to the whole process of multistage environmental management technology.

2.3.2 From Enterprises' Growth to Enterprises' Green Growth

As mentioned above, the connotation of enterprise growth is mainly reflected in the following two aspects: first, the growth of enterprise profits in different periods is caused by changes in the scale of enterprise assets; second, the growth of enterprise profits is caused by a higher return on capital than the average social rate of return in the same period. Together, these two aspects of growth increase enterprise profitability and market competitiveness. Enterprises' growth models can usually be divided into two modes: internal growth and external growth.

The core idea of green growth is to promote economic growth and development and ensure that resources continue to be available along with environmental services on which human beings depend. Green growth is the effective protection of resources and the environment, considering economic growth to achieve economic growth and development while resisting climate change. It also means preventing costly environmental degradation and the inefficient use of natural resources, and it is also a major improvement to the traditional crude economic development model [12]. As mentioned in Chap. 1, green growth is a development model that effectively recycles resources, transforms old motivations of growth into new ones through green innovation, shifts extensive growth to intensive growth, and coordinates economic growth and environmental friendliness. The essence of this model is to use the visible hand of the government and the invisible hand of the market to achieve better economic growth, create jobs, eliminate poverty, promote social equity, and achieve sustainable development [13].

Owing to increasing environmental concerns, stakeholders such as governments, suppliers, and consumers demand that enterprises adopt a green growth model [14]. IKEA is one of the first enterprises to adopt green development as an important strategy of the company. In 2018, IKEA launched the Recycled Cardboard Project, where waste cardboard from shopping malls was transported directly to paper mills responsible for supplying packaging for IKEA products, forming a closed-loop for recycling waste cardboard. IKEA Retail generates approximately 18,000 tons of waste cardboard in China each year. One ton of waste cardboard is recycled to produce 0.83 tons of new product packaging, avoiding 21 trees from being cut down and saving 40 tons of water and 600 kWh of electricity. More than 30 IKEA stores in China have begun recycling cardboard programs. IKEA has committed to reducing CO_2 emissions by 80% on a product-by-product basis by 2030, to reach 100% use of renewable energy, wind, or solar, in all its malls or warehouses.[9] IKEA plans to design all products using new circular design principles, using renewable and recycled materials—this means following sustainable principles in every aspect, such as developing products, sourcing raw materials, expanding the value chain, establishing logistics, and satisfying customers. As a natural resource-dependent company, IKEA considers the sustainable supply of raw materials, such as wood and cotton, and the constraints of relevant environmental regulations. Therefore, IKEA should have this foresight to ensure that its future growth is unaffected. Simultaneously, consumers in Europe, IKEA's main market, attach great importance to environmental protection, driving IKEA to pay more attention to sustainability issues, including the ecological impact of the value chain to be considered to maintain the brand's reputation.

As mentioned in Chap. 1, the "enterprises' green growth model" is one of the "enterprises' growth models" that aims to synergize the economic and environmental performance of enterprises to achieve a high-quality, highly efficient, and sustainable

[9] https://m.thepaper.cn/baijiahao_9307221; https://baijiahao.baidu.com/s?id=1702592899589945518&wfr=spider&for=pc.

development. The enterprises' green growth model is based on the cooperation of various actors in the value network and the application of new technologies and new business models. It is based on the mentioned foundation to create different combinations of production factors to establish innovation chains and to create new business models to realize the coordination of business processes in the value network. Ultimately the enterprises realize the coordination between "growth" and "green" based on "innovation-driven."

The current business environment has undergone revolutionary changes. First, the economic growth rate has gradually shifted from high to medium–low growth. Second, the relationship between supply capacity and market demand has changed from supply being greater than demand to demand being greater than supply. Third, the resource and environmental constraints have changed from relatively lax to tightening. Finally, the increase in consumers' disposable income has led to a shift in their demand decisions from mass consumption, which emphasizes cost-efficiency, to the pursuit of green, personalized consumption, consumer experience. In addition, technological changes provide enterprises with the possibility to implement green growth models; new generation of information technology has given rise to new forms of industry and new business models. Environmental management technology and tools have transformed from the original "end control" to "whole process management." Moreover, the integration of new generation of information technology and environmental protection technology provides technical support for the green transformation of the business growth model. To adapt to the changes in the business environment and technology development, it is expected that the traditional business growth model can no longer cope with the new trends, requirements, and technologies brought about by these changes. Therefore, the transformation and upgrading of the business growth model and the implementation of the enterprises' green growth model have become inevitable.

2.4 Core Ideas of Enterprises' Green Growth Model

2.4.1 Coordination Between Green and Growth is the Overall Goal of the Enterprises' Green Growth Model

The introduction, formation, and development of the green development concept is a strategic choice in line with the global trend of green development, an inevitable requirement to solve the ecological dilemma, and the practical need to implement the new development concept. As the microscopic main body of a country's economy, enterprises are the primary producers and suppliers of various products and the main consumers of various natural resources. Whether the behavior of enterprises meets the requirements of sustainable development has a significant impact on the sustainable development of a region, a country, and even humanity as a whole.

The overall goal of the green growth model is coordination between green and growth. The connotation of green includes "balanced, economical, low-carbon, clean, recycling, and safe," while growth refers to the growth of corporate profit, return on capital, scale, and social benefits. The coordination of green and growth requires enterprises to improve profits, capital returns, scale, and social benefits under the requirements of low-carbon, clean, safe, etc. At the same time, it also requires enterprises to use resources economically and recycle recyclable resources to achieve a balanced state of economy and environment. This is the overall goal of the enterprises' green growth model and the transformation from "labor and resource driven" to "innovation-driven".

2.4.2 Global Optimization and Overall Coordination Are Important Prerequisites for Realizing the Enterprises' Green Growth Model

The self-interest of each value activity unit leads to conflicting goals. For example, manufacturers emphasize "zero inventory, high volume, large-scale production, standardized products, and centralized delivery," distribution centers emphasize "low inventory, low transportation cost, and fast replenishment," customers emphasize "personalization, small volume, and on-demand delivery," and suppliers emphasize "bulk purchase and delivery." Because of the different objectives of actors, their decisions are often partially optimized. The result of partial optimization is that there is no way to achieve global optimization of the value chain; that is, the overall coordination of each link cannot be achieved, and enterprises' green growth model cannot be realized.

In the enterprises' green growth model, the goal of global optimization is to evaluate the value chain of the green growth model to achieve coordination between "green" and "growth". Enterprises identify the activity units that need to be reorganized and reorganize and integrate them according to the principle of global optimization of the value chain. The coordination of "green" and "growth" of individual value activity units is inadequate to realize the green growth model. Together with the implementation of the green growth model by all actors in the value chain concurrently with the coordination and global optimization among all actors in the value chain is the guarantee of "green" and "growth" coordination.

2.4.3 Value Chain Reconstruction and Innovation is the Key Path to Realize Enterprises' Green Growth Model

Business environment changes and the technological developments that enterprises rely on lead to changes in their value-creation mechanisms and sharing patterns.

Green growth models implementation will change from a cost-increasing activity in the traditional sense to a direct contributor to "value discovery, value creation, and value delivery" [15]. For example, under the condition that green consumption has become consumers' decision preference, the provision of green products and services can more effectively improve the targeting of consumer demand. China's supply-side structural reform practices have changed enterprises' value-creation mechanism by "consumer participation generating demand," "cutting overcapacity, reducing excess inventory, de-leveraging, lowering costs and strengthening areas of weakness," and innovation. For example, one of the specific measures for enterprises in the "cutting overcapacity, reducing excess inventory, de-leveraging, lowering costs, and strengthening areas of weakness" is to adjust the product structure and reduce ineffective production capacity, which is to improve the matching of enterprise supply with market demand. This strategy can reduce ineffective resource consumption and improve the environmental and commercial performance of enterprises. New technologies represented by the new generation of information technology, and whole process environmental technology have given rise to new forms of industry and new business models. The most predominant mechanism is the application of new generation of information technology significantly reduces the cost of information exchange between enterprises and customers. Hence the seamless real-time docking can be realized so that customers change from passive recipients of products to participants in value discovery, value creation, and value transfer. These changes in value-creation mechanism and value-sharing mode possibly make enterprises realize the coordination of "green" and "growth."

The implementation of enterprises' green growth model changes the value creation and sharing mechanism, which needs value chain reconstruction. Value chain reconstruction is a means of implementing a green growth model. It involves value chain reconstruction within and outside the enterprise, such as suppliers, manufacturers, consumers, and other actors. The essence of value chain reconstruction is to establish an innovation chain by innovating different combinations of production factor patterns, which is a key for enterprises to implement the green growth model.

2.4.4 Value Co-creation and Sharing is the Driving Force to Ensure the Implementation of the Green Growth Model

The key to the green transformation of the enterprises' growth model is to solve the two core issues: one is the value-creation mechanism and realization method of "enterprises' green growth model", i.e., how to do it; the other is the value-sharing mechanism and realization method of "enterprises' green growth model", i.e., why enterprises do it. To solve these two core issues, we need to build an ecosystem of the green growth model through joint participation of the government, enterprises, consumers, and society. We also need to innovate the value creation and sharing mechanism. New forms of industry and new business models generated by the new technology make value chain actors seamlessly connect at a low cost because of the significant reduction in transaction costs [16]. New forms of industry and new business models have also changed the mechanism of enterprise value creation and sharing. The most typical one is that consumers have become members of value discovery, value creation, and value transfer instead of being passive recipients.

The positive interaction of "capability, motivation, and performance" is the key to building the ecosystem of enterprises' green growth model. Value co-creation and sharing is the guarantee to ensure a smooth and orderly ecosystem operation. As the green growth model pursues global optimization, which is contrary to the individual optimum caused by individual rationality, the value obtained by individuals in the value chain may be lower than their optimum expectation. A reasonable value co-creation and sharing mechanism are needed to fairly distribute the value generated in the value chain to meet the expectations of individuals and guarantee the motivation of individual enterprises to carry out the green growth model.

2.4.5 Environmental Regulation Provides Institutional Guarantee for Enterprises to Implement Green Growth Model

The pressure of environmental regulation is an important driver for firms to transform green growth. Government environmental laws and regulations are often interpreted by scholars as one of the most important factors and driving forces influencing enterprises to implement green growth. In recent decades, countries have proposed corresponding protection bills and regulations for environmental protection and the green growth of enterprises. Here are some examples: the Energy Act of 2020 and the American Clean Energy Act (2021) enacted in the United States, Europe's Green New Deal (2019), the European Climate Law (2020), and the EU Battery Management Regulations (2022) issued by the European Commission. Coercive force is the main driver of corporate green management behavior, and firms tend to adopt similar behaviors when facing similar institutional forces.

From the perspective of externalities, the key behaviors in the government facilitation mechanism for defining property rights and reducing transaction costs are supervision and incentives. From the information asymmetry perspective, key behaviors of the government promotion mechanism are public information provision and disinformation control. Public information provision includes the formulation and promotion of green product standards and environmental labels. The disinformation control requires the government to establish an information monitoring system to regulate and impose penalties.

The government has an important role in promoting the green transformation of the enterprises' growth model, including the implementation of the enterprises' green growth model requires government incentives and guidance to a certain extent, as well as the formulation and improvement of relevant systems by the government. In general, the external environment provides an institutional guarantee for enterprises to implement a green growth model, which is the key to promoting enterprises to implement the green transformation of the growth model with the guidance of the green development concept and achieve the goal of coordinated development of the economy, society, and environment.

2.5 Summary

The goal of enterprises' green growth model is to achieve sustainable competitiveness and coordination between green and growth by value chain reconstruction and green transformation. Implementing a green growth model for enterprises does not only raise costs and increases financial pressure. In the long run, green growth can reduce the potential environmental risks caused by policies to enterprises and provide green products and services to attract customers with green consumption preferences, thus becoming market competitiveness. The application of new technologies and management models, including the Internet of Things, new generation of information technology, with whole process management, can effectively improve the operational efficiency of enterprises and reduce costs. The use of new forms of industry and new business models, such as industrial Internet platforms, can reconstruct the value chain. Enterprises thereby achieve a better allocation of resources and innovative value co-creation and sharing mechanisms.

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Chapter 3
Development Trends of Enterprises' Green Growth Model

Nengmin Wang, Meng Zhang, and Zhengwen He

Abstract The development of enterprises' green growth model is closely related to technological innovation and changes in the business environment. The rapid development and popularization of next-generation information and communication technology, emergence of new forms of industry and business models have encouraged enterprises to implement the green growth model. First, from the perspective of new technologies, this chapter analyzes the impact of the next generation Internet as well as the Internet of Things (IoT) on enterprises' green growth model. The next generation Internet helps enterprises implement the green growth model in three ways: reduction of transaction costs, accurate supply–demand matching, and value co-creation and sharing. The IoT makes it possible for enterprises to realize the entire life cycle of environmental management. From the perspective of new forms of industry, this chapter analyzes the impact of collaborative logistics, crowdsourcing design and manufacturing, networked collaborative manufacturing, and social community manufacturing on enterprises' green growth model. The advantages of such forms lie in reducing ineffective production capacity and wasted resources, meeting customers' demands, and realizing value co-creation, thereby providing new opportunities for enterprises to implement the green growth model. Finally, from the perspective of new business models, this chapter analyzes the impact of online and offline dual channels, closed-loop supply chain, platform economy, and energy performance contracting on enterprises' green growth model. The advantages of such models lie in improving operational efficiency, realizing resource recycling, and increasing energy efficiency, thereby providing new avenues for enterprises to implement the green growth model.

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3.1 New Technologies Providing Methods for Enterprises' Implementation of the Green Growth Model

3.1.1 Next Generation Internet

(1) Reduction of Transaction Costs

The development of next-generation information and communication technology such as the next generation Internet has profoundly affected and shaped the strategic, resource organization, operations management, and other aspects of enterprises. Communication between entities in the value chain has been streamlined, and the organizational structure has flattened, giving rise to a series of new forms of industry and business models. Next generation Internet technology facilitates information exchange throughout the value chain, consequently reducing transaction costs. Such technology also provides effective methods for resolving information asymmetry between multiple entities in the value chain.

Information asymmetry is one of the main contributors to high transaction costs. It hinders customers from understanding enterprises' actual states for implementing the green growth model, which results in the market phenomenon of "bad money drives out good," reflected in terms of some enterprises flooding the market with false green products. The next generation Internet technology provides a new method to address this problem. For example, blockchain technology can find applications in the anti-counterfeiting of products, market supervision, and other aspects. After the identification of "one code for one object," each link's information, from production to transportation to final sales, can be recorded on the blockchain, and the information cannot be tampered with, as shown in Fig. 3.1. The efficiency, transparency, and traceability of the trade can be reinforced by applying blockchain technology [1]. Therefore, the development of next generation Internet technology can effectively solve the problem of information asymmetry. Reducing transaction costs also implies

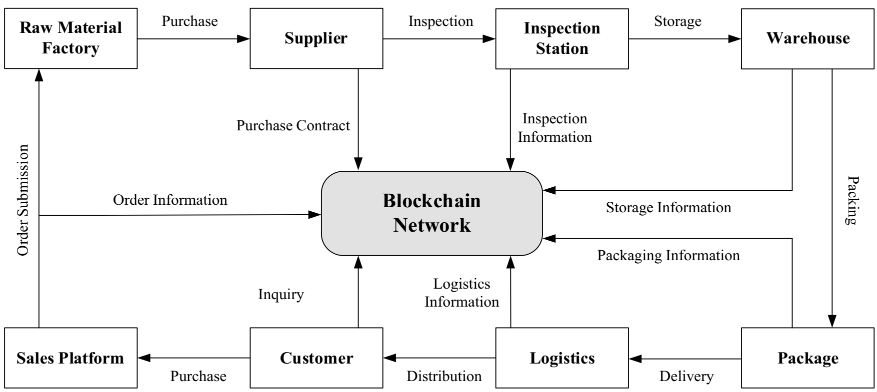

Fig. 3.1 Schematic diagram of blockchain technology

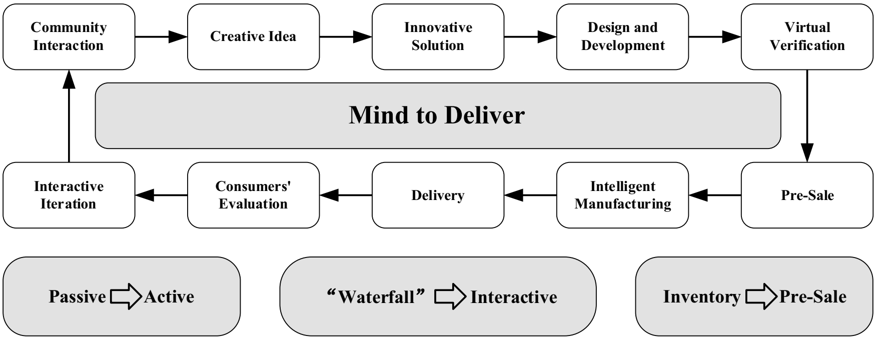

Fig. 3.2 Haier's "Mind to Deliver" model

increasing profits and ensuring effective implementation of enterprises' green growth model.

(2) Accurate Supply–Demand Matching

Whether supply and demand can be accurately matched is the key to the effectiveness of enterprises' green growth model. At present, supply exceeds demand, and the rapid popularization of next generation Internet technology has increased market transparency, resulting in increased competition and enhancing customers' negotiation ability. Simultaneously, an increased focus on the concept of green consumption has led to its growing demand [2]. Green has become an important component of enterprises' core competitiveness, necessitating that they meet the customers' demands for green to win the market.

Next generation Internet technology integrates customers' demands into the value chain actively or passively, provides platforms for customer experience, and creates a seamless, instant, and zero-cost virtual reality for customers. It also helps enterprises understand, forecast, and deliver on the personalized demands of customers more accurately and improve the adaptability of products in terms of green consumption demand. A benign system is formed in which demand leads supply and supply creates demand. Next generation Internet technology has also promoted the rapid demand-driven development of mass customization and manufacturing services [3, 4]. Through the innovation platform, fragmented and independent demands are integrated into the scenario, and supply-side resources, capabilities, and knowledge are incorporated into the platform to provide an agile and low-cost system solution. The evolution of demand from fragmentation to scale to platform and subsequently to ecosystem is realized, such that the contradiction between mass manufacturing and personalized customization can be coordinated and competitive advantage can be obtained.

Some enterprises have begun to rely on next generation Internet technology to adopt customized production as the core competency of enterprises. For example, Haier built the "Mind to Deliver" model with the support of next generation Internet

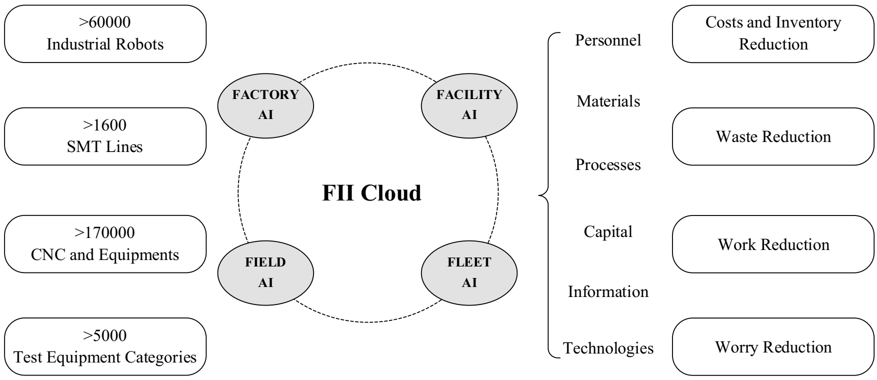

Fig. 3.3 Foxconn's FII platform

technology, as shown in Fig. 3.2.[1] It changed the traditional "product before market" operation into the "market before product" operation, effectively and accurately matched supply and demand, and realized mass customization to enhance competitiveness and improve resource utilization efficiency. According to Haier's Environmental, Social, and Governance Report 2020, it achieved a non-warehousing rate of 78%, ranking first in terms of global market share for healthy self-cleaning air conditioners.[2]

(3) Value Co-Creation and Sharing

The development of next generation Internet technology also provides new methods for cooperation and value creation and sharing between entities in the value chain, helping enterprises transform into "value centers." In the current business environment, enterprises reducing only supply-side costs can ensure limited profits. An enterprise can secure a competitive edge by adding value through cooperation between the entities in the value chain. Mass supply-side customization using next generation Internet can realize standardization, modularization, and serialization of the production process. Integrating piecemeal independent demands and aggregating all supply-side entities can achieve large-scale production, reduce costs across a wider range, and increase the supply-side value of all enterprises. Simultaneously, mass customization and production also help enterprises in the value chain integrate internal and external resources to reduce waste, such as the Foxconn Industrial Internet (FII) platform, which has the largest manufacturing capacity in the global 3C electronics industry, as shown in Fig. 3.3.[3] It integrates more than 3000 third-party participants to help manufacturing enterprises achieve customized mass production through data collection, analysis, and application, while reducing energy consumption by approximately 20%.[4]

[1] https://www.163.com/dy/article/DGGGF6DC0518QT7L.html.

[2] https://www.haier.com/csr/?spm=net.31741_pc.header_128850_20200630.3.

[3] https://www.fii-foxconn.com/.

[4] http://szsb.sznews.com/PC/content/202107/26/content_1067398.html.

On the demand side, next generation Internet technology can provide customers with experience and insights into demand, facilitate personalized, agile, and accurate service solutions to increase customer value, and enable customers to pay higher prices. Simultaneously, the concept of green has become a focal point for both enterprises and customers. The green efforts of enterprises enable customers to manifest greener behavioral intentions [5]. Next generation Internet technology provides convenient methods for enterprises to advertise their green efforts to customers. For example, the 7 Days Inn advertises its green concept online and highlights the hotel's business model of not providing disposable toiletries to promote customers to actively participate in green value co-creation and add demand-side value.[5]

Finally, the overall ecological sharing of revenue is guaranteed through a sharing mechanism and institutional innovation. On the supply side, for example, Huawei HMS, which covers more than 170 countries and regions, has distributed up to 90% of its revenue to third-party participants in 2020.[6] On the demand side, Shanghai VeChain records the energy savings of electric vehicle owners using next generation Internet technology and converts the relevant data into quantifiable carbon credits that can be used to purchase goods and services.[7] In summary, value co-creation and sharing not only integrates the internal and external resources of enterprises to reduce waste but also supports value addition and revenue sharing on both supply and demand sides, thereby guaranteeing enterprises' implementation of the green growth model.

3.1.2 Internet of Things

The Internet of Things (IoT) is an extension of the Internet and an emerging technology [6]. It combines various information-sensing devices with the Internet to form a huge network to realize the interconnections between people, machines, and things at any time and place. With the development of the IoT, remarkable changes have occurred in the sphere of environmental protection. The development and innovation of environmental protection technologies have a profound impact on enterprises' green growth model. The process of IoT and real-time data analysis make entire life cycle environmental management possible. Although the application of new technologies increases costs to a certain extent, these technologies also provide new methods for enterprises in terms of environmental protection and energy savings management.

Relying on the technical advantages of dynamic perception, real-time transmission, and automatic control of the IoT, as well as practical functions such as compatibility between devices and reliable processing of massive information and data resources, a complete, safe, stable, and expandable sound information and data system can be developed to realize the visual and intelligent dynamic supervision

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5 http://www.7daysinn.cn/pinpai.html.

6 https://www.163.com/dy/article/F7ALA5PD05168K55.html.

7 https://www.vechain.com/cn/solution/carbon.

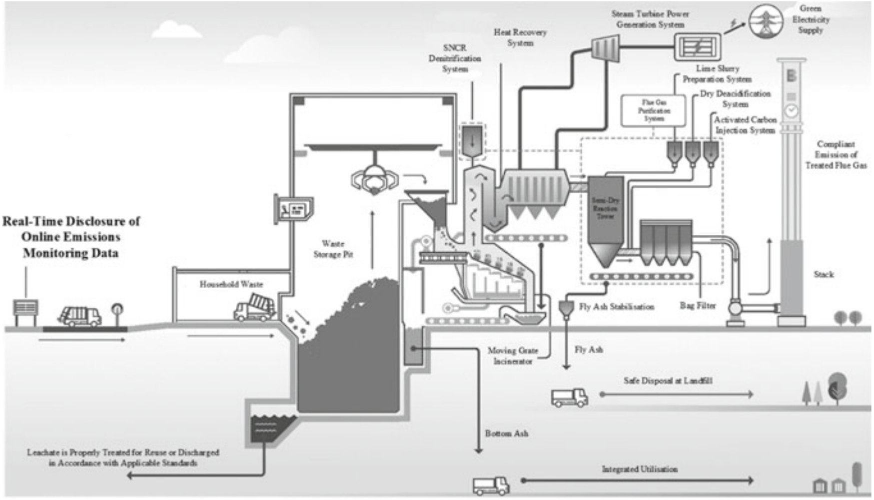

Fig. 3.4 Life cycle environmental monitoring of Everbright Environment

of enterprises' production and operations. For example, the IoT can facilitate access to data such as that on raw material entering and leaving the warehouse, raw and auxiliary material inputs in production, product output, fuel, and water consumption, and waste discharge. It can also build a flow system by using material balance, master the real-time situation with data on the discharge of wastewater and waste gases, and provide them to the pollutant treatment facility system for decision-making, analysis, and early warning. Additionally, emerging technologies can reduce the energy consumption of IoT devices. Eventually, IoT technology can help enterprises build sustainable smart systems [7].

Many enterprises have begun to rely on IoT technology for the entire life cycle of environmental management. For example, Everbright Environment, a leading enterprise in China's environmental protection industry, is the largest waste-to-energy operator in Asia, ranking 283 among China's top 500 enterprises. The Everbright Environment's Suzhou waste-to-energy project is China's first environmental monitoring demonstration project to have realized whole-process monitoring and real-time release, as shown in Fig. 3.4.[8] Real-time monitoring covers the entire process beginning with waste entering the furnace to waste incineration and emission treatment and provides early warning functions through data and working condition analysis to eliminate the pollution at the outset. It also releases real-time monitoring data to provide source data for environmental supervision. In summary, enterprises are able to use IoT technology to collect and analyze data and implement processes to be compatible with visual environmental management, thereby reducing energy consumption and improving resource utilization to generate economic and environmental benefits.

[8] https://www.cebenvironment.com/en/csr/sustainability/sr2020.pdf.

3.2 New Forms of Industry Providing Opportunities for Enterprises' Implementation of the Green Growth Model

3.2.1 Collaborative Logistics

Logistics is defined as the process of planning, implementing, and controlling the flow and storage of goods, services, and related information from the origin to the consumption to meet customers' demands. Collaborative logistics refers to multiple logistics carriers forming coalitions to jointly perform parts of their logistics operations [8]. Carriers integrate logistics tasks and resources according to a certain organizational mode, reasonably schedule logistics resources, and jointly optimize the distribution of such tasks to reduce total costs and increase profits and individual competitiveness. The emergence of collaborative logistics stems from the fact that logistics activities are pure consumption processes. High logistics costs and low logistics efficiency significantly affect growth. For example, in 2020, China's gross domestic product (GDP) was 101.6 trillion CNY, exceeding 70% of the United States (US) GDP for the first time.[9] However, the total cost of social logistics in China was 14.9 trillion CNY, and the ratio of the total cost of social logistics to GDP was 14.7%, much higher than that in developed European countries and the US.[10] Problems such as high carbon emissions and low resource utilization in the logistics process also affect the implementation of the green growth model. In the face of increasingly fierce competition and shrinking profits, logistics carriers seek to strengthen mutual cooperation and explore new ways to reduce costs and improve efficiency.

Collaborative logistics can effectively solve these problems. A fourth-party logistics service provider, Cainiao Logistics, is a typical example. Cainiao Logistics provides high-quality centralized management services such as socialized warehousing, logistics network planning, data-sharing and application platforms, retail order management, and market forecasts for manufacturers, retailers, customers, and third-party independent logistics carriers without undertaking specific logistics operation activities, as shown in Fig. 3.5.[11] By integrating nearly 30 third-party logistics partners and industry resources on a platform, Cainiao Logistics greatly improves efficiency and reduces costs, carbon emissions, and resource wastage through efficient collaboration and technical innovation. According to Cainiao Logistics' Social Responsibility Report 2020, they have reduced more than 600,000 tons of carbon emissions, used hundreds of millions of recyclable cartons, and saved more than 86 million meters of packaging tape in 2020.[12] Collaborative logistics realizes the advantages of high efficiency, low cost, and high resource utilization, providing new opportunities for enterprises to implement the green growth model.

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9 https://www.q578.com/s-9-1286817-0/.

10 https://free.chinabaogao.com/jiaotong/202103/031A355302021.html.

11 https://www.sohu.com/a/243355366_310399.

12 https://zhuanlan.zhihu.com/p/376123041.

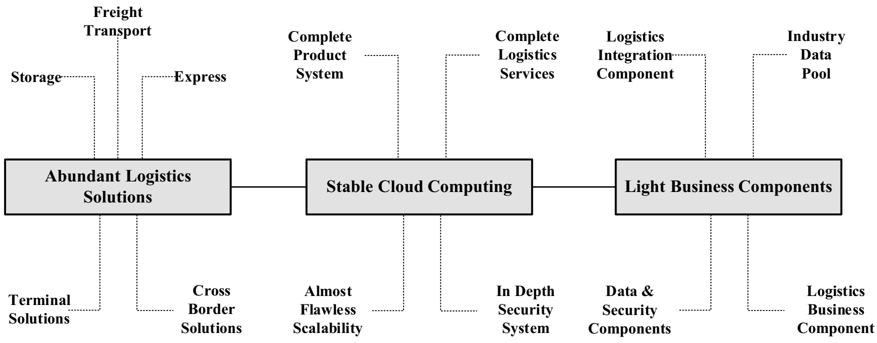

Fig. 3.5 Schematic diagram of Cainiao Logistics

3.2.2 Crowdsourcing Design and Manufacturing

Crowdsourcing design and manufacturing refers to enterprises seeking external inputs from the "crowd" in the form of functional design solutions for new product development [9]. Through Internet crowdsourcing platforms and external resources, crowdsourced design and manufacturing can quickly respond to customers' customization demands, modify the innovation activities previously conducted by the enterprise's internal departments and publish them online, seek resources from outside the enterprise, and transcend the innovation boundaries of traditional business. It also offers a co-creation experience for customers that helps firms better reap competitive advantages [10]. In addition, crowdsourcing design and manufacturing reduces the repeated investment of resources and wastage of production capacity through the integration of internal and external resources and increases resource utilization efficiency. Finally, it also helps realize value co-creation among enterprises and positively affects their green growth.

Internet technology has accelerated the development of social networking. An increasing number of users in different fields are conducting collaborative design and research and development (R&D) with enterprises through the Internet. For example, Haier has built an open innovation platform, the Haier Open Partnership Ecosystem (HOPE), which brings together universities, scientific research institutions, large companies, start-ups, and other groups, covering more than 100 core technology fields and 120,000 community experts.[13] Relying on the interactive scenarios and tools provided by HOPE, participants can submit personalized demands or innovative solutions for household appliances for users to choose from. HOPE uses big data, cloud computing, and other technologies to accurately match the supply and demand to find the best solution for users, as shown in Fig. 3.6.[14] At present, HOPE has designed and produced a variety of environmental protection household appliances

13 http://hope.haier.com/hope_web/?page_id=1277.

14 https://m.sohu.com/a/203703247_697770.

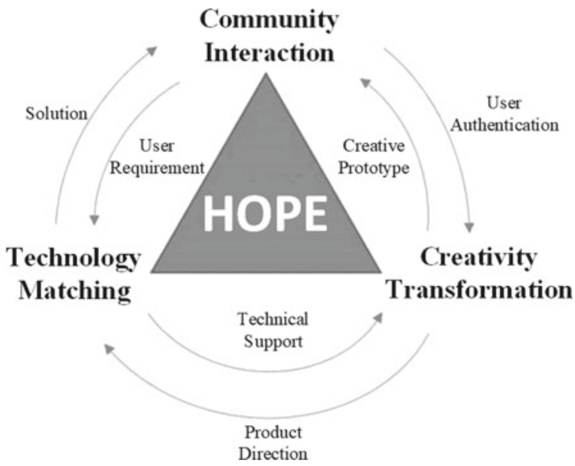

Fig. 3.6 Haier's innovation platform HOPE

based on users' demands, such as energy-saving refrigerators and water-saving dishwashers. By meeting the demands of personalized customization, increasing resource utilization efficiency, and helping to realize value co-creation, crowdsourcing design and manufacturing provides important opportunities for enterprises to adopt the green growth model.

3.2.3 Networked Collaborative Manufacturing

Networked collaborative manufacturing refers to a business that uses the Internet and information technology to realize the cooperation of enterprises in product design, manufacturing processes, and management within and across supply chains. This can achieve agility, flexibility, low cost, and customer centricity by transforming operations [11]. With the rise of the network economy and increasing development of information technology, the market has undergone significant changes. As the degree of innovation, personalization, specialization, and demand dynamics increase, the technical content required to meet market demand is correspondingly higher. An enterprise cannot adapt to this change by relying solely on upgrading internal technology and resource optimization. Modern manufacturing pertains not only to a specific enterprise but also to a group of enterprises, thereby requiring the establishment of closer and more reliable collaborative relationships among enterprises. The integration and optimal allocation of resources, such as equipment, software, technology, and human resources, form the basis of the resource organization model in collaborative manufacturing environments. Networked collaborative manufacturing uses the Internet and various integration technologies to break the constraints of time and space and closely connect enterprises' product design, manufacturing, operation, maintenance, and management within and across supply chains to utilize resources throughout the product life cycle and improve efficiency and product quality.

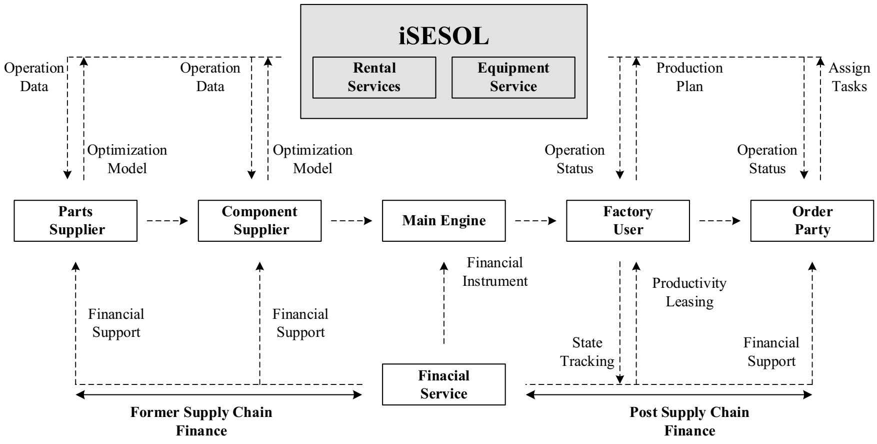

Fig. 3.7 Shenyang Machine Tool Group's networked collaborative manufacturing platform based on iSESOL

Many manufacturing enterprises have begun to implement networked collaborative manufacturing. For example, China's Shenyang Machine Tool Group has built a networked collaborative manufacturing platform based on iSESOL, according to the demands of machine tool users, as shown in Fig. 3.7.[15] This platform relies on many upstream and downstream enterprises that are connected to the industrial chain. According to the different product characteristics and needs of the production process, it can exchange information freely, share knowledge and innovation achievements, and make collaborative decisions. The resources connected to the platform can provide raw material, procurement, and other support for the production processes of related products, enabling manufacturing enterprises to quickly enter the production process, which improves the overall competitiveness of the industrial chain. With the development of industrial Internet platforms, 5G, and other technologies, networked collaborative manufacturing will realize the transformation of enterprises from high-consumption, high-pollution extensive manufacturing to green manufacturing through value co-creation and sharing.

3.2.4 Social Community Manufacturing

Social community manufacturing refers to the product development and production processes in which decentralized manufacturing and service resources establish information, physical and social interconnections through social networks and other media, various communities through self-organization, and interactions between community members and communities and cooperate throughout the product's life

[15] https://www.isesol.com/solution?top=3254.

cycle, as shown in Fig. 3.8. Rapid changes in the global market and the personalized and dynamic diversity of customers' demands have led to large-scale personalization and extensive customer participation as new features of the manufacturing industry. This also encourages enterprises to seek production organization reform and transformation to adapt to the abovementioned changes and maintain competitiveness. Simultaneously, the increasingly subdivided market promotes the continuous emergence of distributed socialized manufacturing service resources. To improve competitiveness and bargaining power, these resources often constitute communities through self-organization, undertake tasks with the overall resource capacity, and improve resource utility through sharing and cooperation. Each community can replace traditional large-scale enterprises in terms of function and business and leads to more flexible and adaptable production organizations. Social community manufacturing has evolved in this context. By breaking down, reorganizing, integrating enterprises, and using and gathering social resources into a community, community members can share information and resources and realize value co-creation with the help of the community and its leading members. In contrast, customers can participate in the entire life cycle of manufacturing by proposing personalized demands, scheme designs, production, manufacturing, and assembly testing, operation, and maintenance, thereby becoming "Prosumers" [12].

With the increasing application of social network technologies and social media to business and enterprise cooperation, the discovery and sharing of social resources, business networking between enterprises, Internet collaboration, and enterprise relationship management have become simpler and more efficient. Enterprises communicate with customers and suppliers through social platforms such as LinkedIn and CloudERP. Simultaneously, cloud computing, social computing, big data analysis, and other information-computing technologies enable the intelligent processing of enterprise production data, real-time active production decision-making, and so on. For example, China's Smart Manufacturing Integrated System (SMIS) framework enables the interconnection and integration of information in enterprises, and the production process becomes intelligent and controllable in real time [13]. These emerging information technologies solve the problems of social community manufacturing in discovering and sharing massive, socialized manufacturing resources, multi-agent interconnections, and interactive cooperation and improve resource

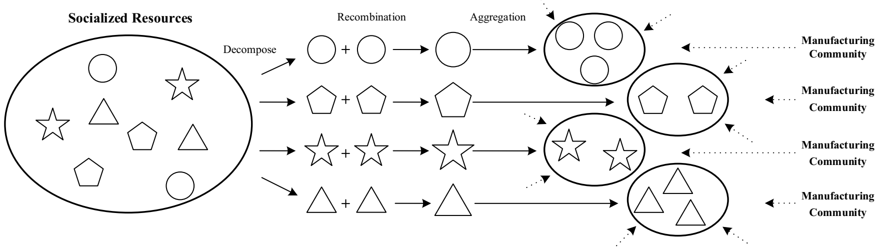

Fig. 3.8 Formation of social community manufacturing

utility and cooperation efficiency. For example, Haier made an active attempt in social community manufacturing with the Haidayuan platform. This platform not only gathers user demands that lead to enterprises' innovation but is also oriented to the large-scale personalized demands of users to connect suppliers' resources, provide solutions, and form a social ecosystem for product design and development, production, manufacturing, marketing, and services.[16] All in all, social community manufacturing is a new concept for realizing large-scale personalized manufacturing of products. It supports community producers and customers to jointly create personalized products and services, which provides a foundation for the efficient organization and utilization of socialized manufacturing resources, service-oriented transformation of manufacturing enterprises, and improvement of the overall interest level of the industry. Therefore, social community manufacturing provides new ideas for enterprises to implement the green growth model.

3.3 New Business Models Providing Avenues for Enterprises' Implementation of the Green Growth Model

3.3.1 Online and Offline Dual Channels

Offline channels refer to trade channels that sell goods through physical stores. Online channels refer to e-commerce trade activities through the Internet. A supply chain system comprising online and offline channels is called a dual channel supply chain. With the rapid development of the Internet and e-commerce, customers have gained access to increasingly convenient channels for product purchases. Previous single and offline channels find it difficult to meet customers' demands. Despite selling through offline channels, more enterprises have established online channels as well to meet customers' demands and improve market competitiveness through dual channels. For example, Heilan used direct-sale stores for early-stage offline sales and then established online consignment channels for online sales, developing rapidly to become the number one brand in China's clothing and home textile industry.[17] As of 2020, Apple had 511 offline stores worldwide and sold products online on its official website as well.[18]

The advantage of a traditional offline channel is that customers can feel and experience the goods. Although online channels are inferior to offline channels in this aspect, they are important for enterprises to reduce advertising costs, meet customers' demands, reduce inventory, and broaden market scope. Simultaneously, they also provide customers with more convenient information and save time. The advantage

[16] http://l.ihaier.com/aboutus.

[17] http://www.heilan.com.cn/abmilestone.

[18] https://www.sohu.com/a/396279345_120335275.

of adopting online and offline dual channels provides an avenue for the accurate matching of supply and demand, which can reduce ineffective production capacity, save costs, add demand-side value, and help enterprises adopt the green growth model.

3.3.2 Closed-Loop Supply Chain

A closed-loop supply chain refers to the complete supply chain cycle from procurement to final sale, including regenerative and reverse processes [14]. Its purpose is to close the flow of materials, reduce pollution discharge and residual waste, and provide services to customers at a lower cost. Social development increases the annual output of new products in the market. The surge in goods such as clothing, toys, daily chemicals, food, digital products, and household appliances not only consumes considerable natural resources but also leads to serious environmental pollution. According to the Global E-Waste Monitor 2020: Quantities, Flows, and the Circular Economy Potential released by the United Nations Institute for Training and Research, in 2019, 53.6 million tons of electronic and electrical waste were produced worldwide, with approximately 7.3 kg per capita. By 2030, the total annual volume of electronic and electrical waste products worldwide is likely to reach 74.7 million tons.[19] Recycling of waste products is one of the basic tasks to realize resource recycling and enterprises' green growth. Enterprises can create excess profits by recycling valuable components of waste products, which is conducive to improving their economic and social environmental benefits. Governments worldwide have also enacted policies to encourage enterprises to recycle waste products and promote the development of a circular economy. Based on the above mentioned economic interests and favorable policies, an increasing number of manufacturers and third-party collectors have initiated recycling businesses, promoting the development of closed-loop supply chains [15].

A closed-loop supply chain is not a simple combination of traditional forward and reverse supply chains but includes the entire process from product design, production, and sale to recycling and reuse of waste products (Fig. 3.9). For example, Apple recycles waste products through an Apple trade plan and then disassembles and reuses waste products using robots such as Daisy and Dave.[20] As China's largest electronic vehicle enterprise, BYD has set up 11 power battery recycling points in China to innocuously recycle and reuse waste batteries, forming a closed loop.[21] According to Huawei's Sustainability Report 2020, it collected 4500 tons of terminal electronic waste through its own recycling channels in 2020, disassembled the electronic equipment that had to be scrapped, and extracted substances such as copper

[19] https://collections.unu.edu/view/UNU:7737.

[20] https://baijiahao.baidu.com/s?id=1730704852691373911&wfr=spider&for=pc.

[21] https://www.byd.com/cn/SocialResponsibility/SocietyDevelopment.html.

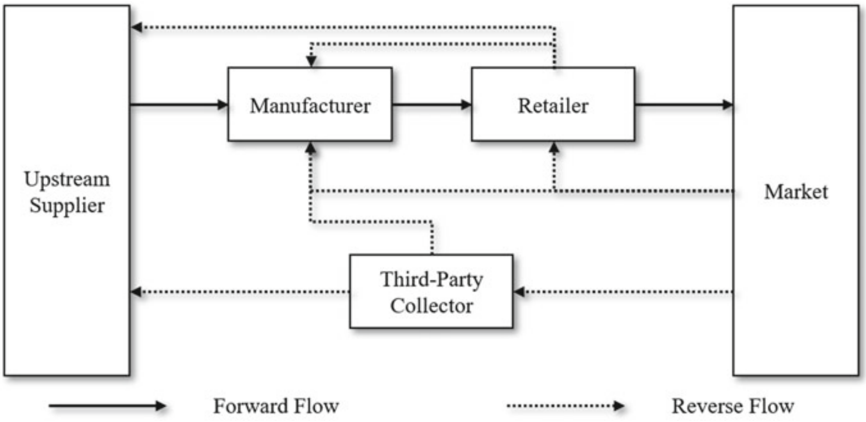

Fig. 3.9 Schematic diagram of closed-loop supply chain [16]

and gold, achieving a final landfill rate of only 0.79%.[22] A closed-loop supply chain effectively reduces the environmental pollution caused by waste products through the reuse and harmless treatment of recycled waste products. Simultaneously, it realizes the recycling of resources and improves resource utilization efficiency. This is an important avenue for enterprises to implement the green growth model.

3.3.3 Platform Economy

Platform economy refers to a new type of economic integration system driven by computing technologies such as the Internet and cloud computing, big data, and the IoT, with many platform enterprises taking the lead and customers and service providers as participants [17]. It connects suppliers and customers on both sides through an Internet platform and provides important connections for the completion of transactions. Generally, the platform does not provide products but mainly intermediary services for users and obtains income by charging certain service fees for users on both sides, as shown in Fig. 3.10. Since the beginning of the twenty-first century, e-commerce platforms have benefited from economic prosperity and the maturity of information technology to become an important consumption channel [18]. By relying on the Internet and digital technology, the platform economy can simplify the transaction process, improve transaction efficiency, and reduce transaction costs.

With vigorous development of the platform economy, an increasing number of enterprises conduct second-hand product trading activities on Internet trading platforms such as Aihuishou and Guazi. In the second-hand market, recyclers can use the convenience and timeliness of Internet transactions to cover more customers,

[22] https://www-file.huawei.com/-/media/corp2020/pdf/sustainability/sustainability-report-2020-en.pdf.

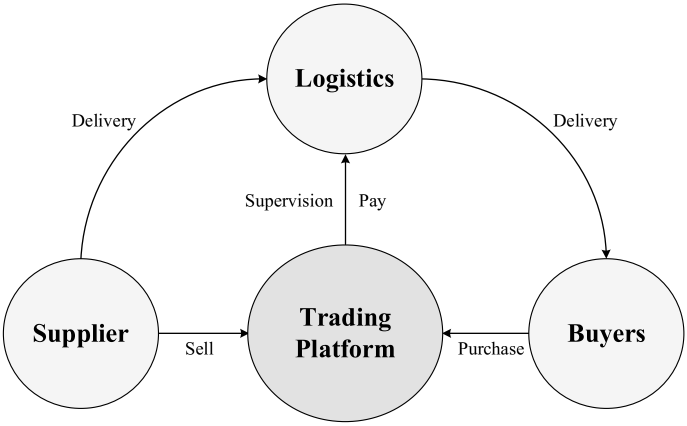

Fig. 3.10 Schematic diagram of the platform economy

expand recycling scope, and improve recycling efficiency to synergize environmental protection and enterprise performance improvement. For example, as the largest electronic product recycling and environmental protection disposal platform in China, Aihuishou achieved an annual trading volume of more than 22 million units in 2021, and its total annual revenue reached 7.78 billion CNY.[23] In addition, by relying on the platform economy model, enterprises can implement the green growth model by comprehensively integrating resources and promoting the joint participation of all upstream and downstream value chain entities. For example, Alibaba proposed the "Scope 3+" carbon emission reduction plan involving the participation of the entire value chain in 2021, as shown in Fig. 3.11. It plans to achieve the carbon emission reduction target of 1.5 billion tons within 15 years.[24] These advantages of the platform economy provide new avenues for enterprises to implement the green growth model.

3.3.4 Energy Performance Contracting

Energy performance contracting is an innovative commercial energy-saving mechanism based on market operations. It refers to the agreement and operation model of energy-saving objectives attained by customers and energy service companies. It requires energy service companies to provide technical services to customers and realize the relevant energy-saving requirements, whereas customers need to pay a certain fee for the energy-saving benefits to ensure the profit of the energy service company, as shown in Fig. 3.12. Energy performance contraction has a highly reliable energy-saving effect. The saved energy cost can be used to pay for investment

[23] https://3g.163.com/dy/article/H26SNAV90539JGBD.html.

[24] https://sustainability.alibabagroup.com/en.

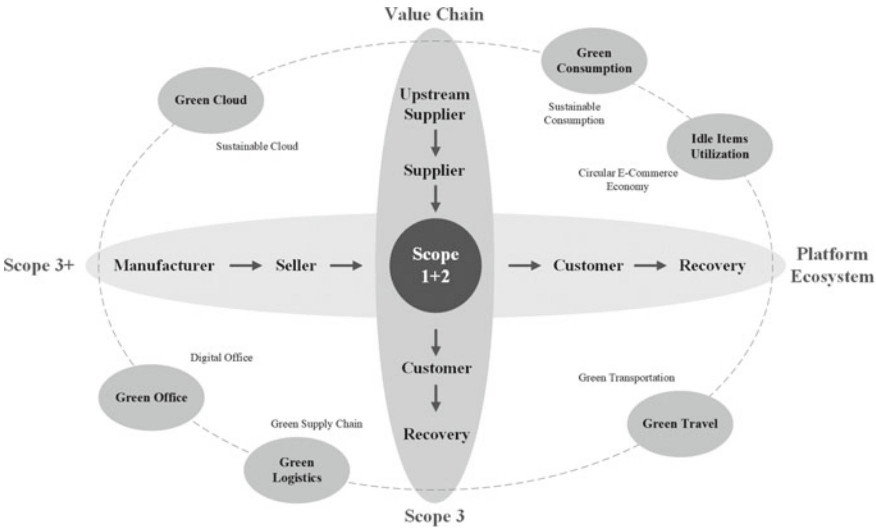

Fig. 3.11 Alibaba's "Scope 3+" carbon emission reduction plan

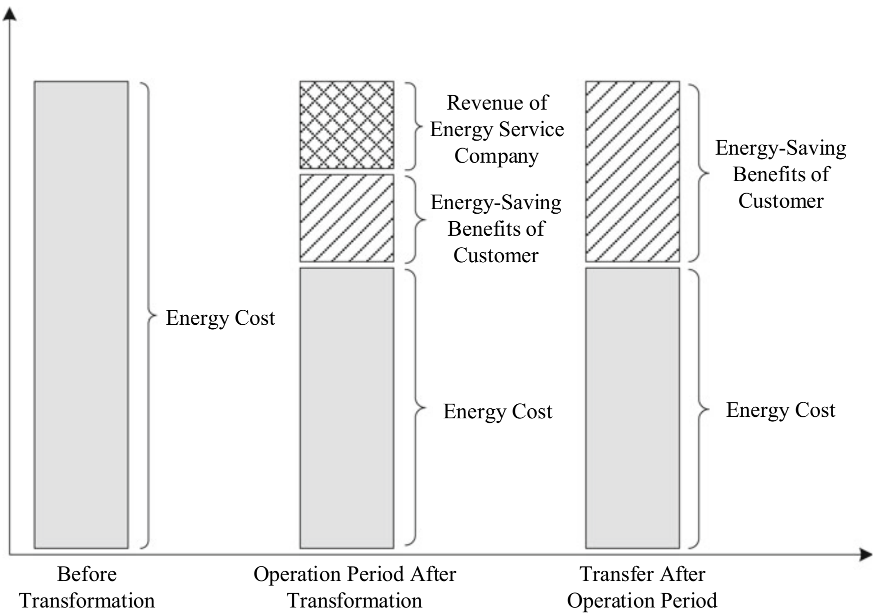

Fig. 3.12 Benefit distribution structure of energy performance contracting

projects, including the costs of transforming and upgrading energy-saving equipment and introducing various technologies. It has gradually become one of the most common approaches for energy savings and emission reduction [19].

Energy performance contracting is a model that provides energy-saving services for customers in need, based on future energy-saving benefits. It has successfully spawned a new energy-saving industry. For example, Econoler International provides customers with energy resource assessments, energy cost analyses, real-time management of energy consumption, and dynamic monitoring of energy-saving equipment and other services. It has conducted business in many countries around the world and has completed more than 2500 energy performance contracting projects.[25] Jiutian Energy implemented an energy performance contracting project for power generation engineering for Chengde Steel. After a one-year construction period, the introduction of advanced steam turbine generator units, transformation of water supply and drainage systems, and thermal control systems have all been completed, and an annual energy-saving income of approximately 180 million CNY has been earned.[26] Energy performance contracting meets not only the demands of modern enterprise operation specialization and service socialization but also the trend of an energy-saving society. It helps enterprises promote green transformation and ensures the effectiveness of their green growth.

3.4 Summary

This chapter discusses the development trends of enterprises' green growth model from the perspectives of new technologies, new forms of industry, and new business models. New technologies, such as next generation Internet and IoT, help to reduce transaction costs, accurately match supply and demand, achieve value co-creation and sharing, and realize the entire life cycle of environmental management. New forms of industry, such as collaborative logistics, crowdsourcing design and manufacturing, networked collaborative manufacturing, and social community manufacturing, help to reduce ineffective production capacity, meet customers' demands, and realize value co-creation. New business models, such as online and offline dual channels, closed-loop supply chain, platform economy, and energy performance contracting, help to improve operational efficiency, realize resource recycling, and increase energy efficiency. Thereby, the new technologies, new forms of industry, and new business models provide methods, opportunities, and avenues for enterprises' implementation of the green growth model.

[25] https://baijiahao.baidu.com/s?id=1673707676973554969&wfr=spider&for=pc.

[26] https://www.docin.com/p-2362925703.html.

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Chapter 4
Value Chain Reconstruction and Innovation

Mengdan Wang, Nengmin Wang, Qi Jiang, and Junling Han

Abstract "Green development" has become an important part of the core competitiveness. Simultaneously, with the development of next generation information and communication technology and environmental protection technology, a series of changes have taken place in value chain activities under the new form of industry and new business model, which requires enterprises to reconstruct their value chain and growth model to adapt to the new development trends. This chapter discusses in detail on value chain reconstruction and innovation in enterprises' green growth model inclusive of four aspects: strategy, technology, activities, and members, and identifies the factors and actions that affect value chain reconstruction and innovation. First, green transformation is strategic transformation in essence, which requires enterprises to evaluate the strategic activities of the original value chain, assess enterprises' strategic activities, and then devise an enterprise strategy with the aim of green growth, so as to reconstruct the value chain. Second, new form of industry and new business model, driven by new technologies, have changed the business environment; enterprises must reconstruct their growth models and value chains. A value chain is an organic system composed of a series of value creation activities. A green value chain can be defined as a dynamic closed-loop process that encompasses product design, raw material procurement, product manufacturing, product marketing, logistics, product consumption, and recycling. In enterprises' green growth model, key value chain reconstruction and innovation activities need to be sustainable at each step, including product design, procurement, manufacturing, logistics, and consumption. Finally, the green growth model of enterprises proposes new requirements for selecting members in the value chain. Suppliers, enterprises, consumers, and governments affect value chain reconstruction and innovation performance, and thus, selecting members according to relevant indicators is necessary.

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4.1 Types of Value Chain Reconstruction and Innovation

4.1.1 Value Chain Reconstruction and Innovation in Enterprises' Green Growth Model

As the market environment becomes increasingly complex for enterprises, optimizing each activity in the value chain becomes difficult, thereby leading to the decomposition of the value chain. Specifically, activities with advantages are identified and retained, whereas those without competitive advantages are handed over to the best partners. In this process, enterprises continuously invest in or outsource activities, which finally results in the reconstruction or merger of the value chain. In a value chain, the distribution of value in each enterprise is imbalanced, and value chain reconstruction requires enterprises to reidentify their valuable and strategic activities. The identification and operation of the activity, which ultimately determine the cost and benefit of enterprises, may exert a decisive influence over other activities. Thus, this activity is also the key to value creation.

For green development, government regulations compel enterprises to establish green, low-carbon, and circular development industrial systems. Customer demand for green products or services forces enterprises to engage in green practices. Green growth has become a priority for enterprises; implementation of the green growth model is the key to long-term development. Reconstruction and optimization of the value chain is an important way for enterprises to implement a green growth model. The enterprise's green growth model has an impact on the value chain reconstruction, which is mainly reflected in the impact of enterprise's green growth goals on value creation. If green development adds value to enterprises, it will change the existing value structure and core competitive advantage of enterprises, thus reconstructing the value chain. Some scholars have discussed the impact of the green growth model on value chain reconstruction. For example, Fan et al. pointed out that in a green economy, a change in the enterprise value chain is a change in the business value chain operation mode, which reduces the cost of products from a strategic perspective [1]. Zhang and Gu believed that the green growth of enterprises implies that the development state in which the economic and environmental performance of enterprises must be balanced in a certain period, and proposed an adoption strategy for ecological innovation [2]. Some studies have explored the impact of corporate green growth models on the value chain from the perspective of low-carbon technologies. For example, Chen et al. believed that as the main body of green innovation, enterprises must equip themselves with green and low-carbon technologies to realize carbon reduction and emission reduction and thereby fulfill their social responsibilities [3]. Jia et al. pointed out that in enterprises' green growth model, the implementation of green and low-carbon technological innovation is conducive to improving the comprehensive utilization efficiency of resources and reducing resource consumption [4]. Bi et al. analyzed the innovation performance of low-carbon technology innovation activities in the global value chain, assessed the influencing factors of China's low-carbon technology innovation performance, and discussed the three aspects of low-carbon technology innovation performance: government regulation, technology promotion, and market pull. The study pointed out that Chinese manufacturing entities, especially manufacturers and government departments, pay more attention to and utilize the power of global value chain governance [5]. Additionally, numerous studies have investigated the specific processes and methods of value chain reconstruction from practices in the existing green growth model. Marimin et al. used the analytic hierarchy process (AHP) method to analyze the green reconstruction of the natural rubber supply chain and proposed three strategies to improve rubber productivity, reduce pollutants in the production process, and recycle waste water [6]. Couto et al. proposed that under green requirements, creating a sustainable and competitive market by optimizing the internal processes and partnerships in the value chain within the enterprise is insufficient. Enterprises must clarify the products' green value in the value chain [7].

Additionally, the information technology has undergone tremendous changes. While enterprises are compelled to implement value chain reconstruction and innovation, new technologies provide support to execute value chain reconstruction in the green growth model. New technologies, represented by the next generation information and communication technology, have spawned new forms of industry and new business models. Internet information technology has reduced the cost of information exchange between enterprises, resulting in a significant reduction in transaction costs. The communication of entities in the value chain is close to seamless, and the structure of the organization tends to be flattened, causing a series of new business models. This has brought new changes to the business environment, as the original model of an enterprise no longer meets the needs of its rapid development. New technologies, new forms of industry and new business models drive enterprises to reconstruct their growth models and value chains, and provide required support for value chain reconstruction and innovation. Based on the characteristics of the business environment and technologies that enterprises rely on, the reconstruction and innovation of the value chain in the green growth model presents the following characteristics.

(1) Customer-Centered Value Chain

Traditional value chain reconstruction usually focuses on enterprises while ignoring the role of customers, which is not suitable for the existing market environment. The core driving force of the market has shifted from production to consumer demand. To upgrade the enterprise structure, the core driving force for enterprises should actively meet changes in market demand. On this basis, the enterprise production process is identified, and the asset structure and core competitiveness of enterprises are ascertained. With consumers increasingly demanding green products and services, the precise matching of demand and supply is key to the effectiveness of an enterprise's growth model. In the process of value chain reconstruction and innovation, enterprises should fully consider the strategic requirements and key activities involved in the coordination of green and growth in the construction of a green growth model. Some well-known enterprises have improved their core competitiveness by implementing the "green strategy". For example, Dongfeng Honda has committed to building a "green factory" and has used environmental protection technology in several production links. When building the first factory, the company fully considered the issue of energy conservation and emission reduction, and independently funded the establishment of a solar photovoltaic power generation system. The annual power generation can save approximately 100,000 kilowatt-hours, which is equivalent to reducing 101 tons of carbon dioxide emissions. Its second factory has greatly increased the scale of photovoltaic power generation. The electricity converted from solar energy is directly transported to the production line for vehicle production and factory lighting, thus reducing carbon dioxide emissions to 550 tons per year, which is equivalent to 5.5 million square meters of forest absorption.[1]

(2) Value Chain Becoming Collaboration Chain

Fierce market competition has promoted the innovative model of dynamic alliance, and the changing market demand has forced enterprises to choose the alliance model. The development of next generation information and communication technology provides technical support for the realization of dynamic alliance. In a dynamic alliance, the value chain system requires all members to work hard to eliminate corporate boundaries, re-examine the channel mechanism and mutual relationship, transform from transaction parties to partners, and build an efficient and orderly value chain system to realize the overall coordinated operation of the system. Under a dynamic, orderly, cooperative, and coordinated operation mechanism, win–win and multi-win situations among enterprises in the value chain system are realized. For example, the COSMOPlat industrial Internet platform created by Haier incorporates the first-class resources of the society into the platform, which can effectively connect people, machines, and things. Through information sharing, different types of enterprises can quickly match intelligent manufacturing solutions, forming an open and win–win organic and whole ecology of users, enterprises, and resources.[2] Next generation information and communication technology is used to analyze the contribution of value chain entities in the dynamic alliance to discover, create, and transmit value. Meanwhile, the impact of value activities on the environment is analyzed by means of material flow, life cycle, and carbon footprint analyses. Through the combination of these technologies, we can establish a system, framework, and methods of value chain reconstruction and decision-making based on the green growth model of data-driven enterprises to provide decision support to enterprises to reconstruct their growth model and value chain and implement a green growth model.

(3) Value Chain Evolving into Ecological Chain

The members of the value chain are not confined to traditional industrial boundaries, and the boundaries of enterprises are becoming increasingly blurred and integrated. Specifically, enterprises become members of the business ecosystem rather than a single or extended enterprise. Enterprises in a business ecosystem co-evolve around one or more innovations. The features of this ecosystem lie in the environmental

[1] https://www.sohu.com/a/316780089_256503.

[2] https://www.cosmoplat.com/platform/company.

factors; human activeness has a significant impact on the construction and efficacy of the value chain system. Enterprises transform from the functional type to the process type, constantly innovate the value chain, actively self-organize and self-adapt to the environment, and finally realize continuous evolution and development. For example, in the Haier RenDanHeYi (RDHY) model, the Haier platform connects “user micro-enterprises” and “maker micro-enterprises”, and uses the chain group as the basic unit to meet users’ needs and experience iterations. A service ecological chain that is user-led, service-oriented, and fully supported by service providers is successfully established, which not only maximizes users’ value by continuously creating optimal user experience throughout the entire process, but also provides a huge impetus for standardization and quality transformation to upgrade the entire household appliance service industry. In the process of ecological chain construction, enterprises usually expand a single type of product into an ecological group according to the application scenario.[3] This ensures that “green development” is considered in product design and partner selection to reconstruct and optimize the value chain. In this regard, adhering to the design concept of “green environmental protection”, Haier refrigerators have led the transformation and evolution of the household appliance industry in green manufacturing, and build a green ecological circle of the household appliance industry, and won the global sales champion for 13 consecutive years.[4]

(4) Closed-Loop Value Chain

Professor Michael Porter of Harvard Business School proposed his value chain theory, arguing that the operation of an enterprise can be divided into activities such as design, production, sales, and delivery activities, which can be represented by a value chain. The traditional industrial organizations and management follow the value chain model. Relying on the Internet, the value chain has become a closed-loop value chain; that is, the operation process of creating value is no longer within a unidirectional chain, but a closed-loop value chain system that includes activities ranging from design, manufacturing, procurement, logistics, and recycling. Resources can be reused, and information can be shared to a great extent in a closed-loop value chain. Under the concept of green development, “unblocking the recycling of resources and building a green industrial ecology” is the key to forming a benign development trend, and promoting healthy and sustainable development of the economy and society. The recycling and reuse of waste products not only meets the green consumption needs of consumers, but also helps enterprises reduce production costs, which successfully connects the links of green production and consumption. Therefore, an increasing number of enterprises have launched a recycling business of used products. For example, Apple and Huawei mobile phones have opened second-hand recycling service on their official websites, through recycling, scrapping, dismantling, and extracting resources to maximize the recycling of electronic waste.[5,6]

[3] https://www.haier.com/rdhy/2021/news/20210922_171251.shtml.

[4] http://www.rmlt.com.cn/2021/0111/604720.shtml.

[5] https://www.apple.com.cn/shop/browse/open/free_recycling?ivk_sa=1024320u.

[6] https://consumer.huawei.com/cn/support/recycling/

(5) From Value Chain to Value Network

In the information age, enterprises must reassess how to deliver value to customers and construct new value chains. A new value chain does not comprise members who add value, but a value network driven by demand, comprising multiple activities, such as design, manufacturing, procurement, logistics, and recycling. It involves multiple actors, such as customers, suppliers, manufacturers, retailers, platform parties, and logistics providers. Based on repeated transactions, the value chain is an intermediate organization between the market and enterprise, that is, a strategic alliance. The value network is more based on demand-driven, relies on new means such as industrial Internet platforms, and quickly builds system service solutions and teams that respond to needs in the value ecosystem. The rise of the Internet of Things enables companies to break through the limitations of time and space, and make it possible to meet user experience at a low cost and agile with the help of online strategies. Internet optimizes the allocation, improves efficiency, promotes platform operation and network ecological reform, and satisfies personalized needs through platform economy. By building a platform ecosystem and connecting more users, platforms can fully exploit the network effect and realize the economy of scale. According to the data generated by the accumulation of user demand, consumption, and feedback, as well as the data of various entities in the supply chain, enterprises can more effectively analyze customer behaviors and predict customer demand. Relying on next generation information and communication technology, enterprises can execute agile and low-cost iterations multiple times for customer needs and experiences, accurately perceive customer needs, and establish fragmented independent demand. Simultaneously, through the agile integration of the capabilities, knowledge, and resources of various entities on the platform, enterprises can continuously optimize user experience, provide system service solutions, and realize the accurate prediction and rapid satisfaction of user needs.

With the development of information technology, various forms of enterprise network organizations continue to appear and evolve. The pursuit of resources and their value by enterprises is no longer limited to the accumulation and cultivation within the enterprise, but has a wider range. For the environmental indicators that companies responsible for strategic activities should meet, the value network associated with the green growth model puts forward corresponding requirements. Through the common goal of forming a green production system and transmitting green value, different enterprises are connected to other members in the chain. Therefore, enterprises should set green growth as their objective, reconstruct and innovate their own value chain, and accurately choose other reliable green partners in the value network to form a green ecosystem of sustainable and circular development. Driven by information technology, different types of value networks have been formed. The first is a platform-oriented value network. For example, Haier industrial Internet platform, built with the purpose of co-evolution and value-added sharing, has become an enabling platform for multilateral interaction and value-added sharing through mass customization mode innovation, technological innovation by integrating information technology and manufacturing technology, and small- and micro-entrepreneurship mechanism innovation across industries and fields. It has also become an incubator platform for emerging new startups, and an entrepreneurship and innovation platform for various types of entrepreneurs.[7] The second type is the core manufacturing enterprise-oriented value network. For instance, when selecting suppliers, Huawei ensures that under the condition of similar performance, it will prioritize purchasing products with satisfactory environmental performance or using recycled materials. By promoting first-tier suppliers to search for environmental compliance performance, Huawei conveys the concept of green environmental protection to a wider range of participants in the electronics industry chain.[8] The third platform type directly matches factory supply and consumer demand. Consider Pinduoduo as an example. By constantly following the consumption habits of platform users and the evolution of ecology at both ends of the supply chain, Pinduoduo maximizes the value of the e-commerce platform by matching them. Based on mobile test scenarios, big data, and artificial intelligence algorithms, it procures orders through unique social and public welfare games. Thus, the demand of 443 million consumers is collected in a short period to connect with the supply side of farmers and factories.[9]

4.1.2 Types of Value Chain Reconstruction and Innovation Caused by Different Driving Forces

The green development of enterprises or the improvement of environmental performance is key to achieving sustainable development and maintaining a competitive advantage [8]. Enterprises' green growth model and value chain reconstruction are the direct results of green development. Both internal and external driving forces contribute to the implementation of the green growth model, and promote the reconstruction and innovation of enterprises' value chain. The internal driving force is mainly manifested in mission-oriented value chain reconstruction and innovation; that is, enterprises hope to shoulder corporate social responsibility in international competition, enhance their competitiveness through green development, and form the competition threshold. The external driving force mainly manifests as problem-oriented and passive value chain reconstruction and innovation in the face of external pressure, such as environmental regulations, social legitimacy, and stakeholder pressures. Enterprises can solve external conflicts and gain competitive advantage through green management.

(1) Mission-Oriented Value Chain Reconstruction and Innovation

First, green development is an important means for future competition. The concept of green enterprise is an inevitable requirement for the development of modern society, and it is also an inevitable choice for enterprises to survive and develop

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[7] https://www.haier.com/haier_cosmoplat/.

[8] https://www.huawei.com/cn/sustainability/the-latest/stories/ipe-green-choice-initiative.

[9] https://www.cqn.com.cn/zgzlb/content/2019-08/08/content_7395942.htm.

in the increasingly fierce competition. To fulfill the responsibility of internal stakeholders and external consumers, enterprises should conduct value chain reconstruction and innovation in an enterprise's green growth model. Li et al. explored the relationship among stakeholders, green manufacturing, and performance in China's fashion industry, and found that corporate stakeholders significantly positively impact green manufacturing, which, in turn, significantly positively impacts performance and practice performance [9]. Singh et al. examined the direct and indirect effects of stakeholder pressures, green dynamic capacity, green innovation, and small and medium-sized enterprises (SME) performance in emerging markets. A prior study, using multi-source data from 248 SMEs in the manufacturing industry, showed that stakeholder pressures affect green dynamic capability, thus affecting green innovation, which, in turn, affect enterprise performance [10]. Attaining sustainable development, implementing green innovation, and realizing the coordinated development of environmental, economic, and social operations are regarded as important sources of deriving competitive advantages [11]. In China, market-oriented green innovation has received increasing attention, and the market is an important factor in promoting green technological innovation [12]. Facing a fierce external competitive environment in the process of green development, enterprises need to evaluate the disadvantages in the existing value chain and parts that need to be reorganized, split, and optimized—based on resource theory, value chain theory, and sustainable development theory. Through the reconstruction and innovation of the value chain, a sustainable competitive advantage is created for enterprises in the market. Currently, DuPont, BP Amoco and other large multinational companies are trying to practice the green development strategy.[10,11] From product design to use, they consider how to save energy and protect the environment. They often implement low-carbon processes through product development and green consumption, which demonstrates a strong sense of corporate social responsibility and enhances green competitiveness.

Second, increasingly severe environmental problems urge enterprises to engage in green transformation. Facing severe constraints of production supply factors, enterprises exhibit a sense of mission to conduct value chain reconstruction and innovation. Extensive economic development results in a waste of resources and environmental damage. In the face of limited resources, enterprises in both developed and developing countries should form a correct green cognition in the international cooperation of energy conservation, emission reduction, and environmental protection, and shoulder the mission of value chain reconstruction and innovation under green development. Gadenne's empirical results showed that green cognition or environmental awareness positively impacts energy conservation and environmental protection behaviors. If managers have a sense of responsibility toward energy conservation and environmental protection along with a willingness to realize environmental values, the energy conservation and environmental protection behaviors of enterprises will be affected [13]. Therefore, enterprises with appropriate green cognition are more inclined to

[10] https://www.dupont.com/news/next-generation-styrofoam-insulation-to-reduce-greenhouse-emissions.html.

[11] https://www.bp.com/en/global/corporate/who-we-are/our-purpose.html.

implement green development strategies, and are willing to become active advocates and practitioners of green development. As the main body of energy conservation and emission reduction, enterprises should not only produce green products but also introduce a green production process. By serving customer demand for green consumption, enterprises can highlight the concept of green development, shoulder the green mission, and shape a green brand.

Third, enterprises can establish a green competitive advantage through value chain reconstruction and innovation. Several scholars believe that green environmental protection innovation improves resource utilization, reduces pollution, and improves the market image and income of enterprises, thus resulting in both economic and environmental benefits [14, 15]. With green technological innovation, the utilization efficiency of natural resources is relatively high. Enterprises can efficiently use resources and energy to manufacture products with lower material and energy consumption, thereby greatly improving the comprehensive efficiency of the circular economy of green enterprises instead of simple economic efficiency or ecological efficiency [16]. Influential large multinational corporations in the world have long infused the green concept into their brand development strategies. For example, BP, an old British oil company, one of the largest oil and petrochemical groups in the world, has been promoting its concept of green production and life, and advocating the development and use of new energy sources [11].

Through active green transformation, improving enterprises' green competitiveness and forming a competition threshold is the purpose of enterprises' mission-oriented value chain reconstruction and innovation. According to Porter's Five Forces Model, enterprises face five basic competitive forces: suppliers' bargaining power, buyers' bargaining power, potential competitors' entry ability, the threat of substitute, and industry competitors' competitiveness [17]. In enterprises' green growth model, the linear chain from suppliers to buyers, and the interactive network comprising enterprises and its external competitors, promote enterprises to reconstruct and innovate the green-oriented value chain. When choosing the path of value chain reconstruction, enterprises should first analyze the value chain with the objective of green growth, modularize internal activities, and determine the activities that should become strategic activities according to the requirements of reconstructing competitive advantage. Additionally, having conditions for the value chain improvement and reconstruction is significant for enterprises [15]. In enterprises' green growth model, based on the "low input, high output, and less pollution" objectives of the circular economy, enterprises should re-evaluate their value-added activities and the internal relationship between the value-added activities. Through the reconstruction and innovation of the enterprise value chain, a new profit model is constructed. Different from their competitors' profit model, enterprises possess unique competitive advantages, form a closed loop value flow to meet the requirements of the circular economy, and realize the value added to enterprises.

(2) Problem-Oriented Value Chain Reconstruction and Innovation

Enterprises face problems, such as external environmental regulations, social legitimacy, and stakeholder pressures, which affect their survival and development. These external pressures drive enterprises to implement green transformation and value chain reconstruction, and ultimately develop in the direction of green growth.

First, environmental regulation pressure is an important driving force for enterprises to undertake green growth transformation. The coercive force is the main driving force for enterprises' green management practices, and government environmental regulations positively impact value chain reconstruction and innovation in the green growth model. Environmental Management Systems (EMS) include the ISO 140001 system, top management commitment in the green system establishment process, teamwork, decentralization, process-related technologies, etc. Studies show that an environmental management system can positively moderate the relationship between environmental product innovation and enterprise market performance [18]. Policy factors are usually the first considerations of enterprises. In order to avoid higher policy fines or even suspension of business, enterprises consider increasing investment in green value chain reconstruction, in line with the government's requirements for local enterprises' environmental protection capabilities and relevant environmental protection laws and regulations. For example, under the pressure of environmental regulations, since 2011, China Baosteel has focused on the implementation of a renovation project of environmental protection equipment and the upgrading of process technology in each unit of raw materials, sintering, coking, and blast furnaces in Baoshan Base, directly aligning with the strictest emission standards at home and abroad. It even considers more stringent indicators in the future to implement green transformation and lead to green development of the industry.[12]

Second, pressure from industry associations and stakeholders will also promote enterprises to reconstruct and innovate the value chain. Enterprises need to not only focus on groups with direct economic interests, but also change from market-oriented value creation to stakeholders-oriented value creation. By integrating stakeholders into enterprises' green strategies, enterprises can identify stakeholders' value-added behaviors and focus on the interaction and learning ability between stakeholders and enterprises. In different activities of the value chain, specific stakeholders' behaviors and their results determine value creation. The value creation of each activity involves identifying which activities generate value for the value chain, and then integrating the internal and external resources that each independent but inter-related member in the value chain possesses, thereby determining the activity's impact on value creation. In the face of the presence of different stakeholders, enterprises must form dynamic alliances through technological and management innovation. Enterprises can deliver greater value to customers by optimizing, reorganizing, integrating, and innovating value activities to construct a new value chain. The value chain reconstruction from the perspective of stakeholders is shown in Fig. 4.1.

Third, the new technologies represented by next generation information and communication technology have brought about new forms of industry and new business models, which have driven enterprises to restructure their growth models and value chains. The extensive application of advanced technology, such as mobile Internet, big data, and cloud computing has seamlessly linked the Internet with

[12] http://cpc.people.com.cn/n1/2018/1223/c415067-30482812.html.

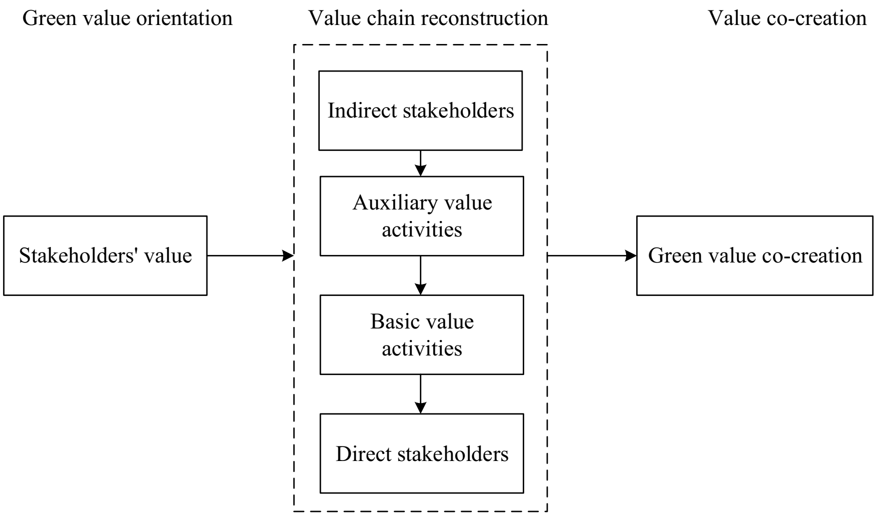

Fig. 4.1 Value chain reconstruction from the perspective of stakeholders

numerous industries. Varied kinds of new economies and businesses prosper with the use of next generation Internet. For example, the emergence of e-commerce has significantly impacted all value chain activities. "Next generation Internet combine with second-hand products" and "next generation Internet combine with recycling" have become important components of green circular economy. In 2020, the number of users of China's second-hand trading e-commerce increased to 223 million, and the scale of second-hand e-commerce transactions increased to 400.17 billion yuan.[13] Depending on next-generation information and communication technology, customer needs and behaviors can be integrated into the enterprise value chain actively or passively, and the effective matching of supply and demand is enhanced. Enterprises also need to consider how to reconstruct and innovate value chains according to green requirement under the support of next-generation information and communication technology.

Problem-oriented value chain reconstruction and innovation requires enterprises to correctly analyze external pressure, and identify strategic activities by combining both internal and external influencing factors. Enterprises need to upgrade the value chain from the perspective of products, processes, and functions and improve the status of independent value units that significantly contribute to green growth. Therefore, the pressures imposed by external environmental regulations and competitive pressures can be addressed. Restructuring the value chain with problem-oriented thinking will help enterprises transform current external risks into opportunities for future development. The innovative transformation of value creation methods aimed at solving green value-added problems can enable enterprises to change their passive competitive positions, and realize the double value-added goals of enterprises and customers.

[13] http://www.100ec.cn/zt/2021zgesdsscsjbg/

4.2 Value Chain Reconstruction and Innovation Based on Strategy

4.2.1 Value Chain Reconstruction Requires Enterprises to Re-evaluate the Strategic Activities

Enterprise strategy means that enterprises choose suitable business fields and products to match their own resources and strength, form their core competitiveness, and win the competition through differentiation in accordance with the changing environment. The value-creation mechanism of enterprises has changed for green development. Enterprises must adapt to the requirements of sustainable economic and social development. The operating philosophy is to conserve resources, protect and improve the ecological environment, and benefit consumers' and the public's physical and mental health. By adopting green technologies and producing green products, enterprises can coordinate environmental protection and economic interests and implement green transformation to achieve sustainable growth. Green transformation is essentially a strategic transformation, which requires enterprises to re-evaluate the strategic activities of the value chain and set corporate strategies to achieve sustainable development and green growth. Thus, a value chain can be reconstructed. For enterprises, green development does not incur high costs. In the long term, green development reduces the potential risks induced by environmental regulations. Meanwhile, upgrading technologies often results in higher efficiency and lower costs. Enterprises can strengthen or confirm their core competitiveness through value chain reconstruction, seek more reasonable and centralized allocation of resources, and secure a leading position in future competition. Through strategic transformation, enterprises can convert the cost advantage derived through green technology into opportunities and competitive elements. Therefore, from the perspective of long-term economic benefits and development, the re-evaluation of green strategies would encourage enterprises to transform from passive to proactive environmental management strategies. Moreover, the new generation of information technology and manufacturing industry are deeply integrated. Against the background of the intersection of the scientific and technological revolution and the new industrial revolution, the industrial Internet has become an important cornerstone of the fourth industrial revolution; further, the traditional value chain extends to the value network. In terms of implementing a green growth model, a single enterprise is only part of the value network. An enterprise's green strategic transformation must reconstruct the enterprise's internal value chain and choose entities with the same concept in the value network. At the strategic level, through value chain reconstruction, enterprises can flexibly adjust value activities and jointly deliver commercial and environmental value to the society with their strategic partners in the value network, which might activate the synergistic effect of the value network.

4.2.2 Strategic Matching of Value Chain Reconstruction in Enterprises' Green Growth Model

(1) Uncertainty of Demand and Supply

The uncertainty of demand and supply is mainly reflected in overcapacity and the mismatch between consumer demand and market supply. First, the supply of products changed from undersupply to oversupply, resulting in overcapacity and an increase in inventory and production costs. Second, consumers' demand structure for products continues to change. Specifically, green development has become an important influencing factor affecting consumers' decision-making preference. Currently, enterprises ignore consumers' green preference in pursuit of economic benefits, leading to a serious mismatch between supply and demand. Enterprises must analyze their own resources and advantages according to changes in the market environment, identify strategic activities with competitive advantages, and adjust the product structure to reconstruct the value chain in their green growth model.

(2) Different Response States of Value Chain

The market demand for products is gradually changing from mass customization to personalization. When dealing with different demands, enterprises' value chains must respond accordingly. From the perspective of product types, consumers who prefer functional products place more emphasis on economy and practicality. In this circumstance, the adjustment of the value chain focuses on the acquisition of resources required for mass production. However, consumers who prefer innovative products attach more importance to personalization and creative products. Consequently, enterprises' knowledge and ability are important factors that affect the value chain's response state. Considering product structure, for integral products, there are relatively high requirements for technology and production capacity that enterprises rely on. Therefore, enterprises must possess the knowledge and ability to produce such products, which emphasize the reconstruction, integration, and promotion of the value chain within enterprises. For modular products, enterprises without knowledge and ability can outsource their corresponding value activities to other enterprises. If enterprises are equipped with knowledge, ability, or both, they can choose the direction of value chain reconstruction, integration, and improvement by comparing the cost, profit, performance, and risk of outsourcing and making in-house products, including the social responsibility risk of environmental management and supply disruption risk. To a certain extent, product structure affects the choice of a specific path for enterprises to implement the green growth model.

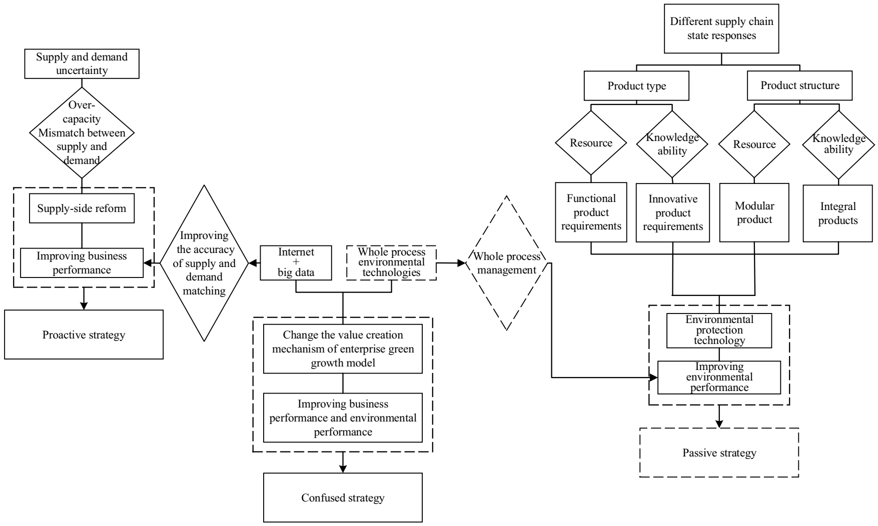

Fig. 4.2 Structure diagram of strategy-based value chain reconstruction and innovation

(3) The Strategic Matching of Value Chain Reconstruction

According to the characteristics of environmental protection technology, including end control and whole process management, product type, including innovative products and functional products, and product structure, including modular products and integral products, we analyze the demand uncertainty of the value chain and supply uncertainty of products and services. Based on this, the value chain's response ability to different demands is evaluated, and a strategic matching model of value chain reconstruction is established. Consider innovative products as an example. Enterprises should strategize to respond quickly to demand. Enterprises must establish a value chain network through outsourcing activities in the value chain. Once some activities are outsourced, enterprises usually adopt fast and effective end-control environmental protection technology in the short term to ensure overall greening of the value network. However, in the long term, enterprises will gradually change their environmental protection technology to implement the entire process management to achieve sustainable development. For functional products, enterprises should adopt an effective supply chain strategy and reduce costs through economies of scale and integrated value chains. In the integrated value chain, it is easier for enterprises to control all production activities, implement the entire process management technology, and finally realize the green growth model of enterprises and the entire value chain. The structure diagram of strategy-based value chain reconstruction and innovation is shown in Fig. 4.2.

4.2.3 Methods of Value Chain Reconstruction and Innovation Based on Strategy

Institutions, stakeholder pressures, growing public ecological awareness, and production costs drive enterprises to choose active green strategies to solve environmental problems. Enterprises adopting active strategies aim for synergy between green and growth. Through active value chain reconstruction, cooperation methods and allocation models of production factors can be innovated to achieve both economic and environmental benefits. For example, by adopting an active strategy to reconstruct and innovate the value chain, enterprise's environmental protection ability can be improved. These abilities can not only meet the government's environmental protection requirements but also effectively improve production efficiency, and reduce waste of raw materials and pollutant emissions, thereby improving enterprises' environmental and economic performance. Hart proposed the resources-base theory, according to which green strategies have three levels: pollution prevention, product management, and clean technology production [19]. These strategies have different sources of competitive advantage based on different key resources. Product management expands the scope of pollution prevention and control and includes the complete value chain or the "life cycle" of the company's product system. To ensure the reliability and effectiveness of an enterprise's green strategy and form its unique competitive advantage, enterprises can consider value chain reconstruction and innovation from four dimensions: product innovation, process innovation, positioning innovation, and model innovation.

(1) Product innovation refers to creating a new product or innovating the functionality of a new or old product. Product innovation based on market competition is an enterprise's market economy behaviors. Reconstructing the value chain according to consumer demand for green consumption is an active, integrated, and innovative solution to environmental problems. Environmental impact and harm are systematically considered during the entire life cycle of products, including design, manufacturing, use, and recycling, which is an innovative model that not only meets the needs of economic development, but also considers the environmental sustainability.

(2) Process innovation, an important aspect of management innovation as well as technical work, refers to the innovation of operating procedures, methods, and rule systems in technical or production activities. Enterprise process innovation includes the transformation and innovation of the management and production processes. Innovation at the management level relies on information technology to solve the problems of slow communication, high cost, and bulky waste. Innovation in the production process must address all aspects of the manufacturing process, effect breakthroughs around key processes, and systematically implement green process innovation through technological applications, such as process merging, process reengineering, green processing, and green materials. Therefore, the aspects that are conducive

to an increase in green value can be identified, and the value chain can be reconstructed and optimized accordingly.

(3) Positioning innovation refers to the innovation of products and services to enter the target market. Innovation units are generally not reflected directly in the components or functions of a product, but rather in the choice of target market segmentation. The driving force behind an enterprise's positioning innovation derives from two sources. First, consumers' knowledge and information acquisition ability drive the transformation of market dominant power. Second, new technologies, integration of new product marketization, market development, and modularization compel enterprises to innovate [20]. Positioning innovation is typically reflected in a centralized strategy. Enterprises focus their limited resources and capabilities on the green market to meet the huge consumer demand for green products and services, thus obtaining the potential for growth. For example, the transformation of automobile consumption from traditional fuel vehicles to new energy vehicles has prompted major automobile enterprises to transform product positioning. They began manufacturing new energy vehicles to fully tap the development potential of the automobile green consumption market. Positioning innovation is the redesign of the value chain—based on an accurate analysis of the target market and characteristics of the products or services—to respond to certain markets.

(4) Model innovation refers to changes in the way companies earn profits. In order to comply with the trend of green development, enterprises need to change from a model that focuses only on economic benefits to a green growth model that equally focuses on both environmental and economic benefits. When an enterprise conducts model innovation, clarifying the basic logic of enterprises by changing their methods of value creation is necessary. Moreover, enterprises need to identify activities that enhance customer value and competitiveness. These activities may include changes in the elements in multiple models and changes in the relationship or dynamic mechanism between these elements. Technological progress and changes in the market operating environment have contributed to the innovation of enterprises' models.

4.3 Value Chain Reconstruction and Innovation Based on Technology

New forms of industry and new business models spawned by new technologies seamlessly connect the entities in the value chain at a low cost. On the one hand, it significantly reduces transaction costs, and changes the mechanism of enterprise value creation and sharing. On the other hand, it also reduces the cost of matching supply and demand, and effectively improves the degree of matching between supply and demand. The emergence of new business models changes the business environment faced by enterprises, and the original model of enterprises no longer meets the needs of their rapid development. Driven by new technologies, new forms of industry and new business models, enterprises must reconstruct their growth models and value chains. The most typical feature of new forms of industry and new business models is that consumers have become members of value discovery, creation, and transmission, rather than being passive recipients. The importance of consumers' impacts on the value chain is highlighted. For example, emerging industrial Internet platforms and consumer Internet platforms aim to meet the needs of users or consumers on the platform. With the support of information technology, different entities are connected seamlessly, which can respond to user needs in time and have strong growth momentum. Haier's RDHY model is a case study of value chain reconstruction and innovation based on new technologies. The implementation of the RDHY model involved data-driven mass customization. With the help of the Internet of Things (IoT), next-generation information and communication technology provides platforms and conditions for creating user experiences to accurately capture needs. Through innovation, fragmented and independent requirements are combined into scenario requirements, and capabilities, knowledge, and resources on the supply-side are integrated on the platform to provide agile, low-cost system service solutions for scenario requirements. Ultimately, the demand changes from fragmented to large-scale to platform-based, and then to the evolution of the ecosystem, thereby enabling enterprises to respond to users' personalized needs in an agile, low-cost, and accurate manner, and to gain competitive advantages.

New forms of industry and new business models brought derived through new technologies also provide new ideas for the construction of enterprises' green growth models. New technologies have changed the way of information transmission between agents and business portfolios between enterprises. With the support of new technologies, enterprises can obtain information feedback of the entire process of the value chain in a timely manner. New forms of industry and new business models have prompted the reorganization or extension of the business functions of the relevant value chain activities inside and outside enterprises, thus highlighting the dominant position of consumers in the market, and connecting the production and consumption end into a closed-loop value chain. For example, recycling logistics and second-hand platform economy business models can realize consumers' green demand and resource recycling. Recycling logistics opens the reverse flow process of waste from consumers to the production, which can reduce the waste of resources and help enterprises reduce costs. In the second-hand platform economy, consumers with idle resources become the main participants. With the help of the platform, real-time communication between buyers and sellers is achieved, and idle resources are redistributed, thus improving the utilization of resources. Consider the second-hand platform of Idle Fish as an example. Idle Fish now supports the recycling of about 60 types of recyclables, including mobile phones, books, old clothes, and bags. By July 2020, Idle Fish had more than 200 million total users, more than 20 million daily active users, and more than 30 million online sellers. More than 1 billion products are released every year, and the annual transaction scale exceeds 200 billion yuan.[14] Additionally, the application of IoT helps enterprises implement

[14] http://industry.people.com.cn/n1/2020/0916/c413883-31863310.html.

environmental management technology throughout the whole process. For example, Everbright Environment's waste power generation project initiated the networking of the flue gas monitoring system with the local environmental protection department, and released emission parameters in real time on an LED display screen for public supervision.[15] These new forms of industry, new business models help enterprises solve the contradiction between cost and profit when implementing green development, explore more innovative green growth models based on new technologies, and implement value chain reconstruction and innovation.

4.4 Value Chain Reconstruction and Innovation Based on Activities

Enterprise activities refer to the team activities organized and planned by the enterprise and participated by employees when creating value, including design, procurement, production, distribution, marketing, etc. In enterprises' green development model, the scope of enterprise activities is extended to service customers, recycling, and remanufacturing, considering both economic and environmental performance.

A value chain is an organic system comprising a series of value-creating activities. The green value chain incorporates the green value of the product and the social value of the enterprise into the value category of the enterprises [21]. The green value chain is defined as a dynamic closed loop process, including product design, raw material procurement, product manufacturing, product marketing, logistics, product consumption, recycling, and regeneration, which considers both business and ethical goals. By incorporating green product value and green social value into the value category, this process aims to maximize green value. Therefore, in enterprises' green growth model, the key activities of value chain reconstruction and innovation include green design, procurement, manufacturing, logistics, and consumption. Some studies have highlighted that green design, green procurement, reverse logistics, and green manufacturing not only bring economic benefits to enterprises but also improve environmental performance [22].

4.4.1 Value Chain Activities in Enterprises' Green Growth Model

(1) Green Design

The business environment of enterprises has changed. The relationship between supply and demand has changed from demand exceeding supply to supply exceeding demand. The increase in consumers' disposable income has changed their demand

[15] https://www.solidwaste.com.cn/news/234061.html.

decision from mass consumption, emphasizing cost performance, to the pursuit of green development, personalization, and desirable user experience. Therefore, product design has undergone significant changes. The product design method of mass production with cost savings through economies of scale is no longer suitable for the personalized needs of consumers. The change in the customer consumption model requires enterprises to make a rapid and agile response to market demand to obtain a relatively high profit margin. This personalized demand depends on the rapid speed of technological innovation and renewal, and consumer environmental protection demand is one of the most direct driving forces of enterprise environmental protection innovation practices. Therefore, enterprises must innovate product design, such as design for modularization, to meet the specific needs of consumers in the enterprise green production model.

(2) Green Procurement and Production

Among value chain activities, procurement and production are the key units of value creation. In enterprises' green growth model, new forms of industry and new business models, the resource and environmental constraints change from relatively loose to tight. Hence, new factors must be considered in procurement and production decision-making, such as remanufacturing and product returns. As remanufacturing generates products with the same performance as new products, new supply sources are added. The key issues to be considered in green procurement include the purchase of a single product, multiple products, and batch procurement under uncertain conditions.

(3) Green Manufacturing

Consumer goods are widely popularized. Further, technological progress has shortened product life cycles, and the number of discarded products has increased sharply. Consumers are increasingly emphasizing green consumption, and public expectations of environmental quality are increasing. Environmental pressure leads to strict environmental regulations, which make environmental friendliness a key element in enterprise competition. As an important aspect of green manufacturing, remanufacturing is of great significance to realize the goal of resource recycling and environmental friendliness. Remanufacturing means that enterprises reprocess and reuse parts that re-enter the supply chain system through recycling activities to save resources, reduce production costs, meet consumer demand for green products, and reduce carbon emissions.

(4) Green Logistics

Product logistics has changed under new forms of industry and new business models. In enterprises' green growth model, a backflow in the logistics system realizes an effective closed loop of resources. Thus, designing a material flow network by taking reverse logistics into account is necessary. In terms of value creation, responding to consumer demand on time is an important part of value creation and transmission. At the same time, the synergy between "green" and "growth" should be taken into consideration to reduce carbon emissions in value activities. The market competition environment and the actual needs of enterprises require enterprises to design a multi-objective network model that considers influencing factors, such as the service level of storage capacity, forward logistics, reverse logistics, hazardous materials logistics, cooperative logistics, and location-inventory-routing integration optimization.

(5) Green Consumption

Owing to the increasing awareness of environmental protection, consumers are more inclined toward green and environment-friendly products. Consumers' consumption model has changed from the ignorance of environmental protection to the green model. Therefore, providing green and environment-friendly products through the implementation of green environmental protection innovation has become an industry norm. Second, next-generation information and communication technology changes previous single and offline channels into online and offline dual channels. Compared with traditional sales channels, online channels have the advantages of wide coverage, low operating costs, easy inventory control, and low-carbon environmental protection. The new channel model has changed consumers' cognition of products and the consumption model of products is no longer limited to offline stores. This model not only increases market demand but also effectively reduces carbon emissions, and meets the requirements of enterprises' green growth models for value chain reconstruction and innovation.

4.4.2 Methods for Value Chain Reconstruction and Innovation in Implementing Green Activities

The whole process of green value chain activities includes green design, green procurement or production, green manufacturing, green logistics, and green consumption. On this basis, enterprises conduct value chain reconstruction and innovation, as shown in Fig. 4.3.

(1) Modular Product Design

Modular design is a method that divides a series of modules based on the functional analysis of products. Different products can be formed through the selection and combination of modules to meet the different market needs. Modular products are independent, interchangeable, and standardized. Modular product design can not only better meet the personalized needs of customers, but also effectively reduce the production cost of new products and remanufactured products. In an enterprise's green growth model, consumers' personalized demand for products is becoming increasingly evident. For modular products, enterprises that are not equipped with knowledge and abilities can outsource value activities to other enterprises. Equipped with knowledge and ability, enterprises can choose the direction of value chain reconstruction, integration, and promotion by comparing the cost, profit, and performance risks, including the social responsibility risk of environmental management and supply disruption risk.

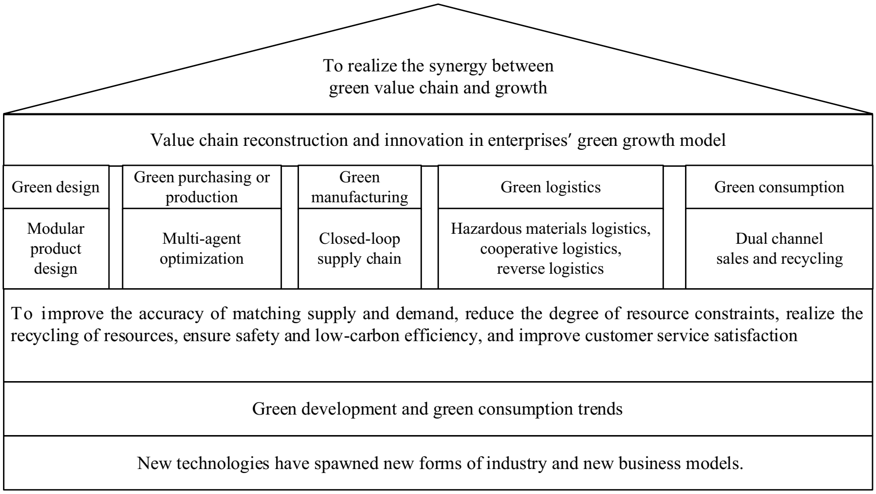

Fig. 4.3 Structure diagram of activity-based value chain reconstruction and innovation

(2) Multi-agent Optimization

As for green procurement and production, the procurement of products with different performance is subject to resource constraints. For example, when producing a single product, the enterprise is constrained by resources, including production capacity and inventory. When producing multiple products, enterprises often compete for the same kind of resources such as production capacity. Procurement and production under uncertain conditions are limited mainly by the uncertain quantity of recycled products. Multi-agent optimization is used to solve the optimal decision-making problem of multiple enterprises under different conditions. A polynomial algorithm is used for the remanufacturing procurement and production batch decision problem of a single product with special properties. For the remanufacturing procurement and production batch decision problem of a single product with an NP-hard (non-deterministic polynomial hard) problem, the approximate solution algorithm based on mathematical programming and operational research is used to solve it. The branch and bound and Lagrange methods are used for procurement and production decisions and optimization problems of multiple products. To address the procurement and production batch decision problem under uncertainty, the corresponding model is established using the principle of the newsboy model.

(3) Closed-Loop Supply Chain

As consumers have higher recognition of green environmental protection products, enterprises should focus on brand image while meeting consumer demand for products. Therefore, corporate social responsibility should be taken into consideration by enterprises during development. According to the environmental protection strategy of extended production responsibility, the enterprise is responsible for the entire product life cycle—especially collecting, recycling, and final disposal—to reduce the environmental impact of the total product while achieving the environmental goal. Producers are responsible for the main functions of waste recycling, including shouldering the responsibility of waste recycling, releasing information, and sharing the recycling cost of waste products. The development of a closed-loop supply chain has positively impact enterprises and society dealing with waste products. Enterprises realize the value of waste products through product recycling, remanufacturing, sales, and other activities. Therefore, research on closed-loop supply chains has introduced new development opportunities and challenges for enterprises to implement green growth models. Through research on closed-loop supply chains, we realize the development of green production and ecological civilization, and improve enterprise profits and environmental benefits. A closed-loop supply chain refers to a closed supply loop formed by the circulation of products from the place of production to the place of consumption, and the residual value returns from the place of consumption to the place of production. It includes two parts: a forward supply chain and reverse supply chain.

(4) Safe and Low-carbon Logistics
(a) Hazardous Materials Logistics

Enterprises' green growth model, new forms of industry and new business model propose the requirements of "safety" and "low-carbon" for logistics activities. As hazardous materials are flammable, explosive, corrosive, or radioactive, if an accident occurs during transportation, it might endanger the life and property of surrounding residents and cause heavy losses. When making decisions on the distribution of hazardous materials, enterprises should simultaneously consider risk and cost. Therefore, enterprises can realize the goal of adding value to the value chain by making decisions and optimizing the vehicle routing problem of hazardous materials distribution.

(b) Cooperative Logistics

As an emerging modern logistics model, cooperative logistics enables multiple independent transportation enterprises to form a cooperative alliance. On this basis, enterprises can operate together, share logistics resources and information, and jointly undertake customer needs to improve the vehicle utilization rate, reduce carbon emissions, improve logistics and transportation service levels, and improve operational efficiency. The cooperative logistics model can maximize the use of existing resources to achieve multiple distribution objectives simultaneously, help solve the problems of repeated waste of resources, urban traffic congestion, and environmental pollution, and promote the development of China's logistics industry in the direction of energy conservation, environmental protection, and sustainability.

(c) Reverse Logistics

In logistics activities, an interdependent relationship exists between the network design of the manufacturer, inventory point or distribution center, customer location, goods distribution, and vehicle routing arrangement of transporting goods. To realize global optimization of the value chain, logistics activities should be comprehensively optimized and managed according to this relationship. Reverse logistics are an important means for enterprises to implement green growth models and value chain reconstruction. Through research on the integration and optimization of inventory, location, and path of forward and reverse logistics, the reconstruction and innovation of enterprise value chains can be realized.

(d) Dual Channel Sales and Recycling

In enterprises' green growth model, the development of Internet has brought significant changes to the supply chain. Enterprises can not only realize the dual channel sales model both online and offline, but also satisfy consumers' market demand and reduce carbon emissions. In the recycling of waste products, considering the increasingly short product life cycle, the dual-channel recycling model can provide convenient recycling services to consumers, meet consumers' requirements for low-carbon and environmental protection, improve enterprise benefits, and realize an environment-friendly society.

4.5 Value Chain Reconstruction and Innovation Based on Members

4.5.1 Enterprises' Green Growth Model Proposes New Requirements for the Selection of Members in the Value Chain

First, suppliers should be able to provide green products and services. Ali Research Institute found that 65 million online users met the characteristics of green consumers, accounting for 16% of active Taobao users, an increase of 14 times in the past four years. The arrival of the green era has led to changes in consumer demand [23]. Consumers are increasingly demanding green products. Whether enterprises can provide environment-friendly products for themselves and customers through green environmental protection innovation has become an important means for enterprises to implement differentiation strategies, realize new profit sources, and obtain a competitive advantage. In the face of fierce market competition, enterprises outsource some businesses while focusing on core competitiveness. Enterprises increasingly require suppliers to provide high-quality and innovative products. Especially in the enterprises' green growth model, suppliers should have the ability to provide green products and services.

Second, enterprises should improve accurate matching between supply and demand. The new growth model, businesses, and models have a different impact on variations in demand information. For example, for online trading, enterprises can test customers' response to discounts more easily than for offline trading, which has a new impact on demand information variation [24]. Effective management of demand information variation can improve the accurate matching between supply and demand, and reduce ineffective production capacity, thus laying a foundation for realizing “green” and “growth”. Additionally, mass customization and manufacturing services are rapidly developing, and demand is the main characteristic. The application of next generation information and communication technology has coordinated the contradiction between “high customization cost” and “personalized demand”. Depending on the next generation information and communication technology, customer needs and behaviors can be integrated into the enterprise value chain actively or passively to improve the effective matching of supply and demand.

Third, consumers should change from passive receivers of products to participants in value discovery, creation, and transmission. Owing to the application of next generation information and communication technology, the cost of information exchange between enterprises and consumers has been greatly reduced, and enterprises and consumers can be connected seamlessly in real time. Customer needs and behaviors can be actively or passively integrated into the enterprise value chain, and consumers’ roles are transformed. Due to these changes in value creation mechanism, enterprises can realize the synergy of “green” and “growth”.

Finally, the government should implement a policy innovation mechanism to promote enterprises’ green transformation. The government plays an important role in promoting green transformation of the enterprise growth model. The implementation of the green growth mode by enterprises needs the encouragement and guidance of the government to a certain extent, and the government further needs to formulate and improve relevant systems. Therefore, the government is the key to promoting enterprises to implement the green transformation of growth models under the guidance of green development and realize the goal of coordinated development of the economy, society, and environment. To ensure that all entities—upstream and downstream of the supply chain—are motivated to implement environment-friendly behaviors in the green growth model, ensuring that all members are motivated to implement environment-friendly behaviors in terms of economic interests through effective decision making and the coordination of all activities. The government can encourage the green production activities of enterprises through subsidies or punishment measures. For specific polluting industries, the government should have innovative and targeted environmental protection policies, including limiting the carbon emissions of enterprises by charging carbon emission taxes, setting the recovery rate of waste products, forcing enterprises to recycle, and guiding enterprises to assume corporate social responsibility through green investment initiatives to establish and maintain a positive corporate image.

4.5.2 Selection of Value Chain Members

(1) Green Suppliers Integration Capability

Supplier integration capability is the ability of manufacturing enterprises to integrate suppliers’ resources to reconstruct the supply chain to adapt to environmental changes [25], and realize innovation at a speed superior to that of competitors. With changes in the international competitive environment and the deepening of the concept of green consumption, enterprises should constantly seek innovation and strengthen their core competitiveness by implementing the green growth model. When choosing upstream cooperative members of the supply chain, enterprises require suppliers to improve their ability to provide green products and services. Interactive cooperation between suppliers can meet these requirements and create new market values.

(2) Corporate Social Responsibility

In the process of development, enterprises should fully consider the triple bottom line of the economy, environment, and society, and be responsible for a series of objects, such as employees, consumers, suppliers, communities, and the environment. In enterprises' green growth model, the implementation of corporate social responsibility not only creates value for society but also for the enterprise itself. Some studies have highlighted that corporate social responsibility positively affects green organizational identity, green adaptability, and the success of new green products, thus promoting the sustainable development of enterprises [26].

(3) Consumers' Green Consumption Behavior

With the concept of environmental protection gradually rooted in the minds of consumers, an increasing number of consumers favor green products with the characteristics of health, energy-saving, and pollution-free. There is a consensus among global consumers regarding low-carbon environmental protection. Green consumption concepts such as "idle economy", "sharing economy" and "recycling" are becoming increasingly popular. Low-carbon environmental protection has become a lifestyle favored by young people, who begin to accept and admire environmental protection and low-carbon consumption behavior, including trading idle goods. According to the Global Green Purchase Report 2021, which surveyed more than 15,000 consumers in Europe, North America, and South America, consumer demand for green packaging continues to grow. Moreover, 67% of consumers believed that they had a strong sense of environmental protection, and 64% prioritized packaging containing recyclable ingredients in their purchase decisions.[16] The 2022 Global Consumer Trends Report released by Euromonitor International shows that in 2021, one-third of global consumers actively reduced emissions and one-quarter used carbon neutralization to offset emissions.[17] The 2021 China Sustainable Consumption Report shows that low-carbon consumption is becoming a daily behavior among an increasing number of people.[18] A growing number of consumers are hoping that the low-carbon consumption market will continue to grow, providing them with more low-carbon products and services to choose from. Consumers' thinking is constantly changing. Specifically, they hope that used products can be recycled again, and their preference for second-hand goods has increased.

[16] https://www.sohu.com/a/470655555_679193.

[17] https://www.163.com/dy/article/GVKCKE9U0530UH99.html.

[18] https://c.m.163.com/news/a/GS16E8B10538BPYH.html.

(4) The Government's Reward and Punishment Mechanism and Supervision on the Green Development of Enterprises

The implementation of green management by enterprises has positive externalities, and public goods in the ecological environment are exclusive. The government should fulfill its responsibilities based on these characteristics. Coercive government environmental laws, regulations, and competitive pressure have a significant positive impact on the transformation of green environmental protection. By identifying the obstacles existing in the green transformation of enterprises' growth models, the government formulates policies and measures from the perspectives of finance, taxation, and green environmental protection under the guidance of innovation. For the implementation of the new policy and regulation mechanism, systematic simulation of the macro environment, including economy, policy, science and technology, and law; and the micro environment, including industrial spatial layout, industrial technical standards, marker entry system, new forms of industry and new business models; can be conducted to evaluate the impact of enterprises implementing the green growth model. The results of the stimulation can help the government assess and adjust policy and regulation mechanisms to ensure their effectiveness and pertinence.

4.5.3 Evaluation Method of Value Chain Member Selection

(1) Index Selection-Combination of Quantitative and Qualitative

Combined with normative research and empirical research, based on the value chain theory and method, we extract the criteria for member selection in value chain reconstruction and innovation, such as the degree of importance of "green". Value chain reconstruction and innovation mechanisms based on member selection are analyzed and identified from the perspective of the entities of the value chain, such as suppliers, enterprises, consumers, and the government; influencing variables such as green product supply capacity, product quality, and environmental protection concept; influencing methods such as consumers' preference for green products; and influencing results, such as commercial value and environmental value.

First, based on empirical research, theories such as the resource-based theory and the dynamic capability theory are comprehensively applied. Using the member selection criteria in enterprises' green growth model, the key variables affecting value reconstruction and innovation are extracted.

Second, through interviews, small sample enterprise research, and case in-depth analysis, the key factors that influence value chain reconstruction are analyzed, and the corresponding framework model is built. In the research process, the most important factors are assessed first, followed by the other factors and the more complex situations. On this basis, relevant theories are integrated to discuss the impact of potential intermediate and moderate variables on value chain reconstruction and innovation.

Third, based on the theoretical model of the influence mechanism, corresponding questionnaires are developed. A large-scale sample survey is administered, and data are collected and analyzed, further, the relevant theoretical assumptions are tested. Thereafter, the mechanism, influence path, and degree of member selection on value chain reconstruction and innovation in enterprises' green growth model are obtained with corresponding management inspiration.

(2) Weight Division: Multiple Approaches to Weigh Importance

The selection of the indicators is a complex process. As multiple participants are involved, it is necessary to consider whether the selection of indicators is based on expert opinions, other research, or a specific conceptual framework of performance measurement. Additionally, there is uncertainty in the modeling process because of the subjectivity of multiple decision makers, incompleteness of historical data, and difficulty of evaluating the intangible aspects of members. Therefore, before modelling the selected evaluation indicators, the weight division should be measured using a variety of methods and evaluated from multiple aspects to improve the robustness of the results. The methods of weight division include expert scoring method, sequence synthesis method, analytic hierarchy process (AHP), and principal component analysis.

(3) Targeted Evaluation-Evaluation Focus of Value Chain Members in Enterprises' Green Growth Model

Combined with the enterprise green growth model, different emphases should be placed on the evaluation of value chain members. The following summarizes several targeted evaluation emphases for each member.

For suppliers, green procurement, green design, environmental management systems, quality, and green capability are important green evaluation criteria [27].

When evaluating enterprises, green practices and corporate social responsibility, including investment in green product design and R&D, consumers and environmental responsibility, green management, and supply chain management should be considered [28].

In terms of consumers, preference for green products, environmental awareness, and attention to green behavior are key factors [29].

The regulation and supervision of green enterprises, green subsidies, and carbon emission quotas are of great importance for the government [30].

Finally, data envelopment analysis, life cycle assessment, and maturity models were used to evaluate the impact of members on the performance of the green supply chain. The members' evaluation indicators in value chain reconstruction and innovation is shown in Table 4.1.

Table 4.1 Members' evaluation indicators in value chain reconstruction and innovation

Value chain member	First-level evaluation index	Secondary evaluation index
Supplier	Environmental management system	Enterprise commitment and support for environmental management
		Green operation practice
		Planning and organizational practice
	Green design	Design products that reduce material / energy consumption
		Design products that are easy to reuse and recycle
		Design products that avoid or reduce the use of hazardous substances
	Green ability	Green warehousing and transportation
		Green manufacturing capability
		Green recycling facilities
	Green procurement	Select suppliers according to environmental standards
		Purchase of environmental protection raw materials
	Quality	Qualified rate of quality inspection
		Product stability
		Quality management capability
Enterprise	Green practice	Proportion of green production technology
		Energy efficiency
		Waste disposal rate
		Energy consumption per unit output value
	Corporate social responsibility	Proportion of green technology R&D expenses
		Proportion of environmental protection expenses
		Proportion of green education investment
		Green recognition of consumers
	Green management and supply chain management	Participate in the design process of upstream and downstream members of the supply chain
		Selection and management level of green suppliers

(continued)

Table 4.1 (continued)

Value chain member	First-level evaluation index	Secondary evaluation index
		Green strategy management capability
Consumer	Green preference	Green cognition level
		Environmental attitude
	Environmental awareness	Perception of environmental problems
		Environmental responsibility
		Environmental values
	Green behavior practice	Green consumption behavior
Government	Ecological construction	Pollution control
		Ecological protection
	Green policy	Carbon emission quota
		Green subsidy
		Green regulation
		Supervision strength

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Chapter 5
Network Design in Enterprises' Green Growth Model

Meng Zhang, Qunli Yuchi, Nengmin Wang, and Qidong He

Abstract Network design refers to the process of locating and arranging the capacities of suppliers, manufacturing plants, distribution centers, retailers, warehouses, and other related facilities involved in the value-added activities of a value chain. Network design acts as decision-making content for enterprises to implement the green growth model. It belongs to the strategic level of value chain reconstruction and directly determines the economic and environmental performance of enterprises. Given the new requirements of the enterprises' green growth model for network design, efficient and reasonable network design decision-making is a key factor to help enterprises realize a green transformation. This chapter starts by introducing the basic framework and methods of network design. Then, focusing on network design considering carbon emissions, an optimization model and solution algorithm are developed, and the influence of carbon emissions on the network design is analyzed. Finally, shifting the focus to the network design of waste product collection channels, a closed-loop supply chain network model of manufacturer-remanufacturing and retailer-recycling is developed. This is used to analyze the influencing factors and mechanisms of network efficiency under different waste product collection channels and reuse technologies.

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5.1 Basic Framework and Methods of Network Design

5.1.1 Relationship Between Network Design and Enterprises' Green Growth Model

(1) Network Design

The value chain network is a complex network composed of multiple entities and the relationships between them [1], as shown in Fig. 5.1. The design and optimization of the value chain network is one of the key decision-making contents for enterprises to implement the green growth model, which belongs to the strategic level [2]. The value chain network includes entities such as suppliers, manufacturers, retailers, and customers, involves value-added activities such as raw material supply, production, finished product storage, transportation, and after-sales service, and considers material, cash, and information flows between entities. Network design and optimization affects the strategic layout, basic investment, production and operation planning, environmental protection, and other aspects, and directly determines the enterprise's economic and environmental performance. A network design scheme is bound to be very difficult to implement or costly to change after capital has been invested and the facilities completed. That is why carrying out an efficient and reasonable network design is an important decision-making problem.

Network design and optimization usually includes the following decision-making aspects:

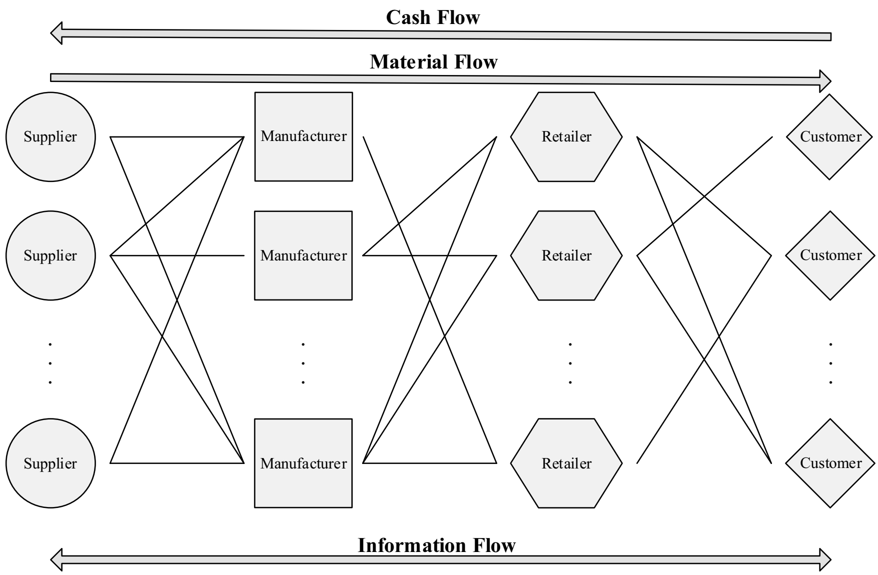

Fig. 5.1 Schematic diagram of value chain network

- Determining roles of the various facilities involved in value-added activities.
- Determining the appropriate number of facilities.
- Determining the location of each facility.
- Determining the services provided by each facility.
- Determining distribution, transportation, inventory, and so on.

The common goal of network design is to find a balance between maintaining a certain service level and minimizing the total of all costs including production, purchase, inventory, facilities, and transportation.

(2) Requirements of Enterprises' Green Growth Model for Network Design

As a result of increasingly prominent environmental problems, there is an inevitable tendency of enterprises implementing the green growth model. Unlike traditional network design, enterprises' green growth model simultaneously brings economic and social benefits into the decision-making category. In addition, the decision-making objectives are more complex and the content more diverse. Network design of the value chain based on the enterprises' green growth model has two key perspectives.

First, it takes account of social and environmental benefits in addition to the traditional value chain network design. The traditional value chain network design primarily considers the minimization of operational costs under the condition of meeting a certain service level. However, the enterprises' green growth model requires that network design decision-making pays attention to not only economic factors, but also the impact on the environment and society. Thus, value chain network design from this perspective considers optimization objectives other than that of cost-minimization. For example, in the case of the green network design for multi-cycle, multi-type products, and limited capacity, Rad et al. developed an optimization model that minimized carbon emissions and total cost simultaneously, with management insights being provided through numerical analysis [3].

Second, it is necessary to design and optimize the value chain network in combination with new forms of industry or business models. For example, network design and optimization of a closed-loop supply chain is promoted by an increase in resource pressure, shortening of the product life cycle, and improvement of consumers' awareness of environmental protection. Contrary to traditional network design and optimization, activities such as recycling and remanufacturing of waste products and accompanying activities, including collection, storage, and transportation, must be considered. Thus, value chain network design from this perspective mainly considers new network design and optimization problems and mathematical models. For example, Prakash et al. developed an optimization model based on mixed-integer programming for a closed-loop supply chain network design problem with the consideration of supply, transportation, and demand uncertainties, and provided a case analysis based on an e-commerce company in India [4].

5.1.2 Basic Framework of Network Design

Based on the process of network design and optimization, the value chain network should first be transformed into an abstract network. The entities in the value chain network, or facilities involved in value-added activities should be abstracted as vertices, while the relationships between entities, namely material, cash, or information flows, should be abstracted as directed arcs. This forms an abstract value chain network $G(V, A)$, where the set of vertices V represents the entities or facilities in the value chain network, and the set of arcs A represents the flows. The general objective of network design is to minimize the total cost. Some basic frameworks of network design are introduced below.

(1) Transport Model

The transport model is a classic network design and optimization decision model, as shown in Fig. 5.2. Let the network have n suppliers and m customers. The maximum supply of each supplier is K_i, while the demand of each customer is D_j. Additionally, the unit transportation cost from each supplier to each customer is c_{ij}. It is necessary to determine which customers each supplier provides materials to while ensuring that the amount of materials obtained by each customer can meet their demands. The objective is, thus, to minimize the total transportation cost. The decision variable x_{ij} represents the quantity of materials provided by each supplier to each customer. The mathematical model is developed as follows.

$$\min \sum_{i=1}^{n} \sum_{j=1}^{m} c_{ij} x_{ij} \tag{5.1}$$

s.t.

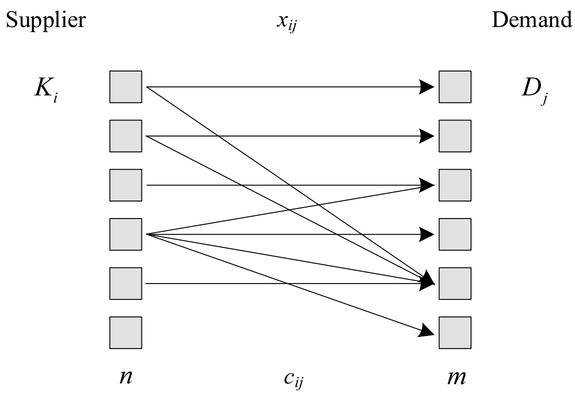

Fig. 5.2 Schematic diagram of transport model

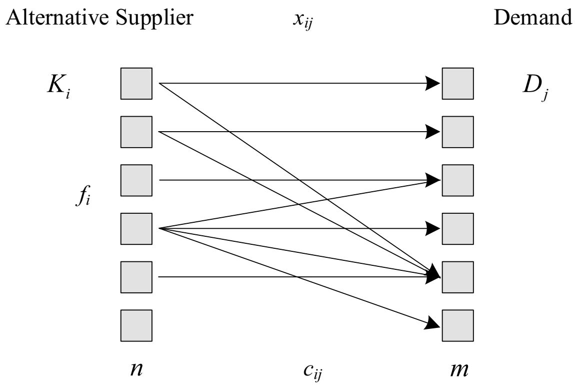

Fig. 5.3 Schematic diagram of facility location model

$$\sum_{i=1}^{n} x_{ij} = D_j \;\; j \in \{1, 2, \ldots, m\} \tag{5.2}$$

$$\sum_{j=1}^{m} x_{ij} \leq K_i \;\; i \in \{1, 2, \ldots, n\} \tag{5.3}$$

$$x_{ij} \geq 0 \;\; i \in \{1, 2, \ldots, n\};\; j \in \{1, 2, \ldots, m\} \tag{5.4}$$

The objective function (5.1) minimizes the total transportation cost given the following constraints. Constraint (5.2) ensures that the demands of each customer are satisfied. Constraint (5.3) means that the quantity of materials provided by each supplier does not exceed the maximum supply. Constraint (5.4) outlines the range of values of the decision variables.

(2) Facility Location Model

The facility location model considers the selection of alternative suppliers based on the transport model, as shown in Fig. 5.3. Again, n alternative suppliers and m customers are considered. The maximum supply and fixed cost of each alternative supplier are K_i and f_i, respectively, while the demand of each customer is D_j. Additionally, the unit transportation cost from each alternative supplier to each customer is c_{ij}. It is necessary to determine which alternative suppliers are selected and which customers each supplier then provides materials to, while ensuring that the amount of materials obtained by each customer can meet their demands. Thus, the objective is to minimize the total fixed and transportation costs. As before, the decision variable x_{ij} represents the quantity of materials provided by each supplier for each customer. The binary decision variable y_i, equaling 1 or 0, represents if the alternative supplier is selected or not. The mathematical model is developed as follows.

$$\min\left(\sum_{i=1}^{n} f_i y_i + \sum_{i=1}^{n}\sum_{j=1}^{m} c_{ij} x_{ij}\right) \tag{5.5}$$

s.t.

Constraint (5.2)

$$\sum_{j=1}^{m} x_{ij} \leq K_i y_i \ i \in \{1, 2, \ldots, n\} \tag{5.6}$$

$$x_{ij} \geq 0;\ y_i \in \{0, 1\} \ i \in \{1, 2, \ldots, n\};\ j \in \{1, 2, \ldots, m\} \tag{5.7}$$

The objective function (5.5) minimizes the total fixed and transportation costs subject to the following constraints. Constraint (5.6) ensures that only the selected alternative suppliers can provide materials, and the amount of materials provided by each one does not exceed its maximum supply. Constraint (5.7) outlines the range of values of the decision variables.

(3) Multi-Level Facility Location Model

The multi-level facility location model is an extension of the facility location model, as it further considers the multi-level network. It is closer to reality and the most commonly used basic model in current research. The following description illustrates a relatively simple multi-level value chain network, as shown in Fig. 5.4.

The network comprises l raw material suppliers, n manufacturing plants, t warehouses, and m customers. The supplies of each raw material supplier, outputs of each manufacturing plant, storage capacities of each warehouse, and demands of each customer are S_h, K_i, W_e, and D_j, respectively. The fixed construction costs of the manufacturing plants and warehouses are f_i and f_e, respectively. The unit transportation costs from each supplier to each manufacturing plant, each manufacturing plant to each warehouse, and each warehouse to each customer are denoted by c_{hi}, c_{ie}, and c_{ej}, respectively. It is required to determine the location scheme of manufacturing plants and warehouses, as well as the entire transportation scheme, so that the amount of materials obtained by each customer can meet their demands. Thus, the

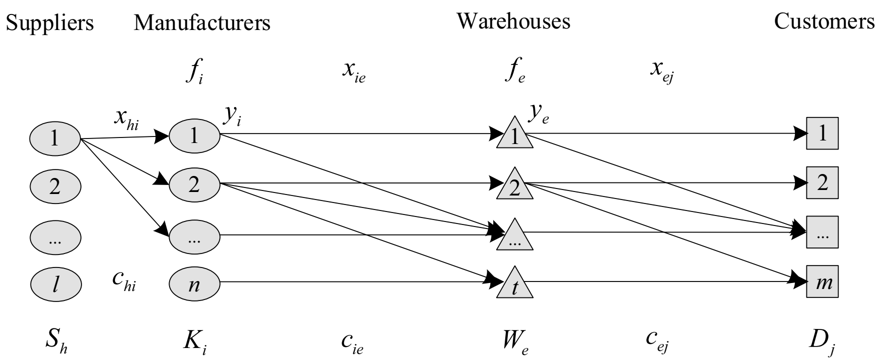

Fig. 5.4 Schematic diagram of multi-level facility location model

objective is to minimize the total fixed and transportation costs. The decision variables x_{hi}, x_{ie}, and x_{ej} represent the transportation volumes at each level of the value chain network, while the binary decision variables y_i and y_e represent if the respective manufacturing plants and warehouses are selected or not. The mathematical model is developed as follows.

$$\min\left(\sum_{i=1}^{n} f_i y_i + \sum_{e=1}^{t} f_e y_e + \sum_{h=1}^{l}\sum_{i=1}^{n} c_{hi}x_{hi} + \sum_{i=1}^{n}\sum_{e=1}^{t} c_{ie}x_{ie} + \sum_{e=1}^{t}\sum_{j=1}^{m} c_{ej}x_{ej}\right) \tag{5.8}$$

s.t.

$$\sum_{i=1}^{n} x_{hi} = S_h \ \ h \in \{1, 2, \ldots, l\} \tag{5.9}$$

$$\sum_{h=1}^{l} x_{hi} - \sum_{e=1}^{t} x_{ie} \geq 0 \ \ i \in \{1, 2, \ldots, n\} \tag{5.10}$$

$$\sum_{e=1}^{t} x_{ie} \leq K_i y_i \ \ i \in \{1, 2, \ldots, n\} \tag{5.11}$$

$$\sum_{i=1}^{n} x_{ie} - \sum_{j=1}^{m} x_{ej} \geq 0 \ \ e \in \{1, 2, \ldots, t\} \tag{5.12}$$

$$\sum_{j=1}^{m} x_{ej} \leq W_e y_e \ \ e \in \{1, 2, \ldots, t\} \tag{5.13}$$

$$\sum_{e=1}^{t} x_{ej} = D_j \ \ j \in \{1, 2, \ldots, m\} \tag{5.14}$$

$$\begin{aligned} & x_{hi}, x_{ie}, x_{ej} \geq 0;\ y_i, y_e \in \{0, 1\} \\ & h \in \{1, 2, \ldots, l\};\ i \in \{1, 2, \ldots, n\};\ e \in \{1, 2, \ldots, t\};\ j \in \{1, 2, \ldots, m\} \end{aligned} \tag{5.15}$$

The objective function (5.8) minimizes the total fixed and transportation costs subject to the following constraints. Constraint (5.9) indicates the supply constraint of the suppliers. Constraints (5.10) and (5.11) indicate the output constraints of the manufacturing plants. Constraints (5.12) and (5.13) indicate the storage constraints of the warehouses. Constraint (5.14) ensures that the demands of each customer are met, and constraint (5.15) outlines the range of values of the decision variables.

The three optimization models of network design described above constitute the basic framework for network design with each model having its own scope of application. The transport model is applicable to situations where the fixed cost does not need to be considered, whereas the facility location model is applicable to situations where the fixed and transportation costs need to be considered simultaneously. The multi-level facility location model considers a value chain network with a multi-level structure. With the deepening of research and closer correlation with real situations, the multi-level facility location model has become the most commonly used basic network design model in research as it matches the actual value chain network structure and incorporates a variety of considerations. However, these network design models do not consider the requirements of enterprises' green growth model. According to the analysis in Sect. 5.1.1, the value chain network design based on the enterprises' green growth model adds the decision-making content of environmental performance to the above models, such as the objective of reducing carbon emissions. New network design models, including recycling, remanufacturing, and other activities can also be considered, such as the network design for a closed-loop supply chain. Sections 5.2 and 5.3 of this chapter will introduce relevant research and analyze them in detail.

5.1.3 Solution Methods of Network Design

While a value chain network is a relatively complex network, network design, as a decision-making problem, is also complex. Depending on the characteristics of specific problems and the difficulty and accuracy requirements of the solutions, network design problems can usually be solved using three types of methods: exact algorithm, heuristic algorithm, and system simulation.

(1) Exact Algorithm

Exact algorithm is an algorithm that finds the optimal solution of a problem using a linear approach. The optimal solution can be determined through enumeration and iteration. The network design scheme generated by an exact algorithm must be the optimal scheme. However, due to the non-deterministic polynomial time complexity of NP-hard problems. Although an exact algorithm can obtain the optimal solution of a problem in theory, the computation time required is astronomical. Therefore, exact algorithms are only effective when dealing with small-scale NP-hard problems. Once the scale of an NP-hard problem is relatively large, the exact algorithm is often powerless because it cannot solve the problem in a reasonable time. Typical exact algorithms include the tabular method, branch-and-bound approach, cutting-plane approach, dynamic programming, etc. Usually, once the mathematical model is developed, the optimal solution can be generated using relevant software such as Lingo and CPLEX.

Given these characteristics of exact algorithms, the network design problems most suitable to be solved by them should be P-problems or small-scale NP-hard problems. The transport model is a type of network design the exact algorithm is well suited to solve because it is a linear programming model that can be solved in polynomial time. The most commonly used method is the tabular method, which obtains the optimal solution based on a supply and demand balance table. However, for the facility location and multi-level facility location models, the exact algorithm can only solve small-scale problems.

(2) Heuristic Algorithm

The exact algorithm requires infinite time to find the optimal solution for a large-scale NP-hard problem. The heuristic algorithm can solve this defect and find a better solution in a limited time; however, this solution may not be optimal. The key advantage of the heuristic algorithm is that it aims to obtain a solution with acceptable quality in a reasonable time range to provide a satisfactory scheme for the decision maker. Therefore, it is suitable for solving large-scale NP-hard problems and dealing with the practical applications of network design. The basic ideas of many heuristic algorithms originate from biological, physical, social, and natural phenomena. Commonly used heuristic algorithms include genetic, simulated annealing, ant colony algorithms, etc.

Due to the above advantages, heuristic algorithms have become the most commonly used solution method in network design and optimization. For example, Farshbaf-Geranmayeh et al. studied a closed-loop supply chain network design problem, proposed a quantity estimation function based on return product prices, and developed a network design model considering the pricing of return products, material flow, inventory, and manufacturing/remanufacturing decisions. This was then, solved using a simulated annealing algorithm [5].

(3) System Simulation

Both exact and heuristic algorithms are aimed at static systems that do not consider changes in parameters with time. By contrast, tools based on simulation models can analyze dynamic or extremely complex systems. System simulations are methods based on system theory, control theory, mathematical statistics, information technology, and computer technology. Using computers, or other special physical equipment as tools, system simulation is used to experiment with real or hypothetical systems. The experimental results are analyzed and studied with the help of expert experience, statistical data, and system data. The system simulation method can simulate the operation and then apply the results of the experiments to real systems. Common system simulation methods include the Monte Carlo and system dynamics simulations.

Scholars often use system simulations to study network design problems. For example, Ozkan et al. conducted an in-depth analysis of the reliabilities of logistics networks through a Monte Carlo simulation. They comprehensively generated several cases of different sizes for a variety of scenarios, tested them, and drew conclusions [6]. However, system simulations can only deal with network design under preset scenarios. If we consider changing the structure, e.g., several customers want to change other warehouses to provide services, we will need to run the simulation model again. A detailed simulation model may require a very long time to execute the system to a certain level of accuracy, which means that the simulations usually provide very few schemes.

The applicable scenarios, strengths, and weaknesses of exact algorithm, heuristic algorithm, and system simulation are summarized in Table 5.1.

Table 5.1 Comparison of solution methods of network design

	Applicable Scenarios	Strengths	Weaknesses
Exact Algorithm	P-problems or small-scale NP-hard problems	Simple and easy to implement	An unreasonable time to solve large-scale NP-hard problems
Heuristic Algorithm	Large-scale NP-hard problems	Relatively high solution efficiency	Difficult to obtain the optimal solution and easy to fall into local optimum
System Simulation	Preset scenarios or dynamic systems	Effective to deal with complex problems	Dealing with the problems under the preset scenarios

5.2 Network Design Considering Carbon Emissions

5.2.1 Impact of Carbon Emissions on the Value Chain of Enterprises

Governments and consumers regard carbon emissions as one of the most important environmental impact indicators [7]. With the growing global focus on carbon reduction, governments and consumers are forcing enterprises to reduce their carbon emissions. Many countries have formulated policies, laws, and regulations to restrict carbon emissions [8]. For example, China has established a leading group headed by the Premier of the State Council to address climate change, energy conservation, and emission reduction. The group is responsible for coordinating and formulating policies related to climate change [9]. An increasing number of enterprises are beginning to monitor carbon emissions during their business activities [10]. If manufacturers want to live up to their social responsibilities and maintain a competitive position, it is imperative to focus on carbon emissions [11]. Procter & Gamble has committed to reducing greenhouse gas emissions by 50% from its value chain by 2030. That amounts to a reduction of approximately 30 million metric tons of carbon emissions by the enterprise.[1]

While reducing carbon emissions is necessary to improve the way enterprises consume energy, this results in increased costs in the short term. However, in the long run, reducing carbon emissions is the essence of the industrial structural transformation of enterprises; it is the process of enterprises moving from low-value and high-consumption industries to high-value and low-consumption industries. Therefore, reducing carbon emissions plays an important role in promoting the green growth of enterprises in the long run [12], and hence, constitutes an important goal of the green growth model of enterprises. As carbon emission reduction is a long-term process, achieving this reduction also involves designing a carbon emission

[1] https://www.environmentalleader.com/2021/06/pg-opens-new-innovation-center-for-sustainability-supply-chains/

reduction value chain for enterprises that can stimulate efficient emission reduction without hindering corporate benefits. This has become a key issue that enterprises are generally concerned about today.

5.2.2 Model of Network Design Considering Carbon Emissions

Product recycling is an effective method of reducing carbon emissions. The reverse logistics network structure of recycling activities affects the related transportation activities, which is the main source of CO_2 emissions [13]. Through the layout of facilities in a reverse logistics network, reducing the driving distance of vehicles plays an important role in reducing transportation related carbon emissions [14]. Therefore, it is important for enterprises to design their reverse logistics networks scientifically and thus reduce carbon emissions. When designing reverse logistics networks, enterprises must consider the carbon emissions generated by transportation. This will promote the reduction of carbon emissions while achieving sustainable development.

The Emissions Trading Scheme (ETS) is currently one of the most effective market mechanisms for reducing carbon emissions [15]. ETS has been widely adopted by the United Nations, the European Union, and many other governments. It is based on the "cap and trade" principle, that is, the government imposes a cap on CO_2 emissions, while each enterprise has a CO_2 emission credit. Enterprises must purchase the same number of carbon credits to meet their social obligations. The main goal of recycling is to maximize profits; therefore, it is typical for the cheapest recycling technology to be used in the recycling process. The ETS forces recycling enterprises to change the way their reverse supply chains operate. They must re-optimize their internal and external processes, design logistics networks, use emission-reducing transport modes to reduce CO_2 emissions, and invest in new carbon-reduction technologies. Can ETS contribute to reducing CO_2 emissions? How does ETS affect an enterprise's reverse logistics network design? These issues will be discussed in this section.

In summary, this section considers an enterprise that adopts the ETS mechanism; its reverse logistics network is shown in Fig. 5.5. An enterprise's reverse logistics network consists of centralized return centers (CRCs), remanufacturing facilities (RFs), initial collection points (ICPs), secondary markets, customer areas, and third-party recyclers. Customers' recycled products are usually returned to the nearest ICP. Returned products are stored at the ICP and then sent to the CRC. The recycled products are inspected at the ICP to collect the used products that can be remanufactured. After being consolidated and sorted at the CRC, the returned products are shipped to RFs for remanufacturing. Finally, products that cannot be remanufactured or are defective during dismantling are sold to third-party recyclers. Remanufactured products are 50–70% cheaper than new products in the secondary market. These damaged products can be consumed through direct reuse or used as a substitute

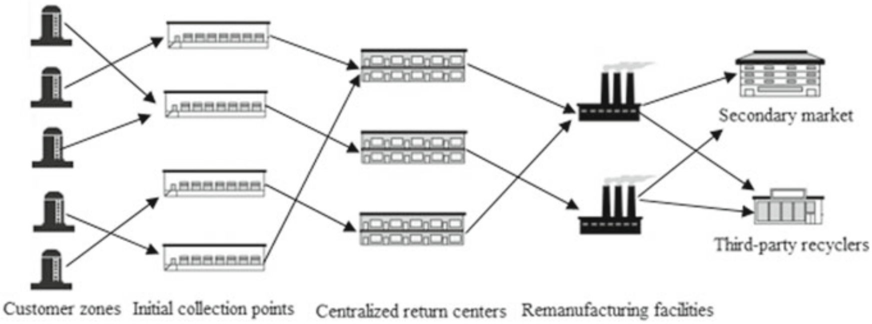

Fig. 5.5 Enterprises' reverse logistics network adopted ETS mechanism

for raw materials within the industry. Therefore, there is no product disposal. The models constructed in this section are designed to minimize total CO_2 emissions and maximize the profits of reverse logistics networks. This reverse logistics network determines the collection period for the ICPs, optimal quantities and locations of the CRCs and ICPs, and distribution of recycling customers for the reverse logistics facility. To reduce CO_2 emissions and transportation costs during transportation, single distribution between reverse logistics facilities is allowed.

(1) Assumptions of Remanufacturing Reverse Logistics Networks Considering Carbon Emission

Before building the model, we state the following assumptions:

- Due to the limited number of returned products that can be received from a single customer and the distance from the RF, the RF does not accept returned products sent directly by customers. Customers can only send the repaired product to the nearest ICPs, who will then send it to the CRC.
- The ICP will send the received reworked products to the CRC on the same day, so that the ICP has sufficient capacity to accommodate the returned reworked products in the customer area.
- The cost of transportation between the customer and ICP is borne by the customer.
- During a given period, the daily number of products returned by the customer remains unchanged.
- The returned product has a negligible waiting time for shipping between the ICP and the CRC.

(2) Constituent Sets of the Remanufacturing Reverse Logistics Networks

$I = \{1,\ldots, i\}$: customer point set
$K = \{1,\ldots,k\}$: set of potential locations for CRCs
$J = \{1,\ldots, j\}$: set of potential locations for ICPs
$R = \{1,\ldots,r\}$: set of potential locations for RFs

(3) Parameters of the Remanufacturing Reverse Logistics Network

w: Number of working days per year
r_i: The number of products returned per day in the customer area *i*, $\forall i \in I$.
f_j: Annual rental cost per ICP
v_k: The variable cost of building a CRC
f_k: Fixed cost of establishing a CRC
c: Collection costs for returned products
${f_r}^h$: Fixed cost of remanufacturing product using technology *h* in RFs
b: Inventory cost per unit of product in ICP
v_r: Variable cost of manufacturing one more unit of product in RFs
d_{jk}: Distance from ICP *j* to CRC *k*
d_{ij}: Distance from customer *i* to ICP *j*
d_{rs}: RF *r* distance to secondary market
d_{kr}: Distance from CRC *k* to RF *r*
D: Maximum service range from ICP to designated customer area
V: Unit capacity level per CRC
L: Maximum capacity level per CRC
N: Government-regulated CO_2-equivalent caps
B: Average recoverable percentage of returned products
Q: The capacity of per ICP
T: Maximum returned period for ICPs
M: An arbitrarily large number
s: The price at which remanufactured products are sold on the secondary market
p: Market price for buying and selling CO_2 credits
a: Income from the sale of one unit of defective product to a third-party recycling facility
COs^m: CO_2 emission factor per unit distance using transport mode *m*
CO^m: CO_2 emission factor per unit distance using transport mode *m* (no load)
CH^h: CO_2 emissions per unit of product using remanufacturing technology *h* in RFs

(4) Mathematical Model

Total profits are used to evaluate the economic goals while total CO_2 emissions are used to evaluate environmental goals. The total CO_2 emissions and revenue-cost components of the objective functions can be calculated as follows:

a. Income. Income consists of two parts. The first is the profit from the sale of remanufactured products on the secondary market. The second part is the profit made from selling defective products to the third-party recycling enterprises. Total revenue can then be expressed as $RE = s\sum_i r_i w\beta + a\sum_i r_i w(1-\beta)$.
b. Recovery costs. Recovery costs are the costs of collecting returned products from customers; it is equal to $CC = c\sum_i r_i w$.
c. Fixed cost of acquiring technology. Different returned products may require different repair techniques. Thus, the fixed cost of technology acquisition is $HC = \sum_h f_r^h Er^h$.

d. Inventory costs. Inventory cost is the product storage cost of the ICP. That is $IC = bw\sum_i r_i X_{ij}\left(\frac{T_j+1}{2}\right)$.
e. Rental cost. The rental cost of ICP is $RCI = \sum_j f_j Z_j$.
f. Remanufacturing costs. The remanufacturing cost of the RFs is $RC = v_r\beta\sum_i r_i w$.
g. Establishing cost. The total fixed and variable costs of establishing a CRC are $ECK = \sum_k G_k^l(f_k + l\cdot v_k)$.
h. Transportation cost. Transportation costs consist of three parts. The first part is the transportation cost from ICP j to CRC k. The second part is the transportation cost from the RF r to the secondary market. The third part is the transportation cost from CRC k to RF r. Thus, the total transportation cost is.

$$TC = \sum_m\sum_k\sum_j Et^m U_{jk}\frac{w}{T_j} f\left(U_{jk}, d_{jk}\right) + \sum_m\sum_r\sum_k Et^m O_{kr} wf(O_{kr}, d_{kr})$$
$$+\sum_m\sum_r Et^m wf\left(\sum_k O_{kr}\beta, d_{rs}\right)\beta\sum_k O_{kr}.$$

$$\alpha = \begin{cases} 1 & U_{jk}\le p_1 \\ \alpha_1 & p_1 < U_{jk}\le p_2 \\ \alpha_2 & p_2 < U_{jk}\le p_3 \\ \alpha_3 & p_3 < U_{jk}\le p_4 \\ \alpha_4 & U_{jk} > p_4 \end{cases} \quad \gamma = \begin{cases} 1 & d_{jk}\le q_1 \\ \gamma_1 & q_1 < d_{jk}\le q_2 \\ \gamma_2 & q_2 < d_{jk}\le q_3 \\ \gamma_3 & q_3 < d_{jk}\le q_4 \\ \gamma_4 & d_{jk} > q_4 \end{cases}$$

i. CO_2 emission cost. The cost of buying or selling CO_2 credits: purchased cost >0, sold cost < 0. The ETS can sell credits if an enterprise's emissions fall below the government-mandated cap. Otherwise, if the enterprise exceeds the cap, it needs to purchase the same amount of carbon credit. The emission costs are given as $EC = CO_{in}p$.

Both transportation and remanufacturing lead to high CO_2 emissions. The total CO_2 emissions consist of two components. The first part of comprises emissions comes from remanufacturing. The second part is the emissions from transport from ICP j to CRC k, RF r to the secondary market, and CRC k to RF r. Total emissions were calculated as follows:

$$CO_{out} = \sum_k\left(\sum_j\left(U_{jk}COs^m + CO^m\right)d_{jk}\frac{w}{T_j}\right) + \sum_h Er^h\beta\sum_i r_i w$$
$$+\sum_r\left(\sum_k U_{kr}COs^m + CO^m\right)d_{kr}w$$

$$+\sum_r \left(\sum_k \beta U_{kr} COs^m + CO^m \right) d_{rs} w$$

In summary, the network considering carbon emissions is as follows.

$$Maximize\, OBJ_1 = E - (CC + IC + HC + RC + RCI + ECK + EC + TC) \tag{5.16}$$

$$\text{Minimize}\, OBJ_2 = CO_{out} \tag{5.17}$$

Subject to

$$\sum_k W_{jk} = Z_j, \forall j \in J \tag{5.18}$$

$$\sum_j X_{ij} = 1, \forall i \in I \tag{5.19}$$

$$\sum_r Y_{kr} = G_k^l, \forall k \in K, \forall l \in L \tag{5.20}$$

$$G_k^l \le \sum_j W_{jk} \le MG_k^l, \forall k \in K, \forall l \in L \tag{5.21}$$

$$Z_j \le \sum_i X_{ij} \le MZ_j, \forall j \in J \tag{5.22}$$

$$Z_j \le T_j \le MZ_j, \forall j \in J \tag{5.23}$$

$$\sum_h Er^h = 1 \tag{5.24}$$

$$\sum_m Et^m = 1 \tag{5.25}$$

$$\sum_i r_i T_j X_{ij} \le Z_j Q, \forall j \in J \tag{5.26}$$

$$d_{ij} X_{ij} \le D, \forall i \in I, \forall j \in J \tag{5.27}$$

$$\sum_j U_{jk} \le G_k^l lV, \forall k \in K, \forall l \in L \tag{5.28}$$

$$\sum_k G_k^l \ge 1 \tag{5.29}$$

$$\sum_j Z_j \geq 1 \tag{5.30}$$

$$l \in \{1,2,\ldots\mathrm{L}\} \tag{5.31}$$

$$m, h \in \{0, 1, 2\} \tag{5.32}$$

$$T_j \in \{0, 1, 2, \ldots T\} \tag{5.33}$$

$$\begin{aligned} &Z_j, G_k^l, X_{ij}, W_{jk}, Y_{kr}, Er^h, Et^m \in (0, 1) \\ &\forall i \in I, \forall j \in J, \forall k \in K, \forall r \in R, \forall l \in L. \end{aligned} \tag{5.34}$$

This model is a dual-objective nonlinear mixed-integer model. The objective (5.16) maximizes the profit of the reverse logistics network. Profit is the total revenue minus total costs. The total cost consists of the collection cost, leasing cost of ICP, CRC setup cost, inventory cost, variable remanufacturing cost, fixed cost of acquiring remanufacturing technology, transportation cost, and CO_2 emissions cost. The objective (5.17) minimizes the total CO_2 emissions. The following constraints are also applicable here:

- Constraint (5.18) guarantees that an open ICP is assigned only to a single CRC.
- Constraint (5.19) ensures that the client area can only be assigned to a single ICP.
- Constraint (5.20) restricts open CRCs to be assigned to a single RF alone.
- Constraint (5.21) ensures that assignments from the ICPs to unopened CRCs do not assign backflow and that certain ICPs must be assigned to open CRCs.
- Constraint (5.22) ensures that some client area must be allocated to an open ICP and no client area is allocated by an unopened ICP.
- Constraint (5.23) states that if the ICP is off, its collection period must be zero; otherwise, the collection period is zero or more.
- Constraint (5.24) requires that the same remanufacturing technique be applied to all the RFs.
- Constraint (5.25) ensures that the total amount of product returned from the client area reaches the maximum capacity limit of the ICP.
- Constraint (5.26) states that only one mode of transport is used to transport the backflow between facilities.
- Constraint (5.27) ensures that the distance between the client area, and each ICP is within a certain allowable distance.
- Constraint (5.28) guarantees that the total amount of the product returned from the ICP reaches the maximum capacity limit of the CRC.
- Constraints (5.29) and (5.30) guarantee a minimum amount of CRC and ICP for product returns.
- Constraint (5.31) represents the range of integer values for the established CRC capacity levels.

- Constraint (5.32) limits the diversity of transport modes m and remanufacturing techniques h.
- Constraint (5.33) limits the range of integer values for the decision variable T_j.
- Constraint (5.34) defines the decision variables Z_j, $G^l{}_k$, X_{ij}, W_{jk}, Y_{kr}, Et^m, Er^has binary integer values.

5.2.3 Solution Method for Network Design Considering Carbon Emissions

The logistics network design problem is generally the NP-hard problem. The problem to be solved in this section is a multi-objective NP-hard problem, while the above model is a multi-objective nonlinear integer programming model that must be solved using a multi-objective optimization method. The traditional multi-objective optimization method converts the multi-objective problem into a single-objective problem and then uses the optimization method to solve the problem. The Pareto solution set is obtained using multiple calls by changing the weights or parameters. Obtaining multiple Pareto solutions usually requires a lot of time and resources. The multi-objective evolutionary algorithm realizes globality based on the population search method, and can obtain multiple Pareto approximate optimal solutions in one operation. In addition, evolutionary algorithms do not require multi-objective optimization problems to be mathematical in nature. The NSGA-II is a multi-objective evolutionary algorithm based on a genetic algorithm, and is one of the best multi-objective evolutionary algorithms. Due to its good accuracy and fast convergence, it is widely used in situations of multi-objective optimization. This section also adopts the NSGA-II to solve the proposed multi-objective optimization problem.

(1) Coding

Binary encoding is used in this solution. Each chromosome is represented by a one-dimensional array. Figure 5.6 illustrates a chromosome with eight ICPs and five CRCs. ICP 1, 4, 6, and 7 are open and the collection periods are 3, 5, 1, and 2, respectively. CRC 2 and 4 are open with the capacity levels 2 and 3, respectively. $E_r{}^h$ represents the remanufacturing technology, while $E_t{}^m$ represents the transport mode.

Since only a part of the decision variables that represent the switching states of the CRC and the ICP can be obtained from the chromosome, two sub-allocation algorithms are developed to determine the decision variables of the distribution relationship between the client area and the CRC and that between the CRC and the ICP.

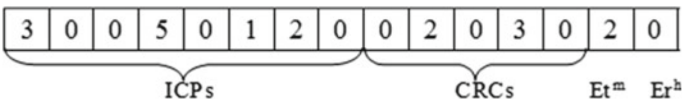

Fig. 5.6 An illustration of chromosome

The first sub-allocation algorithm is used to determine the correspondence between the client areas and reclamation points. First, the distance matrix from each client area to each open ICP is calculated; then, each client area is directly assigned to the ICP closest to it. The second sub-allocation algorithm is used to determine the allocation relationship between ICPs and CRCs. The steps are as follows:

(a) Calculate the transportation cost matrix from each open ICP to each open ICP. If the CRC is closed, then the shipping fee is 0.
(b) Each row of the freight matrix represents the freight from an open CRC to each open ICP, and each row of the freight matrix is sorted according to the freight rate in ascending order.
(c) For each open CRC, calculate the difference between the smallest and the next smallest freight, and sort the difference from largest to smallest.
(d) The ICP with the largest difference is preferentially allocated to the ICP corresponding to the minimum freight. If the recycling volume of the CRC exceeds the maximum capacity of the ICP corresponding to the minimum shipping fee, it is allocated according to the small shipping fee, and so on.
(e) For an ICP that has the same shipping cost as multiple CRCs and has the minimum shipping fee, the minimum shipping fee is preferentially allocated to the ICP that has received the ICP under the condition that the capacity limit of the ICP is met. Otherwise, it is assigned as shown in (d).
(f) If a ICP exceeds the capacity limit of the ICP irrespective of which ICP it is allocated to, it will be allocated according to the maximum freight and marked as an infeasible solution.

(2) Repair Strategies for Infeasible Solutions

The above assignment algorithms and genetic operations may lead to one or more of the following infeasible solutions:

(a) No client area is allocated to one or more open CRCs.
(b) No ICP is allocated to one or a small number of open ICPs.
(c) The total amount of product returned at the ICP exceeds the capacity of the ICP.
(d) The number of open ICPs and CRCs is lesser than the minimum required.

The above-mentioned allocation algorithm may lead to the appearance of the first two infeasible solutions. The repair method is as follows: if the recycling amount of an open ICP is 0, the ICP is closed, and the number of open CRCs is checked if the minimum required number is met. If not, the chromosomes are regenerated and reassigned until the number of open ICPs meets the requirements, and the recycling amount of each open ICP is greater than 0. If the recycling volume of the open ICP is zero, the same repair operation is performed as above.

The third infeasible solution can be fixed by opening more ICPs and determining the distribution relationship between the ICPs and CRCs. However, it is impossible to accurately determine the number and locations of the ICPs to be opened for restoration. Further, the restoration process usually takes a long time to complete.

Therefore, no repair is performed for this infeasible solution and a penalty is assigned directly.

The link between crossovers and mutations in genetic manipulation may lead to the emergence of a fourth infeasible solution. The repair method involves checking if the number of opened ICPs and CRCs meet the requirements after the crossover and mutation operations are performed. If not, crossover and mutation operations are performed again until the number of opened ICPs and CRCs meets the requirements.

(3) Adaptive Weighting Method

The weighted sum algorithm is a simple and traditional multi-objective optimization method. Many studies have applied the weighted sum method based on a genetic algorithm to solve NP-hard multi-objective optimization problems. In this section, the weighted sum method based on a genetic algorithm is used to compare the solution effect of NSGA-II, while the adaptive weight method is used to determine the weights. The adaptive weighting method determines the weights based on ideal points during each iteration. Figure 5.7 shows the principle of generating weights in the object space. Under the current evolutionary algebra, let f_{imax} and f_{imin} be the maximum and minimum values of the ith objective function, respectively. The weight of each objective function can be calculated according to formula (5.35). For a minimization problem with m objective functions, the weighted sum objective function is shown in Eq. (5.36). The smaller the objective function value, the better it is. For unrepairable infeasible solutions, the fitness function is the sum of the objective function and penalty function. The solution that violates the capacity constraint of the recycling center cannot be repaired. Thus, the penalty function is set as $px \times M$, where px is calculated according to Eq. (5.37) and M is the penalty coefficient, which is a number larger than the value of any objective function.

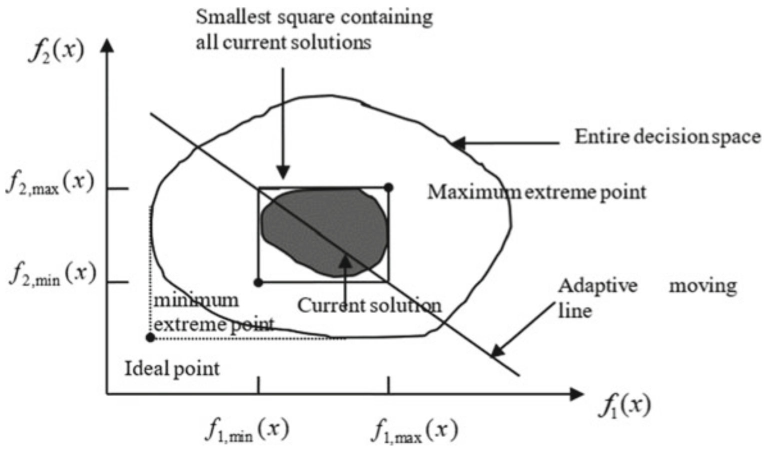

Fig. 5.7 An illustration of strategies for generating weights

$$w_i = \frac{1}{f_{i\max} - f_{i\min}} \tag{5.35}$$

$$f(x) = \sum_{i=1}^{m} w_i(f_i - f_{i\min}) = \sum_{i=1}^{m} \frac{f_i - f_{i\min}}{f_{i\max} - f_{i\min}} \tag{5.36}$$

$$px = \sum_k \left(\sum_j \sum_i r_i Y_{ij} W_{jk} - m_k G_k \right) \tag{5.37}$$

The evolution process of the adaptive weight method is as follows. First, the initial population is randomly generated. For each solution in the population, the objective function and fitness function values are calculated. An empty Pareto optimal solution set is created and the approximate Pareto optimal solutions from the initial population are included in it. New populations are generated through genetic operations and evolutionary iterations are performed. The approximate Pareto optimal solution obtained in each generation is compared with the solutions in the existing Pareto solution set, the dominated solution eliminated, and the Pareto solution set updated. The genetic manipulation process is as follows:

(a) Choice. A binary tournament selection method is used. Two sets of chromosomes are randomly selected each time from the current population, with each set consisting of chromosomes containing two individuals. The fitness weight method selects individuals with high fitness from two sets of chromosomes to enter the next generation until the number of individuals in the next generation reaches the population size.

(b) Crossover. A two-point crossover method is adopted here. The crossover point is randomly selected to perform the operation from the switch bits representing the recycling point and recycling center. As shown in Fig. 5.8, two parent chromosomes are crossed to produce two offspring.

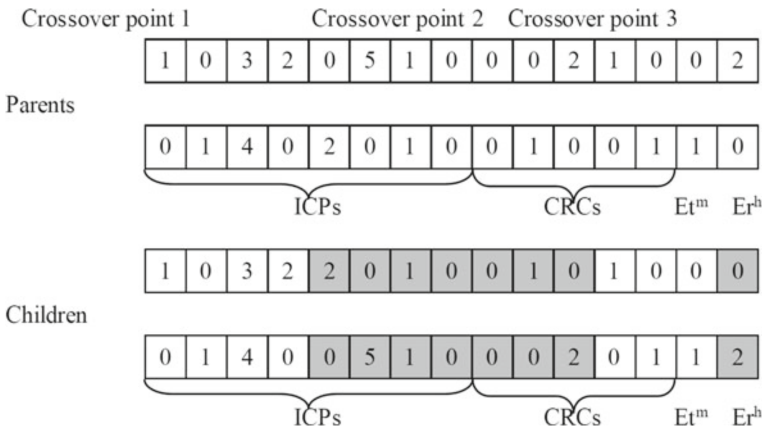

Fig. 5.8 An example of crossover operation

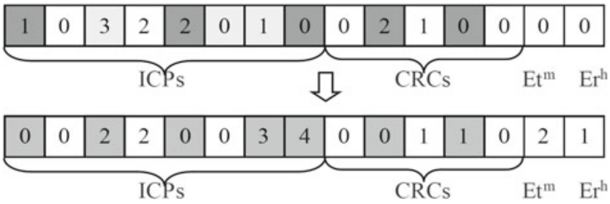

Fig. 5.9 An illustration of the mutation operator

(c) Mutations. The multi-point mutation method is used in this solution. Six genes are randomly selected in the gene to represent the switch position of ICPs, two genes are selected in the gene locus to represent the switch position of CRCs, the transport mode gene, and the remanufacturing technology gene are also randomly selected. Figure 5.9 is an illustration of the mutation operator.

(d) NSGA-II. NSGA-II realizes the evolutionary iterative process of the algorithm based on three mechanisms: non-inferiority sorting, crowding degree distance calculation, and crowding degree comparison. The detailed iterative process of the algorithm is as follows. First, an initial population is randomly generated. The value of the objective function is calculated, individuals in the population evaluated, and the entire population divided into multiple non-dominated sets by applying the non-inferior sorting method. Consider an illustrative objective function minimization problem, such as $\min\{f_1(x), f_2(x), f_3(x)\}$, where $f_1(x_1) < f_1(x_2), f_2(x_1) \le f_2(x_2), f_3(x_1) \le f_3(x_2)$. Then, x_1 is said to dominate x_2. An individual that cannot be dominated by other individuals in the population has a non-dominant level of 1; the non-dominant set of individuals that can only be dominated by a level-1 individual is 2, and so on. The crowding degree distance is calculated for each individual in the non-dominated set. According to the non-dominant level and crowding degree distance, the new-generation population is selected using the binary selection method. If the two individuals have the same level, the individual with the larger crowding distance is selected to enter the next generation. Subsequently, offspring are generated through crossover and mutation. Each iteration then merges the child and parent, selects the optimal number of individuals as a new generation through non-inferior sorting, and calculates the crowding degree distance. This is the elite retention strategy for NSGA-II, as shown in Fig. 5.10. The above operations are repeated until the maximum evolutionary generation is reached.

As a comparison, for the same benchmark, the genetic manipulation of NSGA-II is the same as that of the adaptive weighting method described above. The difference is that in the process of binary selection, NSGA-II selects the best individual to enter the next generation according to the individual's non-dominant level and crowding degree distance. For example, for individuals A and B, rank represents the non-dominant rank of the individual, and distance represents the crowding degree distance of the individual. If $A_{rank} < B_{rank}$ or $A_{rank} = B_{rank}$ and $A_{distance} > B_{distance}$, then solution A is better than solution B.

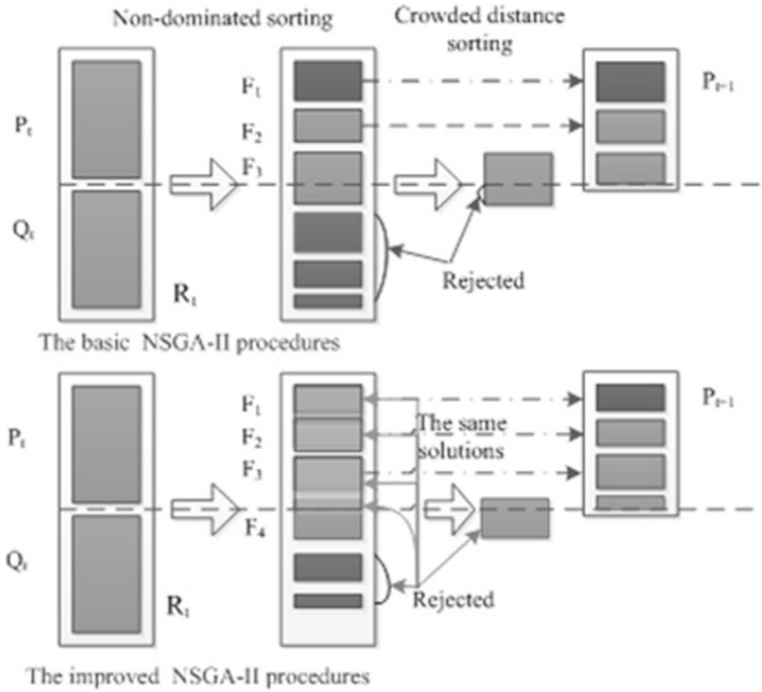

Fig. 5.10 An illustration of elite retention strategies

5.2.4 The Impact of Carbon Emissions on Enterprise Network Design

To study the impact of carbon emissions on enterprise logistics network design, this section conducts a sensitivity analysis of the issue from four aspects: CO_2 credits, ICP service coverage, ICP capacity, and CO_2 emission caps.

(1) Sensitivity Analysis of CO_2 Credit Prices

Through a sensitivity analysis of the price of CO_2 credits, this section studies its impact on profits, CO_2 emissions, and the cost structure. The price of the CO_2 credit can take the values 0, 30, 60, 90, and 120. When the CO_2 credit price is increased from 0 to 120, profits and CO_2 emissions are reduced. This shows that given an increase in the CO_2 credit price, although the total amount of CO_2 emissions decreases, the total cost of emissions increases due to the increase in the CO_2 credit line. In addition to the increase in emission costs, fixed, rental, transportation, and inventory costs also increase, resulting in a decline in profits. Thus, as the CO_2 credit price increases, CO_2 emissions will decrease as the transportation route and duration shortens. This results in an increase in the number of CRCs and ICPS, with the collection period being prolonged; the corresponding construction, rental, and inventory costs will also increase. Furthermore, the longer the collection period of the ICP, the greater the cost of transportation. Therefore, the rise in the price of carbon credits increases the cost of the transportation mode and remanufacturing technology. The results show that if the credit for CO_2 is raised to 120, applying less environmentally friendly remanufacturing technologies will increase the remanufacturing emission cost. All solutions at the Pareto frontier in this section use the most environmental-friendly remanufacturing technologies. This also explains why an increase in the price of CO_2 credits is a good way to encourage investment in environmentally friendly technologies and promote a reduction in the overall CO_2 emissions of the reverse logistics network.

(2) Sensitivity Analysis of Service Coverage

Based on the changes to the scope of services, we perform a sensitivity analysis on the model. The ICP services can take the values 25, 30, 35, and 40. When the service scope is 20 or 50, there is no feasible solution. The reason for this is that the scope of the service restrictions is too strict. The distance from the nearest ICP to customer channels still exceeds the maximum allowable distance. When the service scope is increased from 30 to 40, the number of initial infeasible solutions reduces from 185 to 94. While the minimum emissions reduce, the gap between the maximum and minimum emissions does not change significantly. The maximum and minimum profits also reduce, as does the gap between them. Thus, the average profit increases. This increase is due to a reduction in the total cost. As the scope of the service limit expands, the average number of open ICPs and CRCs is reduced, as is the collection period. This also reduces the construction, rental, and inventory costs. Moreover, with an increased scope of services, more appropriate ICPs and CRCs may be opened and the distance between the ICP and CRC is shortened. Thus, the cost of transportation is reduced with the expansion of the scope of service. These results show that enterprises must improve their scope of customer service. If service coverage is not the main factor affecting the number of returns, it is expected that the expanded service coverage will save costs. It is important to choose an appropriate service scope according to cost constraints and service requirements.

(3) Sensitivity Analysis of ICP Capacity

The ICP capacity can take the values 200,300, 400, and 500. As the ICP capacity increases, CO_2 emissions and profits decrease. The reasons for this phenomenon are as follows. First, as the ICP capacity increases, fewer ICPs are required to satisfy the capacity constraint, thereby reducing the leasing cost. Second, an increase in ICP capacity also leads to an increase in its collection period. The longer the period of collection, the higher the inventory cost. Third, an increase in the ICP capacity and extension of the collection period led to an increase in the setup cost of ICPs. Fourth, the longer the collection period of the ICP, the lower the transport frequency from ICP to CRC, which implies lower CO_2 emissions. Thus, the emission cost is reduced. When the ICP capacity is increased from 200 to 300, the transportation costs decrease, but more crucially, the CO_2 emissions decrease. The increased setup and inventory costs are higher than the saved cost; thus, decreasing the total profit. The results show that an increase in ICP capacity helps to reduce the CO_2 emissions generated by the reverse logistics network but will lead to a reduction in profits.

(4) Sensitivity Analysis of the CO_2 Emission Cap

The CO_2 emission cap in this section can take the values 10,000, 12,000, 14,000, and 16,000. With a relaxation of the cap on CO_2 emissions, CO_2 emissions and profits increase. A strict CO_2 cap will prompt enterprises to shorten the transportation distance and setup more CRCs. Relaxation of the CO_2 emissions cap reduces the setup cost of the CRC. Transportation branches and costs are reduced. With the relaxation of the CO_2 emission cap, investment in transportation methods and environmentally friendly remanufacturing technology is also decreased. It is also implied that with the given change in the CO_2 emission cap, the inventory and rental costs do not change significantly, which means that the strictness of the CO_2 emission cap also affects the promotion of reduction in CO_2 emissions.

5.3 Design of Waste Product Collection Channels

5.3.1 Design of Waste Product Collection Channels Regarding Enterprises' Green Growth Model

The design of waste product collection channels is not only an expansion of the reverse value chain, but also of the whole process, including product design, manufacturing, selling, collection, and reuse, of waste products [16]. To achieve the objectives of the green growth model, enterprises need to reconstruct the existing value chain and business scope. The network redesign of the reverse value chain is an important part of the value chain reconstruction. The enterprise collects and harmlessly recycles the waste products through the collection channels, which effectively reduces environmental pollution by the waste products. Doing so simultaneously achieves the reuse of resources, improves resource efficiency and economic benefits, and finally realizes the goals of enterprises' green growth model. Online and offline collaborations and the domination of waste product collection channels by different collectors together determine if the waste product collection market is in complete competition. This allows the construction of an important value chain network, combining forward and reverse value chains, for enterprises to implement enterprises' green growth model.

5.3.2 Framework of Design of Waste Product Collection Channels

(1) Different Collection Channels for Waste Products

Research on selection strategies for channels to collect waste products is primarily based on Savaskan et al. [17]. The model framework focuses on the efficiency, comparison, and selection of different recycling channels, such as manufacturers, retailers, and third-party collectors [18]. The core objective of this research branch is to develop an optimal collection strategy by comparing different collection channels. For example, Atasu et al. further studied the comparison of collection channels between manufacturers and retailers based on the aforementioned classical model [19], while De Giovanni et al. studied the simultaneous comparison of recovery efficiency among these three collectors [20]. On the basis of this, another branch of research considers collection cooperation among supply chain members.

(2) Factors Influencing the Design of Waste Product Collection Channels
(a) Competitive Factors in Collection Channels for Waste Products

Competition among collection channels affects their design. The competitive behavior of different collectors in the market, with their own collection channels, are primarily analyzed by using the Stackelberg game or completely static game theories, such as competition between the manufacturer and third-party collectors, competition between the manufacturer and retailer, competition between the retailer and third-party collectors, and competition among all three collectors. Additionally, some studies mentioned more specific competition within the same collection channels, such as competition between the same value chain members as multiple retailers, multiple collectors, and multiple manufacturers in the value chain. Moreover, Han et al. have studied the collection competition between different supply chains where competition and integration models are more complicated but are more in line with industrial supply chain integration [21].

(b) Consumer Factors in Waste Product Collection Channels

In the context of competition, consumers' preferences for collection channels also affect enterprises' design of collection channels for waste products. These include economic incentives, willingness to pay for new or refined products, environmental awareness, and perception of the convenience level of collection channels. Most previous research has focused on how to recycle products, e.g., centralized collection, manufacturer collection, or retailer collection, and how to price products to improve collection efficiency. Feng et al. studied the advantages and disadvantages of a single traditional collection channel, a single online collection channel, and a centralized and decentralized mixed dual collection channel to examine consumer preferences for online collection channels [22]. Recently, an increasing number of studies have focused on the factors influencing consumers' return preferences from a psychological perspective. Simpson et al. have used empirical methods to discuss how psychological ownership affects consumers' the return behavior of consumers for reusable products [23].

(3) Different Reuse Technologies in Enterprises' Green Growth Model

To approach a green closed-loop supply or value chain, enterprises should remanufacture waste products after collection for technical, local regulatory, and economic considerations. Using waste product recovery options such as remanufacturing [24] and recycling [25], enterprises can put collected waste products back into the forward production process of the closed-loop supply chain to achieve resource reuse and environmental protection. Waste products should be remanufactured to achieve the identical functionality and appearance of new products, and then be marketed as new products. Collectors that use remanufacturing often use usable parts from waste products to create new products and services, thereby reducing the product costs.

Different reuse technologies exhibit different features. First, when compared with recycling, although remanufacturing brings higher economic benefits, it also has higher technological, capital, and process thresholds. Typically, only manufacturers with certain production and operational advantages can undertake remanufacturing. Recycling, in turn, makes a profit by extracting raw materials, such as precious metals and plastics, from the waste products, or by receiving a subsidy for selling the waste product to the upstream of the value chain. Second, different reuse methods for waste products have different resource efficiencies with remanufacturing having a relatively higher resource effeciency than others.

5.3.3 Model of Waste Product Collection Channel Regarding Different Reuse Technologies

Currently, remanufacturing and recycling are the main environmental protection technologies for collecting waste products and integrating them into the value chain so that the enterprises' green growth model can help enterprises improve their green level and economic benefits. Generally speaking, remanufacturing has higher requirements for the technology, process, equipment, and human resources of enterprises, in addition to a certain threshold for the industry. By contrast, other collectors who are not original manufacturers have difficulty in remanufacturing, which makes recycling a smarter choice for these companies. However, the lower resource efficiency of recycling results in a lower green level of the supply chain. At the same time, the competition model in which different collectors choose different reuse technologies (manufacturers choose remanufacturing, whereas retailers choose recycling) is particularly significant in the real industry. Although non-manufacturer collectors can also profit from recycling, enterprises must consider the lower resource efficiency and potential secondary pollution caused by recycling.

The model of waste product collection channels regarding different reuse technologies mainly studies the competition mechanism between manufacturers and retailers that adopt different reuse technologies of waste products in Fig. 5.11. This section also refines and proposes models of waste product collection channels based on different reuse technologies.

(1) Model of Waste Product Collection Channel Based on Recycling

Let $\tau_i(i = C, M, R)$ denote the collection rate, where C, M, and R are the supply chain alliance, manufacturer, and retailer of the centralized model, respectively. Let c_i denote the consumer perceived inconveniences of the collection channels from the centralized alliance, manufacturer, and retailer. Let s_i denote the level of service provided to consumers through the different channels. Let π_i denote the total profits of the alliance, the manufacturer, and the retailer. Note that this section defines c_m as the manufacturer's cost of the new product, while c_r is the remanufacturing cost; thus, $c_m > c_r$.

For the retailer, k represents the basic surplus value extracted from the reused products and $k \cdot \tau_R$ is the total profit of the retailer from collection activities.

(2) Model of Waste Product Collection Channel Based on Remanufacturing

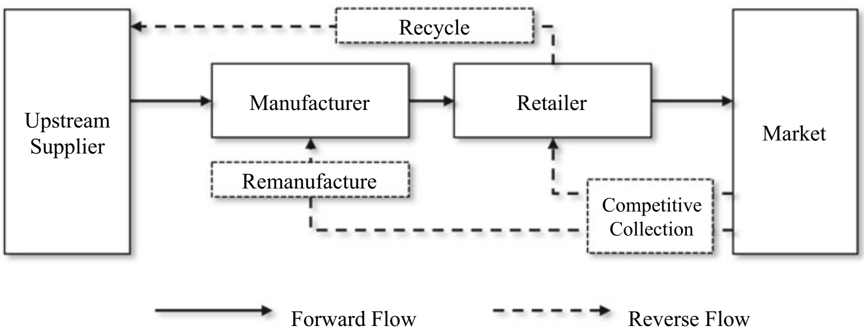

Fig. 5.11 Model framework for waste-product collection channels regarding different reuse options

For manufacturers, there are two ways of production: making new products from new raw materials or making new products from collected products. For the manufacturer and supply chain alliance, the collection rate is the proportion τ_i of all new products that can be remanufactured at the unit cost c_r. Thus $1 - \tau_i$ is the proportion of all new products produced using new raw materials and components at the unit cost c_m. Therefore, the combined cost of the alliance or manufacturer can be expressed as $c_m(1 - \tau_i) + c_r\tau_i$. Further, setting e ($e = c_m - c_r$) as the difference between the cost of the new product and that of the remanufactured product, we have

$$c_m(1 - \tau_i) + c_r\tau_i = c_m - e\tau_i$$

(3) Model of Waste Product Collection Channels Based on Different Reuse Technologies

The model of different reuse technologies for waste product collection channels is based on the long-term operational stability of the single cycle model; thus, the model does not consider inventory, transportation, or delivery, while also assume that the collection and recovery costs and product quality are fixed. This model focuses on the analysis of the competitive and behavioral factors. Assume a linear relationship between the demand for new products and the selling price set by retailers, that is $d = \alpha - \beta p$. In addition, assume a Stackelberg game between the retailer and manufacturer, with the manufacturer as the leader.

In a highly competitive collection market, the consumer-perceived collection inconveniences are c_R and c_M, where $c_R = 1 - s_R$ and $c_M = 1 - s_M$. This model assumes that the collection value of the consumers is uniformly distributed as in $v \sim U(0, 1)$. According to the basic assumption, the more inconvenient consumers feel when returning used products, the less utility they receive from collection activities. The collection utility functions for consumers are as follows:

$$\begin{cases} U_R(v, c_R) = v - c_R \\ U_M(v, c_M) = \theta v - c_R \end{cases}$$

In particular, $\theta \in (0, 1)$ indicates consumers' negative influence on the collection channel of manufacturers. As retailers can easily interact and directly communicate with consumers through the retail network, consumers' initial impression of the manufacturer's collection activities is worse than that of the retailers. Consumers may be faced with four recycling utility functions: if $U_R > U_M > 0$, the retailer collects all used products; if $U_M > U_R > 0$, the manufacturer collects all; if $U_M < 0$, $U_R < 0$, consumers refuse any returning; and if $U_M = U_R > 0$, consumers will choose either channel for returning. Therefore, the collection rates are

$$\tau_R = \begin{cases} 1 - \dfrac{s_M - s_R}{1-\theta}, if \dfrac{1-s_M}{\theta} \leq 1 - s_R \\ s_R, Otherwise \end{cases}$$

$$\tau_M = \begin{cases} \dfrac{s_M - \theta s_R - (1-\theta)}{\theta(1-\theta)}, if \dfrac{1-s_M}{\theta} \leq 1 - s_R \\ 0, Otherwise \end{cases}$$

On this basis, according to the model structure in Fig. 5.11, the profit functions of the manufacturers and retailers are:

$$\pi_M = (w - c_m + e\tau_M)(\alpha - \beta p) - \frac{A}{2}s_M^2$$
$$\pi_R = (p - w)(\alpha - \beta p) + k\tau_R - \frac{A}{2}s_R^2$$

where w is the wholesale price and A is the cost index of service level.

By backward induction:

(a) When $\frac{c_M}{\theta} > c_R$:

$$w_1^* = \frac{\alpha + c_m\beta}{2\beta}$$

$$s_{M1}^* = 0$$

$$p_1^* = \frac{3\alpha + c_m\beta}{4\beta}$$

(b) When $\frac{c_M}{\theta} \leq c_R$:

The retailer's optimal collection investment and selling strategies are:

$$\begin{cases} s_{R2}^* = \frac{ku}{A} \\ p_{D2}^* = \frac{\alpha}{2\beta} + \frac{-\alpha\beta e^2u^2v^2 + 2\beta keu^2 + 2A\beta ev + 2A\alpha + 2A\beta c_m}{2\beta\left(4A - \beta e^2u^2v^2\right)} \end{cases}$$

The manufacturer's optimal collection investment and wholesale pricing decisions are:

$$\begin{cases} s_{M2}^* = \frac{euv\left(\beta eku^2 + A\beta ev + A\beta c_m - A\alpha\right)}{A\left(\beta e^2u^2v^2 - 4A\right)} \\ w_{D2}^* = \frac{-\alpha\beta e^2u^2v^2 + 2\beta keu^2 + 2A\beta ev + 2A\alpha + 2A\beta c_m}{\beta\left(4A - \beta e^2u^2v^2\right)} \end{cases}$$

The collection rates of manufacturers and retailers are:

$$\tau_{R2}^{*} = 1 - us_{M2}^{*} + us_{R2}^{*} = \frac{ku^2}{A} + 1 + \frac{eu^2v\left(\beta eku^2 - A\alpha + A\beta c_m + A\beta ev\right)}{A\left(\beta e^2u^2v^2 - 4A\right)}$$

$$\tau_{M2}^{*} = uvs_{M2}^{*} - us_{R2}^{*} - v = \frac{eu^2v^2\left(\beta eku^2 - A\alpha + A\beta c_m + A\beta ev\right)}{A\left(\beta e^2u^2v^2 - 4A\right)} - v - \frac{ku^2}{A}$$

And the total collection rate of reverse channels is:

$$\tau_{D2}^{*} = \tau_{R2}^{*} + \tau_{M2}^{*} = 1 - v + \frac{euv^2\left(\beta eku^2 + A\beta ev + A\beta c_m - A\alpha\right)}{A\left(\beta e^2u^2v^2 - 4A\right)}$$

The analysis of the model's results shows that, first, collection competition cannot improve manufacturer-led collection efficiency. Although the contract mechanism can achieve optimal recovery efficiency, it still has some shortcomings. Channel discrimination has limited influence on the collection rate and decision-making strategy in a decentralized supply chain. Second, retailers are always willing to compete in recycling, but there is no obvious relationship between the low-cost advantage of remanufacturing and collection efficiency. Thus, the investment level of manufacturers is not high. Finally, retailers' participation in collection greatly increases competition for collection, leading to a decline in collection efficiency. With an increase in investment in collection channels, retailers gradually lose the benefits of the consumer's channel preference. Therefore, collection competition reduces the efficiencies of manufacturers' collection and supply chain resources. Likewise, an elevated level of consumer channel discrimination reduces both total collection efficiency and resource efficiency. Enterprises, such as manufacturers and retailers, should realize enterprises' green growth model with economic, environmental, and social benefits through a value chain reconstruction according to their practical situation.

5.4 Summary

This chapter analyzes and introduces the basic framework of network design and relevant methods, and subsequently proposes two patterns to help enterprises implement the network design of enterprises' green growth model: network design considering carbon emissions and design of waste product collection channels. The network designs from both perspectives reveal how to improve green and growth levels. First, to reduce the network operation costs and carbon emissions, a network design that considers carbon emissions is focused on the entire network to achieve a more efficient value chain network through a series of optimization methods. Second, to maximize the collected core quantities, the design of waste product collection channels focuses on suitable collection mechanisms, interactions of different value chain members' decisions, and a reverse channel collection network regarding different waste product reuse technologies.

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Chapter 6
Coordination of Value Chain Members

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Abstract The innovation-driven coordination of "green" and "growth" in enterprises' green growth model (EGGM) requires value chain members to collaborate, to facilitate the coordination of business processes in the upstream and downstream of the value chain. Value co-creation and sharing among members in a value network drive firms to implement the green growth model and green transformation. From the perspective of the internal and external environment surrounding the green transformation of the value chain, this chapter explores the coordination mechanism among value chain members that is aimed at ensuring the sharing of value among entities. This coordination mechanism also motivates enterprises to implement the green growth model to coordinate "growth" with economic performance goals and "green" with environmental performance goals. With a better understanding of the relationship between the coordination of value chain members and an enterprise's green growth, this chapter introduces the concepts and structure of member coordination in the green growth model, analyzes the path of members to achieve coordination, and finally evaluates the characteristics and mechanism of value co-creation in the green growth model. We show that for the internal coordination mechanism, the Shapley value method and cost sharing contract can coordinate the profits and green level of the value chain. In particular, the Shapley value method has a better coordination effect, which can address the externality effect of green transformation investment and encourage value chain members to make cooperative investments. For the external coordination mechanism, government subsidies can effectively motivate value chain enterprises to invest in green levels and increase the market share of green products.

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6.1 Relationship Between Coordination of Value Chain Members and Enterprises' Green Growth Model

6.1.1 Coordination of Value Chain Members in Enterprises' Green Growth Model

Coordination is the process of managing the dependencies between activities. The purpose of coordination is to achieve the overall goal of all activities [1]. However, value chain members are primarily concerned about optimizing their own goals; these sub-goals may affect and even contradict one another. Individual rational decision-making leads to Olson's dilemma in the overall value chain network. By setting incentive and coordination mechanisms rationally, one may realize the cooperation of multiple members and the overall "growth" and "green" development of the value network. Relative to a traditional value chain, the value chain in enterprises' green growth model (EGGM) shows the following changes in terms of coordination environment and goals.

(1) Coordination Environment

The internal and external coordination environment of enterprises greatly affects the implementation of EGGM [2]. The coordination environment includes external factors, such as environmental pressure and consumers' green preferences; and internal factors, such as environmental protection technologies and the structure of the value chain. The coordination environment changes in EGGM, thus influencing the choice of coordination mechanism.

(a) Environmental Pressure

To alleviate the resource and environmental pressure caused by waste, governments around the world have launched a series of environmental legislations that guide and regulate enterprises as they seek green transformation. Government regulation is a key driving force for enterprises to implement EGGM [3].

To gain a competitive advantage in the market, companies in the value chain must make green transformation investments, that is, products should be harmless to the environment and human health in terms of raw material supply, production, use, and disposal, and resource circulation and recycling should be promoted. In the early stage of the green transformation of enterprises, the maximization of the overall economic, environmental, and social benefits of the value chain network cannot be achieved solely by members' independent behavior. As the production, marketing, and procurement costs of the value chain in EGGM are often much higher than those of the traditional value chain, the green premium often hinders the development process of EGGM under the market mechanism. Consequently, EGGM can be successfully implemented if the government offers sufficient incentives.

Therefore, the active guidance and regulation of the government can help value chain members select coordination mechanisms in EGGM, and effectively achieve not only cooperation but also value co-creation and sharing with one another in the value chain. In practice, governments usually adopt laws and regulations, reward and punishment mechanisms, and financial measures as external factors of the value chain to influence the decision-making and coordination of value chain members.

(b) Consumers' Green Preferences

Environmentally conscious consumers tend to choose green products that are harmless to the environment, and they have a higher willingness to pay for low-carbon and energy-saving products [4]. Stronger public environmental consciousness motivates enterprises to implement EGGM.

In EGGM, the differences in consumers' willingness to pay for green products affect the product pricing strategies and profits of value chain members, which further influence the choice of value chain members' coordination mechanism. This part of the research focuses on the coordination of value chain members under the assumption that consumers have different utilities for green and nonsustainable products [5].

(c) Environmental Protection Technology

In EGGM, environmental protection technology presents a trend of transformation from end control to whole process management, including environmental control of all relevant activities, including the design, manufacture, and recovery of products [6].

The promotion of new environmental protection technologies increases the costs of enterprises and changes the existing decision-making and operation strategies of value chain enterprises. The coordination of various members in the traditional value chain is more about individual optimization, which makes it difficult to achieve the overall optimization of the entire value chain. Therefore, it is necessary to align individual goals with the overall optimization of EGGM.

(d) Structure of Value Chain

In EGGM, the leadership of value chain members also affects coordination decisions among members. In the process of implementing EGGM, core enterprise is responsible for cooperating with upstream and downstream enterprises. Core enterprises play leading roles in decision-making, and their green demand for intermediate products in the value chain directly affects the green behavior of their upstream and downstream enterprises through the procurement and sales chain. For example, Honda achieves green growth for the overall value chain by providing training programs and sharing its green knowledge with partners, including subcontractors or suppliers in the value chain [7].

In EGGM, members of the value chain are not always willing to bear the expenses for implementing green transformation; in this case, the technology and knowledge levels of other enterprises in the chain may be incompatible [4]. When the willingness of value chain members to invest in green transformation is low, the core enterprises of the value chain need to stimulate the enthusiasm of their subordinate enterprises.

Moreover, an effective revenue sharing mechanism should be implemented to ensure the stability of the value chain in EGGM.

In EGGM, the external and internal coordination environment shows changes. Given these influencing factors, the coordination goals of the value chain members in EGGM are as follows:

(2) Coordination Goals

Coordination provides a driving force for members to cooperate in the value chain to achieve global optimization and value co-creation. In terms of coordination goals, the value chain in EGGM aims to consider cost, environment, and security to achieve the innovation-driven coordination of "green" and "growth" goals and to achieve the global optimization of economic, social, and environmental benefits. At this stage, enterprises often encounter the following problems when implementing EGGM.

(a) Members Cannot Form a Stable Cooperation Relationship

Value chain members are often partially optimized because of their self-interest and varying goals. However, there is a lack of an effective value co-creation mechanism among enterprises to share the costs, risks, and benefits of value chain members. Moreover, upstream and downstream enterprises in the value chain cannot form a cooperative and stable value community and thus cannot realize overall optimization and value co-creation for the value chain. The top goals of decision making for the value community need to cover the overall economic, environmental, and social benefits of the whole value chain, the overall optimization of the value chain through coordination and cooperation mechanisms, and the establishment of EGGM for the whole value chain.

(b) Members Lack Motivation for Green Transformation

Most enterprises lack environment-friendly awareness, and green technology is a typical knowledge product that entails high research and development (R&D) investment and features increasing marginal returns, thus making it difficult to quickly generate expected outcomes. Consequently, enterprises lack motivation and incentives to invest in green transformation, leading to the rupture of the cooperation mechanism for green transformation [2].

Establishing a coordination mechanism for value chain management in EGGM is particularly important. Reasonable incentive mechanisms are mainly economic incentives, such as cost sharing, profit sharing, and technical subsidies, which ensure the stability of the green value network and the implementation of EGGM. The coordination of multiple entities in the value chain strengthens the cooperation between enterprises, realizes green transformation, and provides an impetus for the overall optimization of and the value co-creation in the value chain.

6.1.2 Value Co-creation and Sharing in EGGM

The research on value co-creation in EGGM mainly identifies enterprise value, consumer value, and value co-creation mechanism.

(1) Enterprise Value in EGGM

The enterprise value in the traditional value chain is solely the economic value, which is the total income obtained by the enterprise minus the total cost paid for it. Maximizing profits is the optimal goal of an enterprise. EGGM emphasizes the coordination of the economic and environmental performances of enterprises. Implementing EGGM and green transformation to realize value co-creation brings new value to enterprises, such as improved environmental performance, opportunities to enter new market segments, and sustainable competitive advantages [8].

(2) Consumer Value in EGGM

Traditionally, consumer value is defined as the difference between customers' benefits and costs. In EGGM, consumer value includes factors such as consumer loyalty and satisfaction with green brands [9]. Consumers pay more attention to the value brought by using green products that contribute to environmental protection and sustainable development, thus are willing to pay a premium for green value [4]. Consequently, additional markets and new income sources become available for enterprises and help them obtain economic benefits and generate more value. Consumers participate in the value co-creation process in EGGM, and their participation is beneficial for enterprises to integrate consumers' green demands and preferences into product design, meet their personalized green requirements, achieve higher product acceptance and reduced product failure risk, and decrease information asymmetry between consumers and manufacturers [10]. For example, companies such as Patagonia, BMW, and the Body Shop develop innovative ecofriendly products in collaboration with consumers, thereby demonstrating that the development of green products/services has become a new competitive advantage for companies [2].

(3) Value Co-Creation Mechanism in EGGM

The value co-creation mechanism in EGGM mainly identifies the best cooperation method among members of the value chain, determines the way to share green transformation costs and profits, and realizes an increase in consumer value, enterprise value, and enterprise alliance value, as well as the total value of the value chain [2]. Li et al. compared three green value co-creation strategies, that is, manufacturer and supplier, manufacturer and competitor, manufacturer and retailer value co-creation, for sharing the cost of green investment [4]. They showed that manufacturers can collaborate with competitors to co-create value and share the cost of green investments, resulting in higher-quality products, improved industry standards, and increased overall value. When value chain members share green costs, the products can be more environmentally friendly, and the overall profit of the value network can increase [2]. With the joint participation of all members, their respective resources become integrated into the process of co-creation, and they ultimately and share value with all stakeholders.

In EGGM, the value co-creation of green innovation and transformation faces challenges owing to the diverse characteristics, interests, and goals of different stakeholders. Therefore, it is necessary to explore the value co-creation mechanism in EGGM, establish coordination among value chain members, ensure that members are motivated to implement EGGM, and allocate the economic and environmental value created by the value chain through a reasonable mechanism.

6.2 Path of Coordination Among Value Chain Members in EGGM

The value chain in EGGM is composed of multiple members, and these members make decisions independently to maximize their own goals. This condition leads to double marginalization and hinders the overall optimization of the value chain. Therefore, cooperation should be established among value chain members through measures such as technical alliances or revenue sharing to achieve an all–win situation for all members and overall optimization of the value chain.

Contracts are commonly used in member coordination. Classic contracts include wholesale price, buyback, revenue sharing, and quantity discount contracts [11]. The main purpose of these contracts is to align conflicting interests in the value chain, avoid non-optimal results caused by decentralized decision making, and coordinate the profits of a nonvertically integrated value chain close to the centralized scenario level. Other contracts include quantity flexible, sales rebate, transfer payment, cost sharing, and two-part tariff contracts. Given the external and internal driving factors in implementing EGGM, there are three main streams of literature on the contract coordination of value chain members.

6.2.1 Coordination of Value Chain Members Considering Government Environmental Regulations

The research on the coordination of value chain members considering government environmental regulations mainly focuses on the optimal method of government regulations and the profit sharing of members. The environmental control methods adopted by the government usually include regulatory behavior and economic incentive behavior.

From the perspective of government regulations, Xie studied the impact of the threshold energy saving level set by the government on the actual energy saving level and the price of green products. The results indicate that the government's supervision promotes the energy saving investment of enterprises, improves the energy saving level in the production process, and coordinates members with wholesale price, profit sharing, and lump sum transfer contracts [12]. From the perspective of government economic incentives, Zhang and Yousaf proposed a two-part tariff contract between manufacturers and retailers involving government intervention in terms of taxes or subsidies, and proved that such contract can improve the green performance of the value chain [13]. In terms of product recovery, Heydari et al. considered the case in which a retailer offers a discount, in addition to government incentives, for consumers who return used products; their results indicated that governments' tax exemptions and subsidies, quantity discount and increasing fee contracts can increase the number of remanufactured products and the overall performance of the value chain [14].

6.2.2 Coordination of Value Chain Members Considering Consumers' Green Preferences

The second stream of literature focuses on the influence of consumers' green preferences on the decision-making, including pricing, profit, and coordination of value chain members. Consumers' green preferences are reflected in a higher willingness to pay for green products. Cao and Zhang assumed that consumers have different utilities for green products and traditional products and examined the coordination strategy between manufacturers and their upstream suppliers [5]. Zhang et al. studied the impact of consumer environmental awareness on order quantity and member coordination in a value chain consisting of a manufacturer and a retailer [15]. In addition, some studies have integrated the influence of consumers and governments on member coordination. Hafezalkotob studied competitive value chains for green and nongreen products and conducted a game analysis on the basis of direct government tariffs and tradable permits [16].

6.2.3 Coordination of Value Chain Members Considering Green Cooperative Investment

Green technological innovation and transformation often require cooperation among members of the value chain. Cooperative investment has the following advantages: it achieves higher economies of scale, reduces risks, reduces duplication of investment, increases the total investment volume, accumulates more technical knowledge, and avoids free riding. Chen et al. discussed green R&D cooperation among enterprises. In the cooperation process, the two parties first cooperate to make strategic decisions on green R&D investment, and then decide on wholesale and retail prices [17]. By comparing cooperative and noncooperative models, they investigated the impact of green R&D cooperation, technology spillovers, and the value chain power relationship on economic, environmental, and social performances. In previous studies, green cooperative investment between enterprises was often realized through cost sharing or revenue sharing contracts.

Roma and Perrone proposed three cost sharing contracts, namely, quantity proportional, total margin proportional, and fixed share mechanisms; and compared the effects of the three contracts on profits and total welfare [18]. Yang et al. studied horizontal and vertical cooperation in two green value chains under a revenue sharing contract, and found that vertical cooperation leads to higher carbon emission reduction rates and lower retail prices and that horizontal cooperation harms retailers' profits and consumer welfare [19]. Bai et al. used a revenue sharing contract to improve the profit and carbon emission reduction level under a decentralized case such that they match the performance under a centralized case [20].

The existing research mainly focuses on the individual decentralized decision-making of members. However, each member can play cooperative games to form a coalition. Under the decision of maximizing the overall interests of the coalition, members can cooperate in "profit sharing" or "cost sharing" fairly. The Shapley value method measures profit allocation based on expected marginal revenue.

Ghadimi et al. used the Shapley value method to study the fair allocation of profits among three members, including a manufacturer and two retailers, to achieve value chain coordination [21]. Zhang and Liu considered that market demand is affected by the green degree of the product and showed that the profit under cooperative decision-making is better than that under a noncooperative game [22]. Through revenue sharing, Shapley value coordination, and asymmetric Nash negotiation mechanisms, members are motivated to cooperate in producing and selling green products.

In summary, most existing studies focused on using contracts to coordinate supply profit and on providing incentives for green investment. Meanwhile, there is little research that quantitatively analyzes the coordination mechanism with consideration of the impacts of the government and consumers on the value chain system for the implementation of EGGM. The coordination goals in EGGM not only include costs and profits but also extend to the environment and safety perspectives. Through contract design and incentive mechanisms, this study considers the effects of government and consumer incentives and the supervision of enterprises, followed by value sharing among different enterprises in the value chain. The former consideration mainly includes the incentive and supervision mechanisms of the government and society to regulate enterprise behavior. These mechanisms include the government's reward and punishment mechanism, subsidies, and the establishment of carbon emission trading mechanisms. The latter consideration mainly involves the contract design between different enterprise entities in the value chain, e.g., green cost sharing.

6.2.4 Research Gap

(1) Coordination subjects and goals: Various studies have investigated coordination mechanisms. In contrast to these studies, the current research focuses on analyzing the driving and impact factors of enterprises implementing EGGM and the selection of coordination mechanisms among members of the value chain. In EGGM, consumers participate in value creation activities, such as value discovery, value creation, and value transfer. The interaction effects among enterprises, governments, and consumers promote enterprises' green development. In EGGM, the selection of the coordination mechanism among value chain members need to be addressed to ensure that enterprises have the motivation to achieve their "green" and "growth" goals. Previous studies rarely discussed coordination mechanism selection and profit sharing among members of the value chain in EGGM. For the topic of achieving the economic and environmental goals of value chain members, this chapter considers internal and external drivers in investigating the coordination mechanism of green transformation investment by value chain members.

(2) Coordination methods: A stream of literature has considered the coordination of supply chains. Previous research focused on using contracts to solve the problem of insufficient green investment incentives. Relatively few studies have used cooperative game methods, such as the Shapley value method, for member profit sharing in EGGM. Therefore, this chapter considers two internal coordination methods, that is cost sharing contract and the Shapley value method, to coordinate the members of the value chain and thereby build a value co-creation and sharing mechanism. The external driving mechanism considers government subsidies for promoting the green transformation investment of value chain members. This study uses the internal and external dual driving methods to coordinate, motivate, and conduct cooperative games among value chain members and to ultimately reveal the value sharing and co-creation mechanism in EGGM.

6.3 Value Co-creation and Sharing Model of Value Chain Members

Governments have set strict environmental regulations, and consumers have a growing interest in green products. More consumers with environmental awareness favor green products with healthy, energy-saving, and pollution-free features. EGGM is driven by the internal and external environment of enterprises. In a stable internal and external environment, enterprises often lack the motivation to invest in innovative technology and management systems to achieve better green benefits. Therefore, as described in this section, the characteristics of value co-creation in EGGM are studied, and a value co-creation and sharing mechanism is designed to achieve effective cooperation, decision-making, and coordination among members of the value chain in EGGM.

6.3.1 Characteristics of the Value Chain Co-creation Mechanism in EGGM

Relative to that in the traditional value chain, value co-creation in EGGM has the following characteristics.

(1) Reducing the Risks and Costs of Environmental Regulations

Traditional value chain enterprises often incur high costs when dealing with hazardous materials and wastes, whereas value chain companies in EGGM avoid or reduce the use of hazardous materials and hazardous waste through green design and recycling networks. As companies reduce environmental impact, they also reduce the cost of environmental management, such as the cost of emission reduction, and the penalties under environmental regulations [4]. In this way, the economic and environmental benefits of enterprises are increased, and the value added and co-creation across the value chain are achieved.

(2) Extending the Green Market and Enhances Competitiveness

Given their awareness of environmental protection, consumers are paying more attention to green products and remanufactured products, and they are willing to pay higher costs for greener products. Enterprises implementing EGGM and investing in innovation meet consumers' needs and gain differentiated competitive advantages [23], which can effectively protect them from fierce price competition. With the expansion of the market for green products, enterprises have economies of scale, thus achieving win–win outcomes through economic and environmental benefits, which promote the implementation of EGGM.

(3) Promoting Environmental Friendliness and Resource Recycling

Apart from cost, EGGM increases the efficiency of enterprise resources and energy use, and it makes enterprises more competitive [24]. Relative to that in the traditional value chain, value co-creation in EGGM requires all members, including suppliers, manufacturers, retailers, consumers, recyclers, to form a stable green and environmental cooperation relationship and avoid using hazardous materials in the product design stage to minimize the environmental pollution generated by products throughout their life cycles. Meanwhile, recycling, remanufacturing, and refurbishing used products, by-products, waste, etc. save resources and energy, improve the recovery efficiency of resources, and add value to the value chain.

6.3.2 Value Co-creation Mechanism of Value Chain Members Considering the Externality of Green Investment

Government regulations and consumers' preferences for green products have forced enterprises to pay more attention to the environmental impact of their products. Enterprises have invested in green transformation, and an increasing number of green products have appeared in the market, e.g., energy-saving air conditioners and new energy vehicles.

In practice, retailers may sell products from multiple competing manufacturers. Relative to traditional product manufacturers, green product manufacturers carry out green transformation by improving technology in product design and production and investing in a certain degree of product greening efforts, thereby reducing product energy and raw material consumption, as well as waste and environmental hazard emissions. These efforts are likely to be favored by consumers with green preferences, increase demand and sales, and make green products competitive. However, transformation investment inevitably increases the cost of green products. Meanwhile, manufacturers' green investments may have externalities; green investments increase their own sales while other members, including retailers and competitors, also benefit. If the higher production costs of green manufacturers cannot be compensated for in terms of sales prices, the motivation for producing green products is likely to be affected. For example, BYD[1] has invested in green transformation by creating a lithium iron phosphate battery system. This system has some advantages, such as small size and light weight, versatility in deployment, manufacturing that meets the Restriction of Hazardous Substances Directive standard, and absence of harmful substances. Green technology has been applied to multiple BYD car models. However, the development of the industry has hit a major roadblock with sharply falling subsidies and weak demand for passenger electric vehicles (EVs). As a result of the lower-than-expected sales of EVs, BYD is under huge financial and operational pressure with high green technology investment and huge labor costs. Therefore, BYD has started selling in-vehicle batteries to other companies. The move comes as BYD seeks to expand the scale of its battery manufacturing business by supplying to other companies, including DongFeng Motor. It has also shared its green technologies to form alliances with other vehicle producers instead of simply using the key EV component it produces in its own products, thereby further boosting production efficiency. BYD is making a long-term shift in its lithium-ion battery strategy from internal supply to external marketization. In other words, BYD's previous rival becomes a BYD battery customer and forms an alliance with BYD. Under these circumstances, the promotion of cooperation among enterprises in the value chain, the sharing of green technology cost, and the consideration of the value co-creation mechanism among members are urgent problems that BYD needs to solve.

We aim to address the following issues: designing a value co-creation and sharing mechanism when two competing manufacturers sell their products to the same

[1] http://www.juda.cn/news/101824.html.

retailer, achieving effective cooperation among value chain members, and ultimately realizing the overall optimization of the value chain and environmental friendliness in EGGM.

We identify the factor that drives value chain members to invest in green transformation, ensure that enterprises have the motivation to achieve "green" and "growth" goals, and coordinate the value chain from internal and external dual-driven coordination mechanisms. This chapter studies a value chain system composed of a green product manufacturer, a nongreen product manufacturer, and a retailer. Moreover, game theory is used to solve optimal production, pricing, and green transformation investment decisions. Finally, the value chain system is coordinated using internal methods, that is, Shapley value method and cost sharing contract, and external method, that is, government subsidies.

(1) Internal Value Co-Creation Mechanism

(a) Basic Model

We consider a value chain system that consists of two manufacturers and one retailer. Two manufacturers, G and N, first produce green and nongreen products, and decide their wholesale price w_G, w_N and green level m. Meanwhile, the retailer decides the retail price of the two products p_G, p_N to maximize profits.

Assumption 1: Green products are functionally identical to nongreen products because the green manufacturer has invested in emission reduction, which increases production costs. Green transformation investment reduces emissions during the manufacturing process of green products; thus, some consumers with environmental awareness prefer to buy green products. We set product demand as a linear function of the selling price. The demand for green and nongreen products is as follows [25]:$d_G = a - p_G + bp_N + \gamma m$ and $d_N = a - p_N + bp_G$, where a is basic market demand, b represents the cross-price sensitivity of the product to the substitutable product, where $a > 0, b > 0$. γ denotes the sensitivity of consumers to green investment, and m is the green level of the product.

Assumption 2: The green manufacturer incurs a quadratic green transformation investment cost of ηm^2 [26], depending on the green level of products. A higher η means that the green manufacturer's transformation investment is more costly or less efficient.

Assumption 3: As manufacturers have greater bargaining power over the retailer, we implement a Stackelberg game in which the manufacturer is the leader and the retailer is the follower [27]. This research uses backward induction to ensure subgame perfection. The model parameters are summarized, as shown in Table 6.1:

(i) Centralized Model (Fig. 6.1)

The profit function for centralized case can be written as:

$$\max_{p_G, p_N, m} \pi = (p_G - c_G)(a - p_G + bp_N + \gamma m) + (p_N - c_N)(a - p_N + bp_G) - \eta m^2$$

We obtain:

$$m = \frac{((1-b)c_G - a)(b+1)\gamma}{4b^2\eta + \gamma^2 - 4\eta}$$

$$p_G = \frac{2\left(b^2 c_G - ba - a - c_G\right)\eta + \gamma^2 c_G}{4b^2\eta + \gamma^2 - 4\eta}$$

Table 6.1 Notations of parameters

Parameter	Definition
a	Intrinsic demand of products
b	Cross-price sensitivity of the product to the substitutable product
w_G	Wholesale price of green product
w_N	Wholesale price of nongreen product
c_G	Manufacturing cost of green product
c_N	Manufacturing cost of nongreen product
p_G	Selling price of green product
p_N	Selling price of nongreen product
γ	Consumers sensitivity of green investment
m	Product's green level
η	Cost index of green level
d_G	Consumer demand for green product, with $d_G = a - p_G + bp_N + \gamma m$
d_N	Consumer demand for non-green product, with $d_N = a - p_N + bp_G$
t	Cost sharing index
τ	Government subsidy index

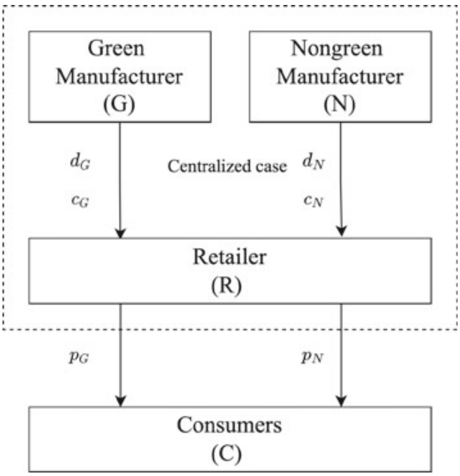

Fig. 6.1 Structure of the value chain under centralized case

$$p_N = \frac{4\left(b^2 c_N - ba - a - c_N\right)\eta + \gamma^2(c_G b + a + c_N)}{8b^2\eta + 2\gamma^2 - 8\eta}$$

(ii) Decentralized Model (Fig. 6.2)

According to assumption 3, the manufacturer is the leader, and the retailer is the follower. First, manufacturers determine the wholesale price w_G, w_N and product green level m to maximize their own profits. The retailer then decides the retail price of green products p_G and nongreen products p_N. The member's product function are as follows:

The green manufacturer:

$$\max_{w_G, m} \pi_G = (w_G - c_G)(a - p_G + bp_N + \gamma m) - \eta m^2$$

The nongreen manufacturer:

$$\max_{w_N} \pi_N = (w_N - c_N)(a - p_N + bp_G)$$

The retailer:

$$\max_{p_G, p_N} \pi_R = (p_G - w_G)(a - p_G + bp_N + \gamma m) + (p_N - w_N)(a - p_N + bp_G)$$

We obtain

$$m = \frac{\left(2c_G - b^2 c_G - (a + c_N)b - 2a\right)\gamma}{4b^2\eta + 2\gamma^2 - 16\eta}$$

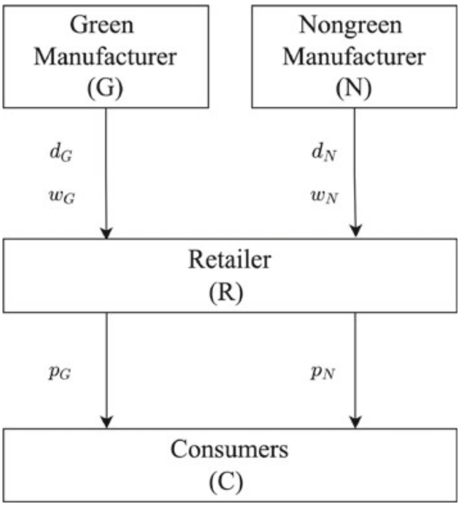

Fig. 6.2 Structure of the value chain under decentralized case

$$w_G = \frac{((-2a - 2c_N)b - 4a - 4c_G)\eta + \gamma^2 c_G}{2b^2\eta + \gamma^2 - 8\eta}$$

$$w_N = \frac{((-4a - 4c_G)b - 8a - 8c_N)\eta + \gamma^2(bc_G + a + c_N)}{4b^2\eta + 2\gamma^2 - 16\eta}$$

$$p_G = \frac{(1 - b^2)w_G^* + \gamma m^* + (b + 1)a}{2(1 - b^2)}$$

$$p_N = \frac{(1 - b^2)w_N^* + b\gamma m^* + (b + 1)a}{2(1 - b^2)}$$

(b) Shapley Value Coordination

(i) Shapley Value Method

In practice, the noncooperative decentralized case always leads to "double marginalization", which reduces the profits across the value chain. The Shapley value method can fairly allocate costs or profits according to the marginal contribution of participants. Therefore, the Shapley value method shares the R&D costs and effort costs of members, reduces the financial pressure of investors, and simultaneously solves the free rider effect among members, thereby achieving the effect of motivating the members of the value chain. The basic principle of the Shapley value method is as follows:

$I = \{1, 2, \cdots, n\}$ denotes a set of all players, which is also called the grand coalition. The coalition formed by several players can be represented as s. Obviously, coalition s is a subset of I, where $s \subseteq I$. $v(s)$ is the maximum payoff of coalition s, and the corresponding payoff equals 0 when the set is empty, where $v(\emptyset) = 0$.

Superadditivity: For any payoff $v(s)$ of coalition s of I, it has superadditivity, that is, $v(s_1 \cup s_2)) \geq v(s_1) + v(s_2)$, $s_1 \cap s_2 = \emptyset . v(s)$ is the characteristic function defined on set I, representing the payoff of cooperation. The formula reflects "1 + 1 > 2," which means that benefits allocated to each member in the cooperative coalition are greater than the benefits when they do not cooperate. The maximum cooperative benefit is $v(I)$.

Shapley value: To allocate the system's payoff, it is necessary to determine the weight of each player and the corresponding marginal contribution. $\phi_i(v)(i = 1, 2, \cdots, n)$ denotes the accessible cooperation payoff of player i of set I, that is, the Shapley value. Then, the allocation of benefits during cooperation can be expressed as $\phi(v) = (\phi_1(v), \phi_2(v), \cdots \phi_n(v))$, where $\sum_{i=1}^{n} \phi_i(v) = v(I)$ and $\phi_i(v) > v(i), i = 1, 2, \cdots, n$.

The Shapley value of each member is given as follows:

$$\phi_i(v) = \sum_{i \in s(i)} w(|s|)[v(s) - v(s \backslash i)] \quad i = 1, 2, \cdots n(Shapley\ value)$$

$$w(|s|) = \frac{(n - |s|)!(|s| - 1)!}{n!}(Weight)$$

where $s(i)$ is all subsets that contains member i of set I, $|s|$ indicates the number of players in coalition s, n is the number of all game players in I, and $w|s|$ represents the weight that is actually the probability that a member contributes to the coalition. In $w(|s|) = \frac{(n-|s|)!(|s|-1)!}{n!}$, $n!$ is the number of permutations of n members, $(|s|-1)!$ represents the number of permutations of the former members of the coalition before the entry of member i, and $(n-|s|)!$ denotes the number of permutations of the latter members after the entry of member i. $v(s)$ denotes the payoff of coalition s, and $v(s\backslash i)$ is the payoff of coalition s minus member i's payoff. After member i joins the coalition s, its marginal payoff can be denoted as $v(s) - v(s\backslash i)$, that is, member i' contribution to the coalition.

(ii) Partial Coalition:

When the green and nongreen manufacturers form a coalition (GN coalition), the profit function is as follows:

GN coalition:

$$\max_{w_G, w_N, m} \pi_{GN} = (w_G - c_G)(a - p_G + bp_N + \gamma m) - \eta m^2 + (w_N - c_N)(a - p_N + bp_G)$$

The retailer:

$$\max_{p_G, p_N} \pi_R = (p_G - w_G)(a - p_G + bp_N + \gamma m) + (p_N - w_N)(a - p_N + bp_G)$$

We obtain

$$m = \frac{\left(c_G - b^2 c_G - ba - a\right)\gamma}{8b^2\eta + \gamma^2 - 8\eta}$$

$$w_G = \frac{\left(4b^2 c_G - 4ba - 4a - 4c_G\right)\eta + \gamma^2 c_G}{8b^2\eta + \gamma^2 - 8\eta}$$

$$w_N = \frac{\left(8b^2 c_N - 8ba - 8a - 8c_N\right)\eta + \gamma^2(bc_G + a + c_N)}{16b^2\eta + 2\gamma^2 - 16\eta}$$

$$p_G = \frac{\left(2b^2 c_G - 6ba - 6a - 2c_G\right)\eta + \gamma^2 c_G}{8b^2\eta + \gamma^2 - 8\eta}$$

$$p_N = \frac{\left(8b^2 c_N - 24ba - 24a - 8c_N\right)\eta + (3bc_G + 3a + c_N)\gamma^2}{32b^2\eta + 4\gamma^2 - 32\eta}$$

When the green manufacturer and the retailer form a coalition (GR coalition), the profit function is as follows:

GR coalition:

$$\max_{p_G, p_N, m} \pi_{GR} = (p_G - c_G)(a - p_G + bp_N + \gamma m) - \eta m^2 + (p_N - w_N)(a - p_N + bp_G)$$

The nongreen manufacturer:

$$\max_{w_N} \pi_N = (w_N - c_N)(a - p_N + bp_G)$$

We obtain

$$m = \frac{\left(c_G - b^2 c_G - ba - a\right)\gamma}{4b^2\eta + \gamma^2 - 4\eta}$$

$$w_N = \frac{a + bc_G + c_N}{2}$$

$$p_G = \frac{\left(2b^2 c_G - 2ba - 2a - 2c_G\right)\eta + \gamma^2 c_G}{4b^2\eta + \gamma^2 - 4\eta}$$

$$p_N = \frac{4(b+1)\left(b^2 c_G + (a + c_N - c_G)b - 3a - c_N\right)\eta + (3c_G b + 3a + c_N)\gamma^2}{16b^2\eta + 4\gamma^2 - 16\eta}$$

When the non-green manufacturer and the retailer form a coalition (NR coalition), the profit function is as follows:

NR coalition:

$$\max_{p_G, p_N} \pi_{NR} = (p_N - c_N)(a - p_N + bp_G) + (p_G - w_G)(a - p_G + bp_N + \gamma m)$$

The green manufacturer:

$$\max_{w_G, m} \pi_G = (w_G - c_G)(a - p_G + bp_N + \gamma m) - \eta m^2$$

We obtain

$$m = \frac{(c_G - bc_N + a)\gamma}{\gamma^2 - 8\eta}$$

$$w_G = \frac{\gamma^2 c_G - (4bc_N + 4a + 4c_G)\eta}{\gamma^2 - 8\eta}$$

$$p_G = \frac{\begin{array}{c}\left(1-b^2\right)\left(4\eta(bc_N+a+c_G)-\gamma^2 c_G\right)\\ -(b+1)a(\gamma^2-8\eta)+\gamma^2(bc_N+a-c_G)\end{array}}{2(b^2-1)(\gamma^2-8\eta)}$$

$$p_N = \frac{(b^2c_N-ba-a-c_N)(\gamma^2-8\eta)+b\gamma^2(bc_N+a-c_G)}{2(b^2-1)(\gamma^2-8\eta)}$$

(iii) Grand Coalition

The grand coalition (GNR coalition) is consistent with the centralized case. The green manufacturer's Shapley values are as follows.

The green manufacturer's payoff is

$$\phi_G^*(v) = \pi_G^*/3 + (\pi_{GN}^* - \pi_N^*)/6 + (\pi_{GR}^* - \pi_R^*)/6 + (\pi^* - \pi_{NR}^*)/3$$

Similarly, the nongreen manufacturer's payoff is

$$\phi_N^*(v) = \pi_N^*/3 + (\pi_{GN}^* - \pi_G^*)/6 + (\pi_{NR}^* - \pi_R^*)/6 + (\pi^* - \pi_{GR}^*)/3$$

The retailer's payoff can be obtained as

$$\phi_R^*(v) = \pi_R^*/3 + (\pi_{GR}^* - \pi_G^*)/6 + (\pi_{NR}^* - \pi_N^*)/6 + (\pi^* - \pi_{GN}^*)/3$$

(b) Cost-Sharing Contract

Next, we set the retailer to share the green investment costs of the green manufacturer, thereby motivating manufacturers to aim for green transformation and maintaining the cooperative relationship among value chain members. The retailer shares $t(0 \le t \le 1)$ proportion of green investment costs with the green manufacturer [28]. The profit function of each member is as follows:

The profit function of the green manufacturer is

$$\max_{w_G,m} \pi_G = (w_G - c_G)(a - p_G + bp_N + \gamma m) - (1-t)\eta m^2$$

The profit function of the nongreen manufacturer is

$$\max_{w_N} \pi_N = (w_N - c_N)(a - p_N + bp_G)$$

The profit function of the retailer is

$$\max_{p_G,p_N} \pi_R = (p_G - w_G)(a - p_G + bp_N + \gamma m) + (p_N - w_N)(a - p_N + bp_G) - t\eta m^2$$

We obtain

$$m = \frac{\left(2c_G - b^2 c_G - (a + c_N)b - 2a\right)\gamma}{4b^2\eta(1-t) + 2\gamma^2 - 16\eta(1-t)}$$

$$w_G = \frac{\gamma^2 c_G - 2((a + c_N)b + 2a + 2c_G)\eta(1-t)}{2\left(b^2 - 4\right)(1-t)\eta + \gamma^2}$$

$$w_N = \frac{\gamma^2(c_G b + a + c_N) - 4((a + c_G)b + 2a + 2c_N)\eta(1-t)}{4\left(b^2 - 4\right)\eta(1-t) + 2\gamma^2}$$

$$p_G = \frac{(1-b^2)w_G^* + \gamma m^* + (b+1)a}{2(1-b^2)}$$

$$p_N = \frac{(1-b^2)w_N^* + b\gamma m^* + (b+1)a}{2(1-b^2)}$$

We compare the coordination effects of the two internal mechanisms and the economic and environmental parameters of internal and external coordination mechanisms.

(2) External Value Co-Creation Mechanism: Government Subsidies

Green investment has a strong positive externality, and individual benefits are less than the overall social benefits, thus making enterprises lack the internal motivation to invest in green transformation. Therefore, government subsidies are needed to promote the implementation of EGGM by enterprises.

Assumption 4: To encourage the manufacturer to produce green products, the government directly subsidizes the green manufacturer on green level of products. We assume that τm is the unit product subsidy given by the government [29], where m is the green level of products and τ is the unit product subsidy coefficient related to the green level.

(a) Centralized Model (Fig. 6.3)

The profit function for the centralized case is

$$\max_{p_G, p_N, m} \pi = (p_G + \tau m - c_G)(a - p_G + bp_N + \gamma m) + (p_N - c_N)(a - p_N + bp_G) - \eta m^2$$

We obtain

$$m = \frac{(b+1)((b-1)(c_N b + a - c_G)\tau - \gamma(c_G b + a - c_G))}{\left(1 - b^2\right)\tau^2 + \left(-2b^2\gamma + 2\gamma\right)\tau + 4b^2\eta + \gamma^2 - 4\eta}$$

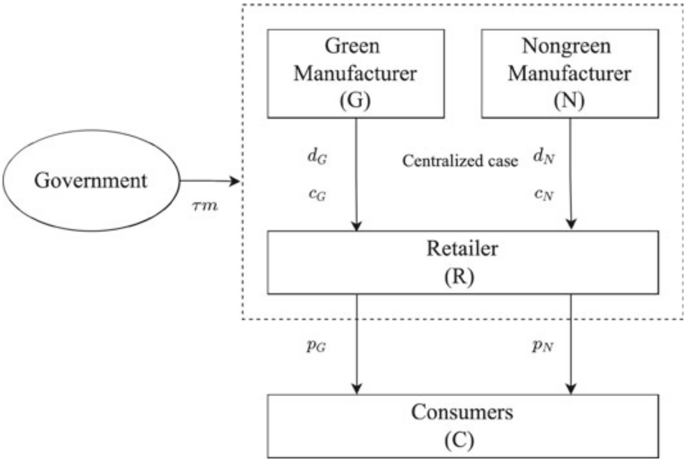

Fig. 6.3 Structure of the value chain considering government subsidies under centralized case

$$p_G = \frac{\begin{array}{l} -(b+1)\left(c_N b^2 + (a-c_N)b - 2a\right)\tau^2 + \left(b^2 c_G + (3a-c_N)b + 2a + 2c_G\right)\gamma\tau \\ + 4b^2\eta c_G - 4ab\eta + 2\gamma^2 c_G - 4\eta(a+c_G) \end{array}}{\left(2-2b^2\right)\tau^2 + \left(-4b^2\gamma + 4\gamma\right)\tau + 8b^2\eta + 2\gamma^2 - 8\eta}$$

$$p_N = \frac{\begin{array}{l} (b+1)(-c_N b + a + c_N)\tau^2 + \gamma\left(-3c_N b^2 + (a+c_G)b + 2a + 2c_N\right)\tau \\ + (c_G b + a + c_N)\gamma^2 - 4\eta(b+1)(-c_N b + a + c_N) \end{array}}{\left(2-2b^2\right)\tau^2 + \left(-4b^2+4\right)\gamma\tau + 8b^2\eta + 2\gamma^2 - 8\eta}$$

(b) Decentralized Model (Fig. 6.4)

The profit function of the green manufacturer is

$$\max_{w_G, m} \pi_G = (w_G + \tau m - c_G)(a - p_G + bp_N + \gamma m) - \eta m^2$$

The profit function of the nongreen manufacturer is

$$\max_{w_N} \pi_N = (w_N - c_N)(a - p_N + bp_G)$$

The profit function of the retailer is

$$\max_{p_G, p_N} \pi_R = (p_G - w_G)(a - p_G + bp_N + \gamma m) + (p_N - w_N)(a - p_N + bp_G)$$

We obtain

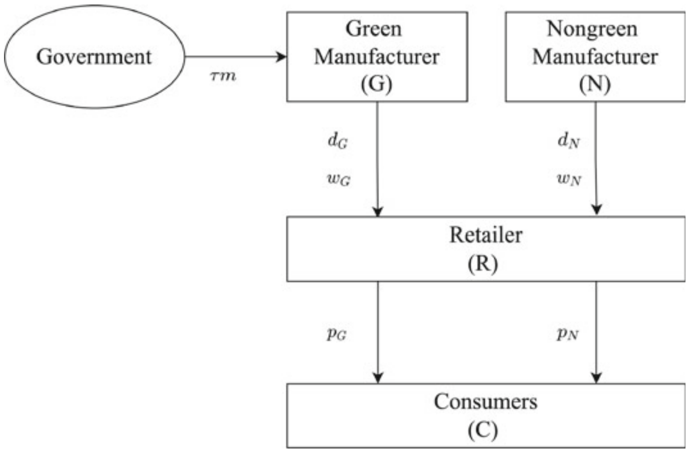

Fig. 6.4 Structure of the value chain considering government subsidies under decentralized case

$$m = \frac{\left(2c_G - b^2c_G - (a + c_N)b - 2a\right)(\tau + \gamma)}{\left(4\eta - \gamma\tau - \tau^2\right)b^2 + 2\tau^2 + 4\gamma\tau + 2\gamma^2 - 16\eta}$$

$$w_G = \frac{\begin{array}{c}((a + c_N)b + 2a)\tau^2 + \gamma((a + c_N)b + 2a + 2c_G)\tau \\ - 4\eta(a + c_N)b + 2\gamma^2c_G - 8\eta(a + c_G)\end{array}}{\left(2 - b^2\right)\tau^2 + \left(-b^2\gamma + 4\gamma\right)\tau + 4b^2\eta + 2\gamma^2 - 16\eta}$$

$$w_N = \frac{\begin{array}{c}(ba + a + c_N)\tau^2 + ((a + c_G)b + 2a + 2c_N)\gamma\tau \\ + (bc_G + a + c_N)\gamma^2 - 4((a + c_G)b + 2a + 2c_N)\eta\end{array}}{\left(2 - b^2\right)\tau^2 + \left(-b^2 + 4\right)\gamma\tau + 4b^2\eta + 2\gamma^2 - 16\eta}$$

$$p_G = \frac{(1 - b^2)w_G^* + \gamma m^* + (b + 1)a}{2(1 - b^2)}$$

$$p_N = \frac{(1 - b^2)w_N^* + b\gamma m^* + (b + 1)a}{2(1 - b^2)}$$

By setting $a = 5, b = 0.4, \gamma = 0.5, c_G = 2.5, c_N = 1.5, \eta = 1, t = 0.5, \tau = 0.1$, we obtain the coordination results shown in Tables 6.2 and 6.3.

Through comparative analysis and numerical study, we obtain the following findings.

From the perspective of the internal coordination mechanism, the coordination of the Shapley value increases the profits of the green manufacturer, nongreen manufacturer, and retailer, as the Shapley value method allocates profits according to the marginal contribution of members. The Shapley value method solves the double marginalization problem, thus reducing the wholesale and retail prices of products, increasing sales volume, and enhancing the profit of the entire value chain. Consequently, each member of the value chain obtains more profit and achieves value co-creation and sharing among the value chain members. For the product green level, when the green manufacturer and retailer form a coalition, the green manufacturer is motivated to invest in the highest green level, which can effectively solve the externalities of green investment and promote green transformation. Second, the cost sharing contract can also effectively improve the green level of the green manufacturer; however, the retailer's sharing of green investment costs leads to an increase in the selling price of green products. In other words, the retailer transfers the costs to consumers. By contrast, the selling price of nongreen products decreases. Although the cost sharing contract can increase profits among members of the value chain, the Shapley value method has a better coordination effect.

From the perspective of the external coordination mechanism, when the government subsidizes the green product manufacturer, a price advantage for green products emerges, and their market share increases. Meanwhile, the market share of nongreen products decreases. Therefore, the government can use subsidy policies to effectively control the proportion of green and nongreen products in the market. Government subsidies increase not only the profits of green manufacturers but also the profits of retailers and the overall value chain because of the increase in sales of green products. However, nongreen manufacturers' profits decrease. This indicates that the profit increase in the market share of green products exceeds the decrease in the market share of nongreen products, thereby increasing profits in the overall value chain.

Table 6.2 Coordination results

Coordination methods		m	w_G	w_N	p_G	p_N	π_G	π_N	π_R	π
Internal coordination mechanism	Decentralized	0.27	4.65	4.18	6.29	6.57	2.25	3.60	4.89	10.73
	Shapley	\	\	\	\	\	2.73	3.91	5.88	12.52
	Cost sharing contract	0.56	4.73	4.20	6.70	6.33	2.33	3.63	4.92	10.88
External coordination Mechanism	Government subsidy (Centralized)	0.90	\	\	5.64	5.02	\	\	\	12.93
	Government subsidy (Decentralized)	0.32	4.65	4.18	6.59	6.30	2.28	3.59	4.95	10.82

Table 6.3 Shapley value method parameters

Coalition	m	w_G	w_N	p_G	p_N	π_{GN}	π_{GR}	π_{NR}	π_G	π_N	π_R
GN coalition	0.38	5.53	4.96	7.04	6.69	6.24	\	\	\	\	3.19
GR coalition	0.78	\	3.75	5.65	6.14	\	8.99	\	\	2.53	\
NR coalition	0.2	4.10	\	6.28	4.94	\	\	10.58	1.24	\	\

By comparing the profits of value chain members, the green levels of products, and the profits of the entire value chain under internal and external value sharing and co-creation mechanisms, we select the optimal coordination mechanism from the perspective of economic goals, i.e., value chain profits, and environmental goals, i.e., product green level. We find that the internal coordination mechanism can motivate the green manufacturer to invest in its green level, for which the Shapley value method can effectively coordinate the profits among value chain members to reach the optimal profits of the value chain relative to the level in the centralized case. The external coordination mechanism of government subsidies can effectively encourage enterprises to invest in green products and increase their market share. The government should subsidize enterprises in the early stage of green transformation so that they can maximize their own targets and optimize the overall profit of the value chain. At present, the green transformation of Chinese enterprises is still in its initial stage, the ability of green management in enterprises is low, and the adoption of environmental protection measures has yet to become a conscious behavior of enterprises. Therefore, at this stage, government subsidies remain the main driving force for enterprises to ensure value co-creation in EGGM. Through proper subsidies, the government can guide and motivate enterprises to adopt green technologies, carry out green transformation, and improve economic benefits to coordinate "green" and "growth" targets.

6.4 Summary

This chapter investigates the value co-creation and sharing mechanism of value chain members in EGGM, that is, their motivation for implementing EGGM. Specifically, this chapter analyzes the main external influencing factors, that is, government, consumers, and internal influencing factors, that is, enterprises' environmental protection technology and value chain structure, of coordination in EGGM. Then, it compares the value chain coordination environment, coordination targets, and changes in enterprise value, consumer value, and value co-creation in EGGM with those in the traditional value chain. Subsequently, this chapter analyzes the path of coordinating value chain members in EGGM. Finally, this chapter proposes internal and external value co-creation and sharing mechanisms, including Shapley value coordination, cost sharing contract coordination, and government subsidies, to promote effective cooperation, coordination, and value sharing among members of the value chain. Consequently, enterprises can achieve overall economic optimization and environmental friendliness for the value chain.

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Chapter 7
Green Product Design

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Abstract Green product design is a fundamental way to reduce environmental pollution and improve corporate performance and competitive advantage. The green product design practice reduces resource waste from the beginning and product environmental pollution in the entire life cycle process. Therefore, green product design is a key process for enterprises to implement green growth models. Existing studies on enterprises' green growth models show that, except for external institutional pressures, internal factors such as internal resources and managers' environmental perception and attitudes also play a vital role in driving enterprises to be greener. Meanwhile, with the development of the Internet, new media attention has been verified to become more powerful in enterprises' strategy adoption. This chapter explores the factors driving enterprises' green product design from internal and external aspects. It further explores the relationship between new media attention and top managers' environmental attitudes toward green product design from a new media and managerial attitude perspective. From the new media perspective, the results show that the new media attention can significantly enhance the impact of customer environmental pressure on top managers' positive environmental perceptions. Therefore, it promotes enterprises to implement a green transformation strategy. Furthermore, from the managerial attitude perspective, the results show that the manager's environmental attitude significantly moderates the relationship between resource management and organizational learning abilities, promoting the implementation of green product design. The research based on the new media

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and managers' environmental attitude perspective enriches the literature on institutional theory and resource-based view. Furthermore, it supports relevant policy-makers to implement strategies, such as the appropriate use of new media power and the manager's environmental attitude to motivate enterprises to implement green product design rather than strict environmental regulations.

7.1 Green Product Design and Enterprises' Green Growth Models

7.1.1 Concept of Green Product Design

(1) Green Product Design

Green products meet specific environmental protection regulations, causing little or no harm to the ecological environment, have low energy consumption and have the highest resource utilization rate in the entire life cycle [1]. Green product design is a proactive approach to integrate product design and environmental considerations without compromising its function and quality, including innovations for recovering product value throughout its life cycle before disposal; that is, it involves the entire life cycle of products from "cradle" to "end of life" [2]. The product design stage usually determines the types of pollutants discharged, solid and hazardous wastes generated, resources obtained, and energy consumed. Innovation and green design at this stage allow enterprises to find solutions to environmental problems. For example, China has strongly supported and encouraged the development of new energy vehicles in recent years, effectively reducing carbon dioxide emissions from the source.

(2) Implementation of Green Product Design

The contents of green product design are shown in the following four aspects. First, for green product design, product materials are marked to facilitate disassembly, such as using color or code, etc. Second, the interfaces between components that are easy to disassemble and repair are designed. Third, "life cycle assessment (LCA)" is used for product design. Fourth, standardized components that are easily reusable are used [3]. For example, marking product materials can help improve the efficiency of disassembly and installation during assembly, maintenance, and recycling. Modular and special product interface designs have been positive for product remanufacturing ability and automatic diagnosis of malfunction. For example, the modular design of Apple mobile phones and computers significantly improves the efficiency of Apple products in terms of maintenance and replacement. In addition, using clean technologies such as LCA can significantly minimize product costs and environmental problems during the life cycle and at the end of life [4]. Green product design is vital for sustainable development [5]. However, the uncertainty in environmental trends and regulations makes green product design more complex. Considering these complexities, enterprises can introduce green innovation into product design to obtain first-mover advantages to reduce this uncertainty. This includes obtaining new technology licenses, developing unique manufacturing capabilities, creating proprietary information, and providing sustainable competitive advantages for enterprises [6].

(3) Characteristics of Green Product Design

Green product design requires designers to combine resource, energy optimization, labor, natural environment protection, and production requirements of function, quality, service life, and cost in the design conception stage. And the characteristics of green product design are shown as follows. First, green product design can reduce environmental pollution through green product design. Therefore, products are harmless or do little harm to the environment from production, use, recycling, and even disposal. Because green product design requires enterprises to develop green designs during the design stage and select clean raw materials and technological processes during production, it helps customers produce no environmental or little pollution when using products, and the scrap products generate the least waste in the recycling process. Second, it can maximize the utilization rate of raw materials. Therefore, green products can minimize and reduce raw materials that are scarce, expensive, toxic, and harmful. Because green product design requires designers to simplify the product structure, properly use materials, make the parts and materials recycled and reused cleaner, and meet the basic functions of products in the design stage. Third, it can save energy to the greatest extent. Green products can lower energy consumption in their life cycle, maximize renewable energy, and adopt advanced technology to improve the utilization capacity to save energy to the greatest extent. For example, "the blade battery" developed by BYD, a powerful battery with new lithium iron phosphate technology, has higher safety than the traditional lithium battery and has obvious advantages in prolonged life span and endurance, finally, significantly reducing the environmental pollution.[1]

7.1.2 Goals of Green Product Design

As the center of green design, green product design considers the product's impact on resources and the environment during the entire life cycle. When considering the function, quality, development cycle, and cost of a product, it is also necessary to optimize relevant factors to minimize the overall negative environmental impact of the product in its manufacturing, use, maintenance, and recycling processes. Therefore, the product can meet the requirements of green environmental protection [7]. Basic thinking of green product design combines all the factors that affect the environment and pollution prevention measures into the product design stage; furthermore, it considers environmental performance as the main design goal and starting point

[1] https://en.byd.com/?s=the+Blade+Battery.

to minimize the product environment effect in the design stage. Therefore, green product design aims to protect the environment, reduce lifecycle costs, and improve enterprise performance [8].

(1) Environment Protection

The primary goal of green product design is to protect the environment and reduce the level of product environmental pollution. However, the level of product environmental pollution is mainly determined by the level of green products in the design stage. With the aggravation of environmental pollution, a green product design strategy has become a fundamental method to solve this environmental problem. Through green product design, the environmental pollution problem can be solved by reducing the use of toxic materials and using recyclable and degradable materials. For industrial design, the main goal of green product design is "3R1D," that is, reducing, recycling, reusing, and degradable [9]. It should reduce the consumption of materials, energy, and the emission of harmful substances, make the products and parts easy to classify, recover, recycle, reuse, and non-reusable components should be easily degradable. The characteristics of green product design in environmental protection are as follows: minimizing the use of non-renewable materials; avoiding the use of toxic materials; using renewable resources according to the replenishment rate of renewable resources; making the product easy to reuse, recycle, or degrade at the end of its life cycle. For example, Nike's "move to zero" series of sports shoes is a typical example that their raw materials are waste plastics. Through a series of green technologies, it can be recycled to reproduce and also can be 100% recycled at the end of life, truly achieving the goal of "3R1D".[2]

(2) Reducing Costs of Product Life Cycle

An additional goal of green product design is to reduce product life cycle costs. As resource and environmental pollution issues become severe in the manufacturing industry, the concept and content of green design have become the focus of green research. However, preliminary research about green design is mainly from the aspect of manufacturing technology. It only considers how to make greener products using manufacturing design schemes and technologies but does not consider green costs. Therefore, a cost–benefit analysis is required for further exploration. The traditional cost–benefit analysis of manufacturing holds that the product cost is the sum of the sales and manufacturing costs, excluding service and environmental pollution costs. Thus, the cost–benefit analysis of green manufacturing further considers the income of energy savings, reused parts, and recycled materials. Additionally, it considers the ecological cost savings caused by reducing pollution in product production, the reduction of environmental protection expenses during the product life cycle, and the disassembly, material regeneration, and other waste disposal costs. Therefore, implementing enterprises' green product design strategy reduces the manufacturing and

[2] https://news.nike.com/news/move-to-zero-spring-summer-2022-official-images.

sales costs and greatly reduces production costs in their entire life cycle, recycling, and scrap degradation stages.

(3) Improving Enterprises' Performance

Enterprise performance can be divided into economic, environmental, and social performance. Existing studies suggest that enterprises' green product design strategies can significantly improve their economic and environmental performance and obtain a sustainable competitive advantage. Green product design can significantly improve the reusable and recycling abilities of the product and the utilization efficiency of resources and energy by using the lowest lifecycle cost to design green products to reduce production costs and improve enterprises' economic performance. Integrating the green concept into an enterprise's product design can improve its financial performance by significantly reducing the risk of punishment for violating established environmental regulations and the relevant operational costs. In addition, an enterprise's green product design strategy significantly affects its environmental performance. By combining the "3R1D" into the product design stage, product environment pollution in the entire life cycle can be effectively reduced, and enterprises' environmental performance can be significantly improved [10]. Enterprises obtain good economic, social, and ecological performance through the green product design strategy. Enterprises can meet customers environmental protection needs through green product design and provide them with low-cost and high-quality products. It can improve customer satisfaction and loyalty, further, to obtain the recognition of various stakeholders and a good reputation, and improve corporate social performance. For example, BYD's successful R&D of "the blade battery" significantly reduces the production cost, provides higher safety, and prolongs the product life cycle.[3] Therefore, it improves an enterprise's economic, environmental, and social performance.

7.1.3 The Importance of Green Product Design for Enterprises' Green Growth Models

The core of enterprises' green growth model is to achieve green growth and overall optimization. Enterprises can reduce environmental pollution while achieving good economic, social, and operational performance. Green product design is well placed to help companies achieve a green transformation of the whole process from the source of the product and achieve sustainable growth by reducing costs and operational risks, which could achieve overall optimization. As a key step in the greening of products, green product design lowers production costs by increasing product reusability and recycling, thus effectively reducing environmental pollution and

[3] https://en.byd.com/?s=the+Blade+Battery+performance.

increasing efficiency through modular design. Green product design can reduce regulatory risk, lower operational costs, and enhance the economic and environmental performance of enterprises. Additionally, implementing a company's green product design strategy satisfies laws and regulations while meeting the environmental needs of customers. It reduces environmental pollution while gaining support from various stakeholders and improves the company's social reputation and image, achieving green and sustainable growth. Although green product design requires a large amount of capital, companies with a strong green product design can also help them earn more benefits.

For example, in September 2021, the Ministry of Industry and Information Technology of China announced the green product design enterprises and the MACO list. With a strong industry influence and market competitiveness, good business management status, and a leading position in the industry in the product market, MACO has established a sound management system for quality, environment, energy, and occupational health and safety. It has strong technical research and innovation capabilities, product design and development institutions, professional teams, well-known independent brands with obvious industry or regional characteristics, and strong representativeness, innovation, and replicability. By incorporating the concept and requirements of green design into the strategic planning of enterprise development, this company possesses the basic ability to carry out product life cycle evaluation to apply the basic database of green design and advanced design tools and methods. It can transform green design applications such as inspection and verification, measurement and testing, and large-scale production. Green design-related work has been carried out. The products meet the relevant standards for green design product evaluation or participation in formulating technical specifications, standards, or policies related to green design products. The proportion of green design products in the product design has increased annually. They are the production volume and output value leaders in the industry. Emphasis on green design and environmental planning is one of the main reasons for MACO's strong core competencies. The company has a reputation for being the cleanest factory in the world. With the introduction of the world's most advanced dust collection system, MACO's particulate matter has been tested by a third-party authority to be less than 1 mg/m, below the detection limit of the standard method, and is considered "undetectable." In the actual testing environment, the particulate matter emission concentration of the MACO factory is less than 20ug/m, reaching the international quality air standard of 0-25ug/m. It is far lower than the Chinese quality air standard of 0-50ug/m, achieving the "MACO miracle" of emission of the same standard as the international quality air in 2019. In October of the same year, MACO was officially awarded as the designated supplier for the China Pavilion at the 2020 Dubai World Expo.[4]

[4] http://www.meichao.com/

7.2 External Factors of Green Product Design

Green product design seeks to create products with the least environmental impact. This includes many activities, ranging from disassembly design (such as interface and component design) to broader life cycle assessment practices [11]. Although research and practices on green product design have been well developed, there are still obstacles to implementing them. These include external new media pressure, government rewards and punishments, customer demands and peer pressures, and enterprises' internal resources and organizational learning ability [12]. Motivations and abilities are key factors for success in implementing green product design practices. Therefore, the key factors affecting enterprises' green product design can be divided into external pressures and internal abilities. This section mainly explores external pressures from the perspective of new media attention.

7.2.1 The Influential External Factors of Green Product Design

With deteriorating environmental pollution, motivating enterprises to implement proactive environmental strategies such as green product design, which is the way to solve environmental pollution. Existing studies on the driving forces for encouraging an enterprise to implement green product design include external institutional pressure, top managers' environmental perception, and the new media supervision effect. However, with the establishment of China's environmental laws and regulations, the power of institutional pressure on enterprises' green product design has decreased. However, with the development of the Internet, the media, as one of the stakeholders, plays a more important role in enterprises' green transformation, especially new media. Media supervision can reduce enterprises' environmental pollution and amplify other external stakeholders' powers through their fast response speed and wide communication range, encouraging the implementation of green product design. For example, the Tengger Desert pollution case is famous for its high penalty amount (620 million RMB) in China.[5] When local governments and newspapers reported this case in 2012 and some pollution enterprises in this industrial park were punished by the government and environmental protection departments, they responded passively by covering up the pollution pool. However, when this pollution event was mentioned again by the government and other stakeholders, reported by the China Central Television (CCTV), and spread by new media in 2014, enterprises proactively implemented green transformation and green environmental strategies. Therefore, this section further explores the driving forces that promote enterprises to implement green product design and how new media works.

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[5] https://tv.cctv.com/2019/11/30/VIDERL5YzkmySZNq1kdXRPYW191130.shtml.

According to the literature review, existing studies mainly focus on institutional theory to explore how these regulatory, customer, and competitor pressures motivate enterprises to be greener. For example, the government can use the rewards and punishments pressure to motivate and drive enterprises to implement green innovation. Additionally, customers can support or resist enterprise-related products or services to influence their green product design. Competitors can affect the focal firm's perception of green strategy by promoting product design implementation and competitive advantage. However, most existing studies ignore the effects of new media attention on green product design [13]. With the development of new media, the supervision and incentive effects are more powerful. New media can significantly regulate the relationship between stakeholders and corporate environmental strategy by providing a communication platform for stakeholders. For example, in Nestle's incident, the boycott activities of NGOs by publishing their video on social platforms pushed Nestle to be greener, implement a proactive environmental strategy, and use sustainable palm oil.[6] However, acting as a "regulator" to regulate the impact of various stakeholders on enterprise strategy, whether the attitude of new media attention is positive or negative, new media attention can also promote strategic transformations through its reports.

Existing studies based on institutional theory mainly focus on the direct impact of institutional pressure on green product design without considering the mediation effect of top managers' environmental perception. However, top managers' attention and interpretation of external pressure to the external environment are critical to linking external pressures and enterprises' proactive environmental strategies [14]. The stronger the new media dissemination role in the external environment, the more obvious the amplification effect of new media attention, and their moderation effect between institutional pressures and top managers' environmental perception. Furthermore, new media attention has enhanced external institutional pressure through timely and extensive coverage of environmental needs from various stakeholders. This pushes top managers to perceive more opportunities toward the external environment and adopt a green product design strategy more willingly. Therefore, based on institutional theory and upper echelon theory, this section explores the motivational effects of external institutional pressures, new media attention, and top managers' environmental perceptions on green product design from the new media perspective, as shown in Fig. 7.1.

7.2.2 Green Product Design Model and Hypothesis from the Perspective of New Media Attention

Based on the literature review, we propose the following theoretical model (see Fig. 7.2) and further explain the relationship between various motivation factors.

[6] https://www.greenpeace.org/international/?s=Nestle&orderby=_score.

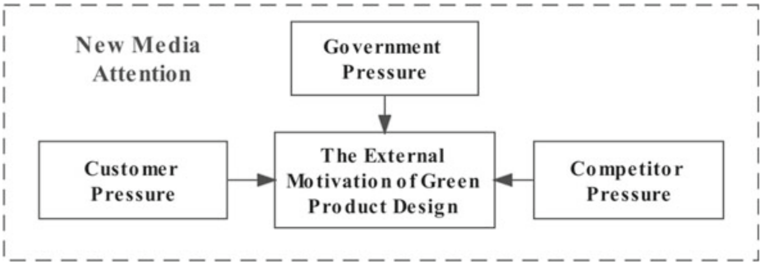

Fig. 7.1 The external motivation of green product design

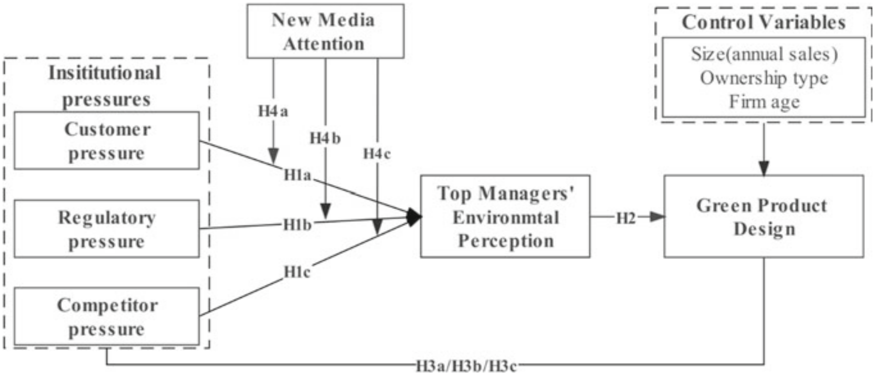

Fig. 7.2 Theoretical model

(1) Customer Pressure

Based on institutional pressure, some studies show that customer needs for green products or services are the second main driving force for enterprises to implement green product design [13]. Early studies on institutional pressure and enterprises' green product design indicated that the government's regulatory pressure was the main motivation to implement green transformation. However, with improving customers' environmental awareness, customers have become the main source of inspiration for enterprises' green transformation. This is because customers can directly affect enterprises' economic performance by supporting and resisting their products in the market. In addition, customers' support and loyalty to their products provide a good reputation and competitive advantage for enterprises' sustainable development. Therefore, actively responding to customers' environmental needs has become a top priority for top managers [15]. Implementing a green product design strategy can meet customers' environmental needs and significantly reduce the products' production and operational costs by implementing green behaviors, such as modular design and using reusable and easily recyclable materials in the product design stage. Therefore, implementing this strategy can significantly improve customer satisfaction and enhance enterprise performance and competitive advantage. The BYD's "the blade battery" is a case in point. Therefore, we propose the following hypothesis:

Hypothesis 1a: Customer pressure positively affects top managers' environmental perception.

(2) Regulatory Pressure

Regulatory pressure emanating from the government and relevant departments, and which is gradually viewed as the greatest driving force motivating top managers to implement green innovation [16]. There are two ways in which regulatory pressure encourages top managers percept these pressures as opportunity to adopt green product design. On the one hand, the government and relevant departments can reduce costs and market risks for the enterprise's green product design strategy by formulating relevant incentive policies, such as environmental protection subsidies, lowering taxes, and establishing green channels. For example, BYD is the leading electric vehicle enterprise in China, and the success of its green product design and innovative concept is based on the government's supportive policies. In addition to the relevant capital support and consumption subsidies, the government supports BYD's innovation and green product design by constructing infrastructure and charging piles [17]. On the other hand, the government can also improve rules regarding environmental criteria and strengthen the implementation of regulations and policies to promote reactive enterprises to become greener. Through such regulations, the government stipulated the target level of environmental performance and punished enterprises with poor compliance or even moved them out [18]. For example, as the Chinese "double carbon" goal strives to achieve a carbon peak by 2030 and carbon neutralization by 2060, many thermal power enterprises have been pushed to become greener.[7] Therefore, we propose the following hypothesis:

Hypothesis 1b: Regulatory pressure positively affects top managers' environmental perception.

(3) Competitor Pressure

In addition to regulatory and customer pressure, competitors who successfully implement green transformation strategies are also an important driving force motivating top managers toward green product design. Competitor pressure occurs when enterprises imitate competitors who have successfully carried out green transformations and attempt to copy their success [19]. The competitors' successful green transformation gives them the advantages of first-mover, unique market share, and market competitiveness. These advantages persuade enterprises to implement green product design and reduce the survival risk. Therefore, they need to be greener to maintain the market share and competitiveness of enterprises. By positively responding to competitor pressure, the enterprise can reduce the risks of uncertain results and green product design activities and obtain the legitimacy of entering the green market

[7] https://www.drc.gov.cn/DocView.aspx?chnid=379&leafid=1338&docid=2904498.

and getting scarce resources, for example, the success of NIO's new energy vehicle. Therefore, we propose the following hypothesis:

Hypothesis 1c: Competitor pressure positively affects top managers' environmental perception.

(4) Mediation Effect of Top Managers' Environmental Perception

According to upper echelon theory, top managers' environmental perception is vital for an enterprise to successfully implement green product design practices. Studies show that executives' perceptions, beliefs, and attitudes can significantly affect an enterprise's green strategy. In a complex decision environment, managers who make strategic choices are determined by their environmental perception and how they interpret these external pressures. When managers view the unpredictability of new technologies and green strategies as threats to their jobs or their company's operations, they are less likely to risk and choose a proactive environmental strategy and seek to minimize losses rather than maximize gains. Therefore, these managers are unlikely to search for innovative environmental technologies because they can disrupt the current production and operating systems. However, with increased institutional pressures and the vital role of environmental issues in enterprises' survival, the top manager usually interprets the external environment, such as issue legitimation and discretion, as an opportunity to choose proactive environment strategies [20]. Hence, we propose the following hypotheses:

Hypothesis 2: Top managers' environmental perception positively affects an enterprise's green product design.

Hypothesis 3: (a) Customer pressure, (b) regulatory pressure, and (c) competitor pressures positively affect the enterprise' green product design via the top manager's environmental perception.

(5) The Moderation Effect of New Media Attention

Firms are under pressure from many outside stakeholders who want them to change. These pressures are stronger when expressed through new media attention and often persuade management to make changes. With the development of new media, such as Twitter, websites, and other social media types, media power has become stronger through their timely, fast, and widespread influence. Therefore, it is easier for new media to blow institutional pressures on irresponsible companies, damaging their reputation and pushing managers or enterprises towards greener strategies. Existing studies explore the relationship between new media and green product design directly. First, as one of the stakeholders, new media can affect enterprises' green strategies by investigating and reporting their relevant environmental problems and protection activities. For example, in the Enron accounting cases, the media's investigations and reports exposed the fraud in Enron.[8] Second, as an effective information dissemination and exchange platform, new media can significantly amplify external environmental pressures through the timeliness of the information and wide transformation effect [21]. For example, the government and consumers' environmental pressures on enterprises' green strategies can be significantly strengthened by reporting and dissemination of new media. Finally, in addition to the amplification effect, new media can also supervise enterprises' environmental protection behaviors through its timely and extensive impact and encourage them to implement green transformation through its rapid and extensive communication ability.

However, some researchers have realized that no matter how powerful the new media's amplification effect and supervision role, it must influence the managers' perception, and then, affect the enterprises' environmental strategy [14, 22]. The tone of new media coverage and the level of external stakeholders' environmental needs can directly affect top managers' reputation, capital income, and careers, thus influencing managers' environmental perception. Some studies indicate that positive new media attention can significantly improve managers' reputation, future careers, and enterprises' performance and competitive advantage, thus increasing top managers' positive environmental perception. However, some researchers find that negative new media attention can also improve top managers' environmental perception. Their negative attention threatens managers' interest and enterprises' survival, pushing them to be more positive. Furthermore, negative media attention will increase operational costs and reduce enterprises' performance. Still, it can also seriously damage executives' careers, and this attention is directed toward enterprises' upstream and downstream partners [23]. Therefore, managers will cultivate more positive perceptions of external environmental pressures, especially through amplifying new media attention. Thus, we propose the following hypothesis:

Hypothesis 4a: New media attention moderates the positive relationship between regulatory pressure and top managers' environmental perception. The relationship is stronger when new media attention is high and weaker when low.

Hypothesis 4b: New media attention moderates the positive relationship between customer pressure and top managers' environmental perception. The relationship is stronger when new media attention is high and weaker when low.

Hypothesis 4c: New media attention moderates the positive relationship between competitor pressure and top managers' environmental perception. The relationship is stronger when new media attention is high and weaker when low.

[8] http://large.stanford.edu/courses/2018/ph240/smith1/

7.2.3 *Results and Conclusions of Green Product Design Model from the Perspective of New Media Attention*

(1) Data Sources and Analysis

The data were collected through a questionnaire and using a Likert 7 scale. The questionnaire items are mature scales. The reliability and validity of the questionnaire were tested through a small-scale pre-test. The results show that the questionnaire has good reliability and validity. Then, we conducted large-scale data collection through online and offline methods and distributed 200 and 1000 questionnaires, respectively. 71 and 274 valid questionnaires were collected, with an effective rate of 35.5% and 27.4%, respectively. Furthermore, we used SmartPLS software (version 3.3.3) to analyze the survey data.

(2) Reliability and Validity Test

Table 7.1 shows the descriptive statistical analysis results of the participants' basic information, and Table 7.2 shows the reliability and validity of test results. All reliability and validity indicators were greater than 0.7, indicating that the questionnaire was valid and reliable.

(3) Common Method Variance

There may be a false correlation between variables due to the data collection method. Independent and dependent variables were measured during the questionnaire design

Table 7.1 Sample profile

Item	Sample characteristics	Frequency	%
Enterprise size	Less than 500	77	22.3
	500–999	152	44.1
	1000–5000	76	22.0
	More than 5000	40	11.6
Ownership type	State-owned	81	23.5
	Publics	22	6.4
	Private	162	47.0
	Wholly foreign	26	7.5
	International joint	54	15.7
Enterprise age	Less than 10 years	107	31.0
	10–30 years	219	63.5
	More than 30 years	19	0.1
Media Type	Traditional media	49	14.2
	New media	296	85.8
	Total	345	100

stage to eliminate common method variance (CMV). Procedural remedies were adopted during the data collection stage. We interoperated the survey to be anonymous, and there were no right or wrong answers so that the participants could answer the questions honestly. There was a 3-h break between surveys #1 and #2 in the outline data collection stage. We inserted a 30-s video in the middle of the survey in the online stage to reduce common method bias. Finally, we used Harmon's single-factor test to detect CMV. The results show that no factor accounts for >40% of the variance, indicating that the CMV is not a concern. These results suggest that CMV is unlikely to be a severe concern in this study.

(4) Results

We used the SmartPLS software (version 3.3.3) to test the hypotheses. Figure 7.3 shows the results. This research model can explain 41.9% of the deviation in green product design. The results indicate that customer environmental, regulatory, and competitor pressures have a significant positive effect on green product design ($\beta = 0.238$, $p = 0.000 < 0.001$; $\beta = 0.264$, $p = 0.000 < 0.001$; $\beta = 0.200$, $P = 0.000 < 0.001$). Therefore, Hypotheses 1a-c are supported. Top managers' environmental

Table 7.2 Reliability, validity, and correlation

Constructs	Alpha	CR	AVE	CUP	RP	COP	TMP	NMA	GPD
CUP	0.779	0.857	0.600	**0.775**					
RP	0.728	0.845	0.513	0.283	**0.803**				
COP	0.866	0.909	0.713	0.600	0.344	**0.845**			
TMP	0.831	0.888	0.664	0.547	0.494	0.403	**0.815**		
NMA	0.725	0.827	0.548	0.486	0.513	0.399	0.472	**0.740**	
GPD	0.728	0.846	0.648	0.506	0.533	0.395	0.517	0.462	**0.805**

Note Alpha = Cronbach's alpha; CR = Composite reliability; AVE = Average variance extracted; COP = Competitor pressure; CUP = Customer pressure; RP = Regulatory pressure; TMP = Top managers' environmental perception; NMA = New media attention; GPD = Green product design. The bold values in diagonal cells are square roots of AVEs

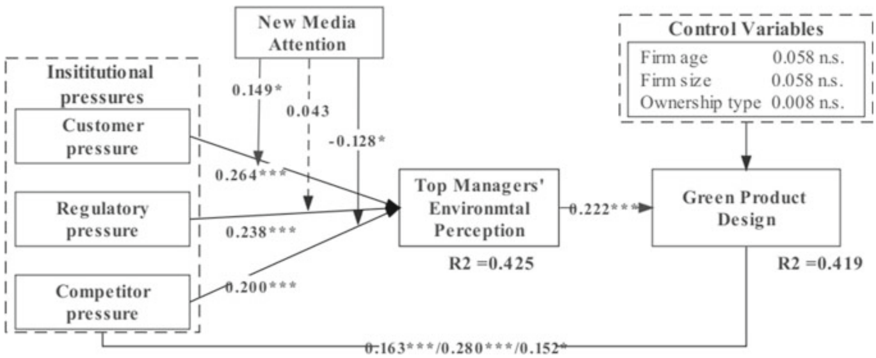

Fig. 7.3 Theoretical model result

perception has a significant positive impact on green product design ($\beta = 0.222$, $P = 0.000 < 0.001$); thus, Hypothesis 2 is supported. The three institutional pressures also have a significant positive effect on green product design ($\beta = 0.152$, $p = 0.037 < 0.05$; $\beta = 0.280$, $p = 0.000 < 0.001$; $\beta = 0.163$, $p = 0.000 < 0.001$). Thus, supporting Hypothesis 3. However, institutional pressures on green product design show that customer pressure becomes the greatest force motivating enterprises' green product design, followed by regulatory and competitor pressure, inconsistent with the literature review.

The path coefficients show that Hypothesis 4a ($\beta = 0.149$, $p = 0.022 < 0.05$) and Hypothesis 4c ($\beta = -0.128$, $p = 0.020 < 0.05$) are significant. This indicates that new media attention can positively moderate the relationship between customer pressure and top managers' environmental perception. However, the relationship between competitor pressure and top managers' environmental perception is negative; thus, Hypothesis 4a is supported and Hypothesis 4b is partly supported. However, there is no significant moderating effect between regulatory pressure and top managers' environmental perception. Therefore, Hypothesis 4c is not supported.

To further interpret this moderating effect, we plotted a simple slope. Three regression lines of competitor and customer pressure on top managers' environmental perception were plotted above and below the mean of the dependent variable based on one standard deviation. Furthermore, we plotted the interaction in Fig. 7.4 and Fig. 7.5. As shown in Fig. 7.4, a simple slope analysis confirms that new media attention can positively moderate the relationship between customer pressure and top managers' environmental perception ($\beta = 0.149$, $p = 0.022 < 0.05$). Conversely, it negatively moderates the relationship between competitor pressure and top managers' environmental perception, weakening top managers' environmental

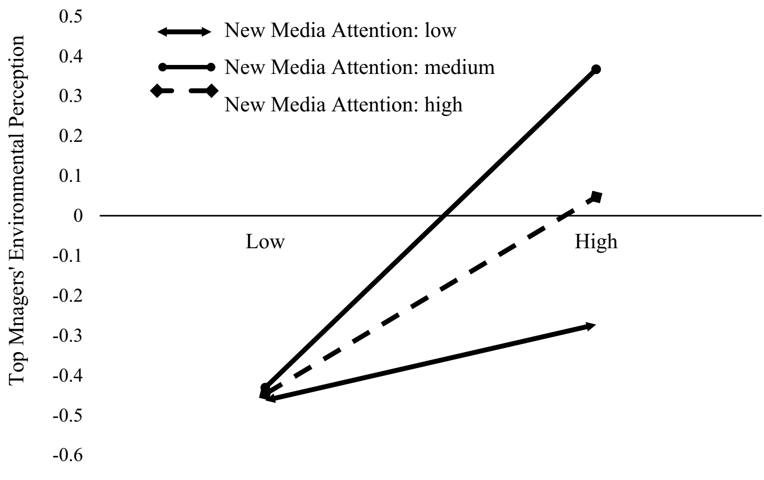

Fig. 7.4 Interaction of customer pressure and new media attention on top managers' environmental perception

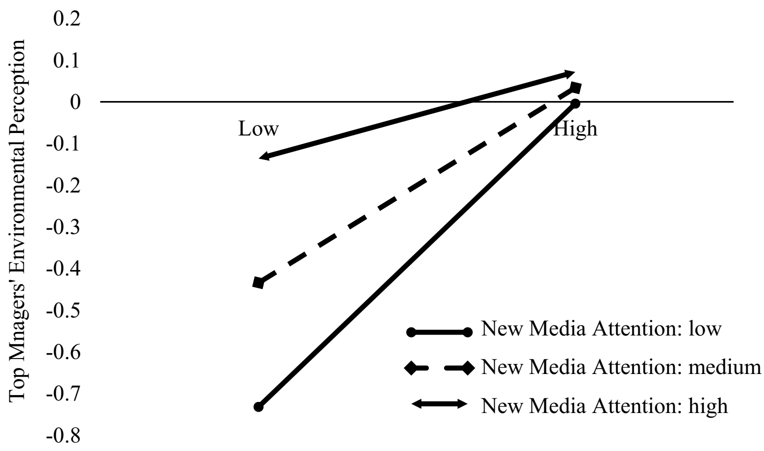

Fig. 7.5 Interaction of competitor pressure and new media attention on top managers' environmental perception

perception when new media attention increases from low to high, as shown in Fig. 7.5 ($\beta = -0.128$, $p = 0.020 < 0.05$).

(5) Conclusion

The results show that the three institutional pressures positively affect top managers' environmental perception of green product design and positively motivate them to implement it. The results also indicate that customer pressure has the most significant impact on enterprises' green transformation, followed by regulatory and competitor pressures. In addition, new media attention significantly enhances customer pressure and motivates top managers to adopt green product design strategies. However, the effect of competitor pressure on new media amplification is weaken. The widespread use of new media provides customers with more opportunities to express their environmental needs, significantly enhancing external environmental pressure, providing top managers more opportunities, and promoting enterprises to implement green product design. Enterprises that imitate competitors' successful environmental practices can better maintain their performance and competitiveness. However, excessive imitation can cause enterprises to lose innovation and market share. Thus, new media attention negatively moderates the relationship between competitor pressure and the enterprise's green product design strategy [24]. With the development of environmental laws and regulations, regulatory pressure plays a basic role in motivating enterprises to be greener; therefore, new media attention can positively moderate the relationship between regulatory pressure and top managers' environmental perception, but the effect is not significant.

7.3 Internal Factors of Green Product Design

In addition to the external factors that influence the design of green products, factors within the company also influence the effects of green product design. For example, the company's resource management capabilities, manager's environmental attitude, and organizational learning capabilities are particularly influential on green product design. This section explores the impact of these significantly influential internal factors on green product design.

7.3.1 The Influential Internal Factors of Green Product Design

(1) Research Background

With the introduction of more environmental policies, many companies are positioning green product designs as the basis for their business development. Different subsidy policies have made companies frequently engage in green product design. The larger the company is, the more pollution the company discharges. Therefore, companies need to manage their existing resources to maximize the value to adapt to changing market conditions.

Several companies risk avoiding penalties and use the same design production models. These phenomena also make it more difficult for regulators to monitor the situation, leading to pollution accidents. For example, in March 2021, Tangshan Songting, Tangshan Jinma, and Tangshan Zhonghou Plate did not redesign products to meet market demand but instead used concealment, misrepresentation, and false reporting of corporate information to avoid scrutiny by the relevant review authorities.[9] The fact that these three companies were polluting was eventually discovered after residents reported them. The managers of the above three enterprises adopted illegal production methods despite knowing about the policy penalties, placing them at the risk of seizure and suspension.

By contrast, committed to developing and applying new energy technologies to address the climate and energy challenges facing humanity in the future, BYD has helped the company achieve its annual "carbon reduction" target through its green product design approach. According to BYD's annual report, revenues have grown from 127 to 261 billion during 2019–2021.[10] Companies primarily engaged in green product design realize environmental and income benefits, creating a win–win approach to environmental revenue. In 2020, Bloom-berg was also named BYD's founder, Wang Chuanfu, one of the world's top 30 environmental leaders.[11] Wang

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[9] http://tingshen.court.gov.cn/live/27281538?

[10] https://www.bydglobal.com/cn/Investor/InvestorAnnals.html.

[11] http://bydauto.com.cn/auto/news/2020-03-04/1514435985113.

Chuanfu has produced environmentally efficient results year after year through his positive environmental attitude and built the company into a high-end new energy vehicle company with green product design. Wang Chuanfu, an engineer by training, has led the company's technological upgradation, product development, and design. His attributes have influenced the company to have a good organizational learning environment and the ability to better develop green product design. This shows that a manager's environmental attitude has a crucial influence on the development of companies and the way they choose to design green products. Therefore, the research question is: Does the manager's environmental attitude influence green product design?

(2) Enterprises' Resource Management Capacity

Enterprise resource management capability is the ability to manage physical assets and technology [25]. The possession of scarce resources is the basis for green product design; however, the possession of resources alone does not guarantee effective product design. Resources are separate entities. Thus, resources can be used with high efficiency if they are linked and allocated. Therefore, resources must be managed effectively to achieve an effective green product design. A company's resource management capabilities include integration, bundling, and access to resources [26]. These are three ways in which a company can support a green product design process. These three areas are discussed in more detail below:

(a) Consolidation of the Resources of the Enterprise

In designing green products, labor, technology, and capital markets are often subject to opportunism and information asymmetry, complicating the efficient allocation of resources between companies. Therefore, the management of the company's resources is also a test for the company's managers: the better the ability to manage resources, the better the ability to construct a portfolio of resources. The construction of a resource portfolio is accumulating and acquiring resources. Enterprises can regroup resources by re-managing them to achieve a new mix and provide a resource base for green product designs. Abundant human and material resources can contribute to the process of green product design. Simultaneously, the recombination of resources can also generate more valuable resources for the company, further enriching the resource conditions for green product design, forming a beneficial virtuous circle.

Companies have quicker information about the resources they control than other companies and are more likely to recognize the value of their resources. When the value of external resources is difficult to assess, they become even more important. There are many obstacles to accessing external resources, especially in resource-poor environments, therefore, accumulating resources is vital. The regrouping of existing resources can also lead to the discovery of new links between resources and thus to the accumulation of more resources. A wealth of resources makes it easier for companies to design green products. Additionally, when diversified resources are accumulated, companies with fewer external needs are more resilient to risk than those that need external resources entirely, ensuring a good operating environment for green product design. Based on the abundance of resources, as companies do not need to compete fiercely with other companies for resources, a favorable isolation mechanism for green product design will emerge, further increasing the efficiency and safety of green product design.

(b) Bundling Resources

Bundling resources can help firms develop unique resource portfolios, enabling them to find inspiration for green product design within a richer portfolio of resources [26]. Competition between firms for green product design is often driven by similarities or differences in the means by which firms use their resources and not necessarily by similarities in the resources they control. When successful companies design green products through a diversified design approach, they may be able to develop green products more effectively than their competitors, resulting in unexpected design outcomes. There is no substitute for the importance of bundling resources in a company. Many companies create and design green products by explicitly allocating resources in difficult ways for competitors to imitate, making the product more unique in the marketplace—the stronger its resource management capabilities, the greater its perceived value potential. Nevertheless, the company could develop better abilities to support its green product design by bundling resources. However, bundling resources requires a delicate balance between concentration and fragmentation to achieve greater diversity of resources, further testing a company's ability to manage resources.

(c) Access to Resources

In a healthier external environment, access to resources can help companies increase their competitiveness. This places greater demand on a company's resource management capabilities. Business managers must acquire external resources based on their business situations. A common development method is to make acquisitions that can help a company quickly acquire the resources it needs. In addition, because the information is asymmetrical in the environment, strategic acquisitions allow for timely information updates so that managers can better assess their resources. By acquiring and managing existing resources, companies can create a better design environment and foundation for green product design. In addition, as the diversity of a company's resources increases, the differences between the company and its competitors grow. This increasing heterogeneity makes it more difficult for competitors to imitate, further increasing the uniqueness of the green product. However, acquiring a resource often implies a long-term commitment to hold that resource. When a resource is highly liquid, there are more hidden risks. For example, acquiring would create hidden risks because the availability of the resource usually depends on how well it matches the requirements of the external environment [27]. Managing resources also plays a vital role in controlling risk by helping companies find the most appropriate resources at the most appropriate time, reducing the risk for companies that lack resources and affect their green product design.

(3) Manager Environmental Attitudes

Manager environmental attitudes refer to their views and opinions on environmental issues [28]. From a stakeholder perspective, the values, experiences, and perceptions of business managers can significantly influence their perceptions and interpretations of the environment, and then influence their decisions.

The manager's decisions play a decisive role in a company's operational strategy. Although market orientation and a company's green product design environment cannot be separated, it has different dimensions and does not have a comprehensive impact on green product design. Managers are more inclined to design products consistent with environmentally friendly standards when they show a higher acceptance and positive attitude. Thus, managers' environmental attitudes drive companies' consideration of green product design.

The basic theory of values suggests that environmental attitudes are a combination of values, including egoism, altruism, and ecological orientation [29]. Individuals and ecologically oriented organizations are more likely to make their products more compatible with green standards. A positive environmental attitude increases the amount of money companies spend on green product design. Therefore, the degree to which managers have positive environmental attitudes determines the strategic choices made by companies, including the amount of human and material resources invested in green product design. However, according to attitudes, behavior, and context, a company's green product design behavior results from its internal environmental attitudes and external environment. Therefore, energy efficiency and environmental protection are high when customers demand green products. Companies are more likely to engage in more intensive green product designs to meet market and consumer needs, and can provide their managers with a more positive environmental attitude.

Managers who value the environment must have an even higher initiative in dealing with pollution in highly polluting industries. If these companies value customer feedback, they are more likely to make green product design improvements and adopt positive environmental attitudes to maintain their image with customers, increasing their competitiveness. Conversely, managers with a negative attitude towards the environment will try to design more cost-efficiently, reducing product performance in environmental friendliness and sustainability.

With the growing market demand, the demand for green products is also increasing. Therefore, implementing a green product design is an important tool for companies to differentiate themselves from their competitors and improve visibility. Furthermore, for companies more concerned about their competitors' gathering information on various aspects, a manager with a positive environmental attitude will update their company's products and choose more advanced and environmental-friendly processes to achieve green product design.

(4) Enterprises' Organizational Learning Capacity

Organizational learning is the process by which firms develop new knowledge and insights from the shared experiences of corporate members and has the potential to enhance firm capabilities [30]. Previous research has shown that organizational learning capabilities can lead to more prominent creative design capabilities in firms [31].

Within a company, organizational learning and knowledge are prerequisites for green product design, as outstanding organizational learning capabilities can increase the company's flexibility to achieve green product design. There are several steps in the process of organizational learning: first, the company acquires knowledge and information related to green product design; then, the information is shared and explained so that employees understand the meaning of the information and transform it into new public knowledge, and finally, the new knowledge is stored so that the company gains a higher level of competitiveness in terms of its knowledge base. The stronger the organization's ability to learn, the greater its ability to transform knowledge and create new knowledge. Therefore, the knowledge base plays a crucial role in the inspiration-finding phase of green product design.

Organizational learning allows companies to develop capabilities to create better sources of inspiration for green product design. At the same time, green product design is also a process of transformation and exploitation of existing knowledge. A company's organizational learning capability increases its absorptive capacity; in this sense, the stronger the organizational learning capability, the better the green product design. The organizational learning capability is divided into exploitation and exploratory learning [32]. The impact of different competencies on green product design varies.

(a) Exploitation Learning

Exploitation learning in business involves improvement, selection, production, efficiency, implementation, and execution and is a way of learning that builds on previous knowledge [32]. In the case of green product design, the exploitation learning approach tends to add more green elements to the original product design, such as reducing pollution emissions.

Exploitation learning is more related to existing knowledge than exploratory learning. In terms of product sustainability, the higher the learning capability is, the easier it is for companies to produce green products that meet the current needs. The learning capability focuses on existing resources and modifying existing resources for design purposes. However, these products are more likely to be fast-moving, that is, products with a short sales cycle and lose market value as customer demand changes, such as green food. However, the greater the ability to exploit learning, the greater the risk of long-term inertia, leading to reduced adaptability to new opportunities and, consequently, reduced product development efforts. Long-term exploitation learning allows companies to enjoy short-term successes rather than being willing to upgrade and design products in time for significant technological and market changes. Therefore, exploiting knowledge is extremely powerful and can compromise the continuity of green product design.

(b) Exploratory Learning

However, as exploratory learning advances, there is a tendency to rely on this approach for green product design. Such a green product design approach requires much more knowledge and involves technical difficulty than an exploratory learning approach, delaying the design cycle of the green product design. This is likely to result in new green products behind market demand and thus miss the best time to enter the market. Even with strong exploratory learning, the cost of integrating too much new knowledge cannot be significantly reduced. Second, too much exploratory learning can lead to the development of entirely new product features incompatible with customer needs, increasing costs that should be reduced.

From the perspective of resource-based theory, the company's resources, executive decisions, and internal competencies are the resources on which the company relies. Therefore, the richness of a company's resources can help it better differentiate itself from its competitors and thus better design and launch its green products.

An enterprise has distinct resources. An enterprise's resource management capability is a good green product design source, which can help enterprise design products. However, enterprises cannot transform their resources directly into green products. In addition to good resource management capabilities, they need better organizational learning capabilities to continuously accept, analyze, understand, and internalize the key resources of the enterprise and ultimately make greater use of the available resources for green product design. The better the resource management capability is, the better the company's understanding of its resources is, and the easier it is to internalize and realize its resources for green product design. Organizational learning theory explains how a company transforms its resources into green product design outcomes [33].

A company's strategy is determined by its top management. Green product design cannot be achieved without a corresponding strategy, even with the best-quality resources and the ability to transform resource products. Managers' environmental attitudes moderate the impact of corporate resource management capabilities on organizational learning capabilities and thus indirectly influence corporate green product design. As in the comparison between the three Tangshan companies and BYD mentioned above, managers with positive environmental attitudes are more inclined to bias their corporate strategies toward environmental friendliness and carry out green product design.

7.3.2 *Model and Hypothesis for Green Product Design from the Perspective of Manager's Environmental Attitudes*

There has been much research on internal factors affecting green product design. The most studied internal factors include prospects for competitive advantage, cost reduction, market effectiveness, expectations of improved reputation, opportunities for innovation, and improved product quality [34, 35]. However, there is little research on internal influences, such as resource management capability. In addition, little research has been conducted on executive environmental attitudes that moderate resource management capabilities on organizational learning capabilities. Although there is a direct correlation between organizational learning capability and green product design, few studies have considered the mediating effect of organizational learning capability in the green product design process.

The above model is then constructed, as shown in Fig. 7.6. For a company, managing resources is an important capability for increasing the value of the company's resources and building a good foundation for green product design. Good organizational learning capabilities are also essential for companies to understand resources, internalize them, and carry out green product design processes. Developing the relevant competencies will allow companies to shorten the green product design cycle and thus be well prepared when facing changing consumer demands and excessive market pressures.

However, corporate managers need to support even the best corporate attributes, especially environmental attitudes. Positive executive attitudes can help companies choose environmentally friendly raw materials and implement proactive environmental strategies. By combining their strengths with their managers' strategies, companies can achieve greater advantages, gaining comparative advantage in a highly competitive market and profit. They ultimately design green products with high

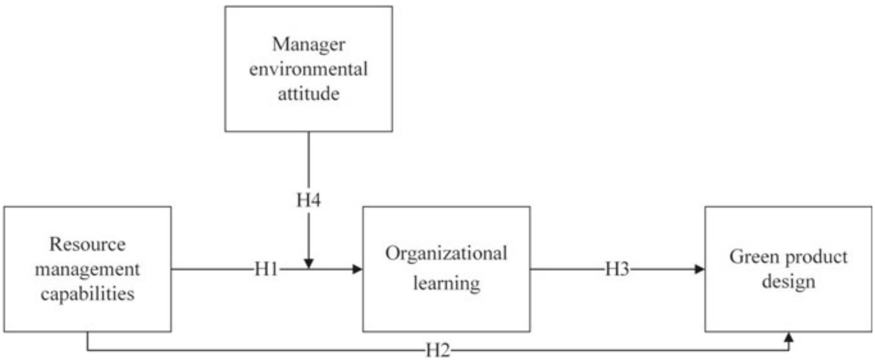

Fig. 7.6 Theoretical model

returns and a high corporate social responsibility image. Therefore, we propose the following hypotheses:

Hypothesis 1: Resource management capabilities contribute positively to the organizational learning of firms.

Hypothesis 2: Resource management capabilities positively contribute to firms' green product design.

Hypothesis 3: Organizational learning contributes positively to a firm's green product design.

Hypothesis 4: Managers' environmental attitudes play a positive role in the influence of resource management capabilities on a firm's organizational learning.

7.3.3 Results and Conclusions of the Green Product Design Model from the Perspective of Manager Attitudes

(1) Data Sources and Analysis

The study was analyzed using questionnaires, and the scales used were mature. This study collected data from corporate managers through interviews, mail, and electronic questionnaire distribution. A total of 1200 questionnaires were distributed, of which 300 were distributed online and 900 offline. A total of 439 valid questionnaires were collected, of which 115 were online, and 324 were offline, with an effective response rate of 36.6%. The company's size, ownership situation, and the number of years of business are listed in Table 7.3.

The processing tool for this study was SmartPLS 3.0, and the data were analyzed as follows.

(2) Test of Reliability and Validity

All data in this study had a confidence validity above 0.6, as shown in Table 7.4, indicating good convergent validity.

As shown in Table 7.5, the bold values in diagonal cells are square roots of AVEs. All square roots of AVE are greater than the correlation between the corresponding structure and any other structure in the same row, again demonstrating good discriminant validity.

(3) Common Method Deviation

Previous studies have shown that the effect of common method bias can be found in the measurements [36]. However, this study used two questionnaires to differentiate the independent variable from the dependent variable to avoid bias. In addition, to

Table 7.3 Sample profile

Item	Sample characteristics	Frequency	%
Firm size	Less than 500	173	39.3
	500–999	161	36.6
	1000–5000	82	18.8
	More than 5000	23	5.3
Ownership type	State-owned	19	1.79
	Publics	90	20.5
	Private	67	15.2
	Wholly foreign	239	54.5
	International joint	34	7.9
Firm age	Less than 10 years	32	7.1
	10–30 years	248	56.6
	More than 30 years	159	36.3
	Total	439	100

Table 7.4 Factor loading

Loading	RMC	GPD	MEA	OL
RMC1	0.685			
RMC 2	0.717			
RMC 3	0.681			
RMC 4	0.681			
RMC 5	0.717			
RMC 6	0.765			
RMC 7	0.709			
GPD 1		0.768		
GPD 2		0.788		
GPD 3		0.793		
GPD 4		0.722		
MEA1			0.882	
MEA 2			0.891	
MEA 3			0.883	
MEA 4			0.876	
OL1				0.768
OL 2				0.751
OL 3				0.718
OL 4				0.757

Note RMC is resource management capabilities; GPD is green product design; MEA is manager environmental attitude; OL is organizational learning

Table 7.5 Reliability, validity, and correlation

Constructs	Alpha	CR	AVE	RMC	GPD	MEA	OL
RMC	0.834	0.876	0.502	**0.708**			
GPD	0.768	0.852	0.59	0.617	**0.768**		
MEA	0.906	0.934	0.78	0.604	0.647	**0.883**	
OL	0.807	0.866	0.564	0.547	0.55	0.52	**0.751**

Note Alpha = Cronbach's alpha; CR = composite reliability; AVE = average variance extracted

prevent respondents from linking the two sets of questionnaires, a relaxation video was played between completing the two sets of questionnaires to address this issue. Therefore, common variance bias was not a concern in this study.

(4) Results

This study used a partial least squares structural equation modeling approach for data analysis, using SmartPLS 3.0, to test our hypotheses, shown in Fig. 7.7. The results show that resource management capabilities (β = 0.403, T = 5.8, P = ** < 0.01) and (β = 0.453, T = 8.287, P = ** < 0.01) positively contribute to organizational learning and green product design, thus supporting Hypotheses 1 and 2. Organizational learning capability positively contributes to green product design (β = 0.303, T = 8.287, P = ** < 0.01). Corporate organizational learning contributes positively to green product design (β = 0.303, T = 4.868, P = ** < 0.01), thus supporting Hypothesis 3. Managers' environmental attitudes contribute to the influence of organizational learning on resource management capability (β = 0.129, T = 3.486, P = ** < 0.01), thus supporting Hypothesis 4.

Figure 7.8 shows further tests of the moderating effect, where the impact of resource management competencies on organizational learning progressively increases with managers' environmental attitudes.

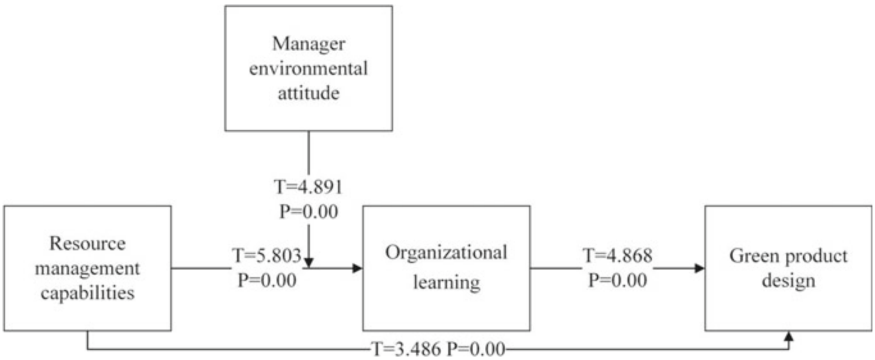

Fig. 7.7 Theoretical model result

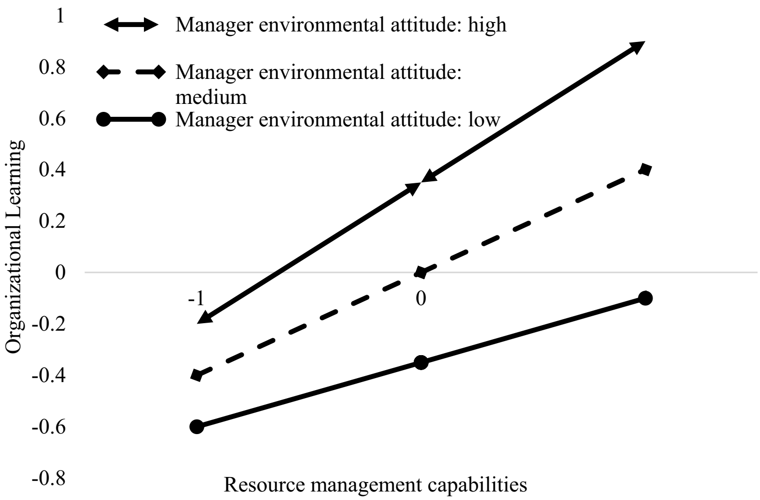

Fig. 7.8 The moderating role of manager environmental attitudes

(5) Research Findings

The data show that resource management capability positively affects organizational learning and green product design. In line with the hypothesis of this section, the stronger the resource management capability is, the more it can help companies design green products. Green product design requires more resources to pave the way, and better corporate resource management capabilities can help companies make better use of resources, ultimately influencing green product design. Effective organizational learning can also effectively implement green product design behaviors, a hypothesis further tested by the data results. Managers' environmental attitudes also play a vital role in the influence of resource management capabilities on organizational learning. Managers' attitudes also affect the efficiency of implementation strategies, making it easier for companies to accept and implement new resources and techniques. The data results also support the validity of this hypothesis.

Resource management capabilities, organizational learning, and managers' environmental attitudes significantly impact the design of a company's green products. These factors also guide companies to focus on the main factors to achieving more efficient green product design.

7.4 Summary

This chapter explains the specific impact of external factors such as regulatory pressure, customer pressure, new media, and competitor pressure on green product design.

In addition, internal factors such as resource management capabilities, manager environmental attitudes, and organizational learning capabilities are also presented as important influences on green product design. Finally, two models are constructed based on real-life events to visualize the different factors influencing green product design.

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Chapter 8
Pricing for Green Product

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Abstract The rise in consumers' green preferences promotes manufacturers to produce and provide green products and services, which is conducive to achieving sustainable enterprise development and meeting consumers' growing green consumption demand. In the competition between green and common products, price is still one of the key factors affecting consumers' purchase decisions. There is information asymmetry in the green product market, which will lead to "bad money drives out good". Consumers have incomplete knowledge and information about green products, and cannot accurately know about the green state of products. Consumers can only make indirect judgments through product prices. If the price is too high, some consumers give up their purchases. Whereas if it is too low, it will not only fail to cover the production cost but will also make consumers question the quality of green products. Based on the above analysis, this chapter focuses on the impact of green product pricing in enterprises' green growth model of and analyzes the differences in pricing between green products and common products. In addition, it discusses the factors that enterprises need to consider when making green product pricing decisions. Then, based on the theoretical analysis, pricing models of green products between manufacturers and consumers, retailers, and the government are established, and the influence of information asymmetry on the pricing of green products under different conditions is analyzed. Finally, the conditions for distinguishing qualified and unqualified green products in the market are discussed to promote standardized operation of the green product market and improve the confidence of consumers in the green market.

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8.1 Pricing for Green Product and Enterprises' Green Growth Model

8.1.1 The Impact of Pricing for Green Product in Enterprises' Green Growth Model

(1) Affecting Market Demand and Corporate Profits

Dissimilar to common products, green products have green value in addition to the functional value of common products. With the continuous development of a green economy and consistent improvement of consumers' awareness of environmental protection, consumers will pay more attention to the impact of products' on the environment, and green products are favored as they integrate innovative technologies and environmental-friendly design. In 2019, JD Big Data Research Institute released the "2019 Green Consumption Trend Development Report", showing that the types of "green consumption" commodities exceeded 100 million, the growth rate of sales volume exceeded 18% of JD.com, and the types of "green consumption" are constantly penetrating the low-line market.[1] However, the development and production of green products usually require enterprises to use green technologies and implement cleaner production, etc. In addition, it has to pay a lot of costs, which objectively increases the price of green products. For example, for the same series of air conditioners manufactured by Haier, the price of air conditioners with energy efficiency level 1 is higher than that of air conditioners with energy efficiency level 3; further, the price of BYD electric vehicles is higher than that of oil-burning vehicles of the same series. Yang et al. analyzed 991 valid questionnaires and found that public willingness to pay for green products is generally low, accounting for only 30.1% [1]. Zhong and Chen found that the average green premium that Chinese consumers are willing to pay for low-carbon agricultural products is low [2]. The above research shows that the steep pricing of green products has become the main obstacle for consumers to shift from their green consumption willingness to actual purchase behavior. In contrast, Berger argued that green products can generate signal benefits, which can incentivize consumers to pay a premium for environmental-friendly products. This, in turn, can compensate for price disadvantages, which implies that marketers should price green products more expensive than non-green products so that they can be clearly identified as green products [3]. The underlying reasons behind the two contradictory impacts of green product prices on consumer demand are as follows. As an important market signal, green product prices convey the high-quality image of green value to consumers, which is in line with consumers' psychology of "high quality with high price". However, a large amount of green costs in green prices will be passed on to consumers. Nevertheless, consumers still hope that product prices are relatively cheap, so higher green prices will cause companies

[1] https://www.sohu.com/a/363240287_694904.

to lose some consumers. The price premium of green products needs to be controlled at a reasonable level. Salladarre et al. studied the willingness of French consumers to pay for ecologically labeled fresh seafood products, and found that on average, the highest premium paid by consumers was about 10% of the product price [4]. Green price is an important means of green product marketing. Setting green prices reasonably is important in corporate marketing decisions, which directly affects the market demand for green products and corporate profits. Therefore, enterprises need to reasonably set green prices, find the best premium space, choose the most favorable green pricing strategy to seize vitality, and obtain long-term development in the fierce market competition.

(2) Promoting the Value Chain Cycle and Green Growth of Enterprises

Green products are the final market-oriented result of the green development of enterprises. The ultimate goal of producing green products is to turn ecological environmental protection into a new driving force for economic development. Similar to traditional industries, the virtuous cycle of green industry development needs to smoothly transform the productivity invested in the production process into capital for enterprises to continue green production. Therefore, obtaining green consumption is key for enterprises to realize the transformation from cost input to economic benefits. The price of green products, as the only means to balance high investment and output in green development, is the economic pillar of enterprises and the key to unlocking their dependence on traditional development paths. However, green premium affects consumers' willingness to pay. Li et al. found that nearly half of the consumers were willing to pay a premium of no more than 5% for green products, which is lower than the premium for green products relative to non-green products [5]. However, the actual premium for green products generally exceeds this level, reducing the dominant position of green products in the market. Based on a comparative analysis of consumer survey data and online sales data of green products in representative cities, Wang et al. used a fuzzy cognitive map to quantitatively study the influence of their interaction mode on the gap between green intention and actual behavior. It was found that the difference between the actual premium of green products and consumers' willingness to pay an additional price is currently the biggest factor hindering green behavior [6]. To control the green price within a reasonable premium level, open the channels between production and sales, implement enterprises' green growth model, and achieve green transformation, enterprises need to carry out local and overall optimization from the perspective of the whole value chain to reduce production costs and improve green payment willingness from the demand end.

With the support of the next-generation information and communication technology and other technologies, core enterprises can quickly build a production system involving designers, suppliers, logistics providers, and other partners aiming at resource conservation and low-carbon recycling. Through complementary advantages and resource sharing, low-cost and innovative green product production can be realized to effectively control premium space, reduce product prices, promote green consumption, open up the entire value network from green production to consumption, realize the value chain cycle, and promote the spiral green growth of enterprises. For example, Haixiangtao, a sub-platform of Haier's COSMOPlat in the ceramics industry, has comprehensively empowered Tongyi Ceramics through a series of empowerment fields such as open resources, sales empowerment, procurement empowerment, intelligent manufacturing, R&D empowerment, and financial services. It helps enterprises and ecological partners realize the value and benefits of data sharing, cost reduction, digital transformation, energy conservation, environmental protection and inventory reduction, efficiency improvement, quality improvement and innovation, and strive to build a new ecosystem.[2]

(3) Reasonably Allocating Resources and Improving Resource Use Efficiency

The scarcity of resources makes it an obstacle to economic development. To overcome this obstacle, it is necessary to use limited resources more efficiently. Through the green product price mechanism, along with the use-value and exchange value of the product, the resource value is also considered. Factors such as the loss of natural resources, environmental pollution, treatment and restoration, enterprise resource utilization, and the resulting social and environmental costs are included as environmental costs in the green product pricing mechanism, which can truly reflect the value of resources and enable enterprises and consumers to form the concept of "resources are paid for use". The formation of the price mechanism for green development requires the joint efforts of the market and government. Taking the energy field as an example, the price mechanism can play a significant role in improving the industrial and energy structures and reducing the pollution degree of fossil energy. Sha et al. found that negative fossil energy price distortion further hinders green economic efficiency by inhibiting technological innovation and hindering optimization of the energy consumption structure. To realize China's green economy, it is necessary to improve the market-oriented energy pricing mechanism and formulate differentiated regional energy pricing policies [7]. Knappl et al. investigated consumers' energy attitudes and willingness to pay for renewable energy and found that green power programs, such as utilities' green tariffs, provide consumers with a market-based mechanism to fulfill their desire to buy renewable energy [8]. Green price reform based on the ecological environment will help leverage more private capital into ecological and environmental protection; promote resource conservation, environmental protection, pollution prevention, and control; and foster the formation of green development spatial patterns, industrial structures, modes of production, and ways of life. For example, the government's subsidies for new energy vehicles enable enterprises to have more flexible pricing space, help them reduce pricing pressure, and encourages them to enter the field of energy vehicles.

[2] https://www.cosmoplat.com/news/detail?newsid=2513&sourcePage=search.

8.1.2 Difference Analysis of Pricing Between Green Products and Common Products

(1) Product Cost

In contrast to common products, enterprises producing green products need to bear the cost of natural resources consumed by green products and environmental costs owing to environmental problems, in addition to traditional product costs. Therefore, resource and ecological environment costs are important factors in distinguishing the pricing differences between green products and common products. The green product premium is a market way in which enterprises transfer input resources and environmental costs to consumers to compensate for green expenditures. Therefore, enterprises can effectively control premium levels by reducing costs. From the perspective of enterprises, cost-efficiency can be improved through the green process and product innovation [9]. From the perspective of the entire value network, different entities should coordinate green production and sales goals and establish cost-sharing, resource-sharing, and revenue-sharing mechanisms. Zhang et al. studied a two-level supply chain composed of a manufacturer and a retailer and designed a Stackelberg game model with cost-sharing contracts and wholesale price contracts, which considered the consumer reference price effect. They found that the consumer reference price effect would reduce the proportion of cost-sharing contracts when the manufacturer was dominant. However, the problem of double marginalization can be alleviated by lowering wholesale and retail prices for both contracts, thereby increasing consumer surplus [10].

(2) Market Demand

Compared with common products, the impact of pricing for green product on product market demand is mainly reflected in two aspects.

First, the effects of green pricing vary by types of purchasing choices. As green consumption is affected to a certain extent by the level of economic development, the current green consumption market has not yet been fully developed. The results of global public opinion surveys show that, although most citizens have a positive attitude toward environmental protection issues, purchase preferences demonstrate that their attitude is not implemented in practice. In fact, consumers' shift from their green consumption attitude into actual green purchasing behavior still largely depends on green product prices. Green consumers can be divided into three categories according to their behavior status: light green, green, and dark green consumers. Light green consumers have the lowest attitude toward environmental standards, whereas dark green consumers have the highest attitude toward environmental standards [11]. Du et al. investigated the role of cost, consumers' green segmentation, and competition in enterprises' green production decisions and found that in the competition, traditional enterprises may lower the price of traditional products to defend their market share, resulting in a balance in which green products are only sold to green market segments [12].

Second, the information transmitted by green prices affects market demand for green products. A green market is a typical decision-making environment with limited and ambiguous information. In reality, the publicity of many green products is ambiguous, and may even deceive and mislead consumers. Owing to professional and technical limitations, consumers usually lack effective knowledge and methods to identify green products before purchasing them, and it is difficult to evaluate the authenticity of green information even after purchase. In this case, consumers usually judge the green value of products based on their price [3]. Therefore, if the price is low, it will not only can not compensate for the green cost already paid by enterprises, but also make consumers misperceive that the green degree of products is not high or not up to standard. However, if the price is too high, it will inhibit some consumers' purchase desires. Therefore, when determining green product prices, enterprises also need to consider the asymmetric factors of green market information and avoid pricing products too high or too low based on the psychological perception of consumers.

(3) Competition

In contrast to common product pricing, green product pricing, in terms of competition, is reflected in the effect of the product price on the direction of the consumer market. This is reflected in the market competition of green products caused by pricing. From the positive flow direction of green product output to sales, there is information asymmetry between the producer and receiver, where the seller has more information about the greenness of the product than the buyer. The cost of green products was positively correlated with greenness and price. If two enterprises produce similar products with different greenness, but the enterprise with lower greenness still promotes its products with high greenness, it will bring unfair competition in the "lemon market" [13]. Therefore, in green market competition, it is important to understand how an enterprise producing high green products enables consumers to identify products with different greenness through reasonable pricing in an environment of information asymmetry. The green product pricing strategy enables consumers to distinguish between genuine and fake product information, which is conducive to ensuring the fairness of the green product market. This kind of "lemon market" dilemma caused by incomplete disclosure of information transparency is less threatening in the common product market.

(4) Policies and Regulations

Judging from existing practices, promoting the green upgrade of products is inseparable from the role of relevant policies and regulations. Specifically, the differences in the pricing of green products and common products in terms of policies and regulations are mainly reflected in the following two aspects.

First, policies and regulations promote green consumption, which has a positive pulling effect, prompting more consumers to accept the premium of green products. Since the green market starts late, the green market order is chaotic, green products are mixed, and consumers are disadvantaged by information. Given the lack of effective government supervision and the support and constraints of relevant policies and regulations, the phenomenon of "bad money driving out good" is highly likely to occur, thus hindering the development of the green market [14]. By contrast, if the government actively supervises, formulates effective policies and regulations for the problems of the green market, develops a complete evaluation standard and certification system for green products, and improves consumers' trust in the green market, consumers can have a higher green premium, which ultimately promotes the formation of a reasonable and sound green product pricing mechanism.

Second, a policy inclination toward green industries can appropriately reduce green product prices. Supportive policies, such as tax incentives and financial subsidies, can compensate for the green cost of enterprises' implementation of green development, R&D, and production of green products. Otherwise, to compensate for the green cost of additional investment, enterprises set a higher green price to transfer part of the cost to consumers and reduce consumers' willingness to buy, which hinders the smooth circulation of green production and sales. Government's provision of support and subsidies for the environmental and resource costs consumed by enterprises in terms of taxes and subsidies can reduce the cost of enterprises, thereby indirectly reducing green product prices and increasing the market demand for green products. For example, in the field of new energy passenger vehicles in China, the subsidy standards for energy vehicles in 2022 are as follows. Pure electric passenger cars of more than 400 km (including 400 km) are subsidized by 12,600 yuan per vehicle, whereas pure electric passenger cars ranging from 300 to 400 km (including 300 km) are subsidized by 9100 yuan per vehicle. There is no subsidy for purely electric passenger cars with a range of less than 300 km. Thus, the government's subsidy policy has promoted the development of electric vehicles.[3] The comparison between green products and ordinary products is shown in Table 8.1.

8.1.3 Factors to Consider in Pricing for Green Product

(1) The Trend of Green Consumption

The trend of green consumption promotes the development of the green industry and improves consumer acceptance of green product premium space. At present, consumers are not only willing to buy high-quality green products but also pay attention to the impact of production methods on the ecological environment. According to the Survey and Research Report on the Current Situation of Public Green Consumption in China (2019 Edition), the concept of green consumption is becoming increasingly popular in the public's daily consumption, and 83.34% of the respondents expressed their willingness to support green consumption behavior.[4] The release of green consumption potential will provide an important driving force for the green

[3] http://www.gov.cn/zhengce/zhengceku/2021-12/31/content_5665857.htm.

[4] http://sdg-china.net/portal/article/index/id/727/cid/5.html.

Table 8.1 Comparison between green products and common products

	Green product	Common product
Product cost	Production, inventory and logistics costs, including green costs such as resource recycling and environmental friendliness	Production, inventory, logistics and other economic costs
Market demand	Product pricing has different impacts on the demand of light green consumers, green consumers, and dark green consumers, and green price can convey green information	The effect of product pricing on market demand has nothing to do with consumers' green preference
Competition	Information competition and market competition are obvious	Information competition and market competition are not obvious
Policies and regulations	Policies and regulations favor green industries	There are no supportive policies

and low-carbon transformation of traditional industries and the industrialization of ecological and environmental protection technologies and lay an important foundation for achieving carbon peaking and carbon neutrality goals. Green consumption leads enterprises to improve the green value of products from the demand side, which also creates new opportunities for enterprises to price green products. Consumers' attention to the green value of products shows that the scope of the premium they bear is expanding. In the future, with further development of green consumption, several light green or green consumers may become dark green consumers. The inhibitory effect of the green product price on consumers' purchase behavior is relatively reduced, which is conducive for enterprises to maintain their reasonable interests through price strategies and realize compensation for green input in the early stage of the sales link.

(2) Policy Tilt

Two main types of policies affect the pricing of green products. The first type of policy starts from the production of green products and provides tax incentives, subsidies, and technical support for enterprises implementing green development. The second type starts from the sales side of green products and aims to promote green consumption. For the first type of policy, for example, to promote the green development of enterprises, in 2016, the Notice on the Construction of Green Manufacturing System issued by the Ministry of Industry and Information Technology of the People's Republic of China mentioned that the Ministry of Industry and Information Technology will use relevant policies such as industrial transformation and upgrading funds, special construction funds and green credit to support the construction of green manufacturing system.[5] For the second type of policy, to promote the development of the green consumption industry chain, in March 2020, China's National Development and Reform Commission and the Ministry of Justice jointly issued a notice on "Opinions on Accelerating the Establishment of a Green Production and Consumption Regulatory System", further promoting "green consumption" into the lives of the masses.[6] In the subsequent executive meeting of the State Council, it was decided that: first, the new energy vehicle purchase subsidy and purchase tax exemption policies would be extended for two years; second, the central government would adopt incentives instead of subsidies to support key regions such as Beijing, Tianjin, and Hebei to eliminate diesel trucks with emission standards of National III and below.[7]

(3) Information Asymmetry and Bad Money Drives out Good

Information asymmetry theory is a core component of microeconomic research and is used to explain the influence of the asymmetric distribution of relevant information on market transaction behavior and market operation efficiency in an incomplete information market [15]. Information asymmetry in economic activities is generally manifested in two aspects. First, after the transaction is completed, the information-dominant party conceals relevant information from the information inferior party, resulting in information asymmetry. Second, there is an asymmetry in the ability and information state of people participating in economic activities to obtain information before trading, which is also an important reason for "adverse selection" [16]. Information asymmetry in the green product market is reflected in the latter. The latter "adverse selection" mainly refers to the wrong choice made by the information inferior party, which objectively leads to the unreasonable distribution of the market. This further results in the economic phenomenon of "lemon market" and "bad money drives out good money". Before trading, manufacturers, and sellers in the production system of green products have a lot of information about the price and greenness of products, whereas consumers' information about products comes only from the promotion of products by manufacturers or sellers. Under such asymmetric information, consumers often judge the greenness of products by price, which also allows enterprises to use false quality. To reduce the risk of buying high-priced but low-quality products, consumers are only willing to pay the price according to the average green degree of the product. Then, sellers with higher quality withdraw from the transaction, leaving only low-quality sellers to enter the market. In extreme cases, the phenomenon of "bad money drives out good" may occur, resulting in the shrinkage of the entire green market.

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[5] https://www.miit.gov.cn/jgsj/jns/wjfb/art/2020/art_40aa852f1c654540bc53b7f9594809e1.html.

[6] http://www.gov.cn/zhengce/zhengceku/2020-03/19/5493065/files/8c46733fd72b47779e8ae64b4fec2977.pdf.

[7] http://www.gov.cn/zhengce/2020-04/01/content_5497820.htm.

8.2 Game Analysis of Pricing for Green Product

8.2.1 Background

Green products refer to products that cause no or extremely low harm to humans or the environment during production, use, and consumption; these include environmentally labeled products and organic food. In recent years, driven by both government environmental regulations and green consumption, green products have gradually replaced traditional products. In addition, building a green growth model for enterprises has become a new growth point for their high-quality development. The price of green products is a key factor in determining whether consumers engage in green consumption behavior. Therefore, to realize the smooth flow of green products from production to consumption and to open up the entire value chain of the enterprise's green growth, it is necessary to formulate a reasonable pricing strategy. From the perspective of the entire value network of green production, the factors that affect the pricing of green products include external consumers' green consumption intentions, relevant government policies, competitors for producing substitutes, and the influence of information asymmetry between buyers and sellers. In addition to production costs, enterprises should consider resource and environmental costs. Information asymmetry leads to the replacement of real products with fake products. In a market with asymmetric information, there is a large operating space to obtain profits using false quality information pricing, and enterprises tend to use false quality information pricing. For green products, due to their high cost, the price of green products is generally higher than that of common products, and the price of products is one of the few pieces of information related to the green quality of products available to consumers, which also provides an internal driving force for enterprises to obtain high profits by using false quality information.

To promote the healthy development of the green product market, break through the links of green production and consumption, and reduce the adverse effects of information asymmetry on the green product market, we discuss the game models between manufacturers and consumers, manufacturers and retailers, and manufacturers and governments under information asymmetry from the perspective of stakeholders in the production, sales, use, and supervision. Moreover, we try to distinguish between qualified and unqualified green products in the market through model analysis and pricing mechanisms to reveal the operational law of the green product market, safeguard consumer interest, and promote sustainable development.

8.2.2 Literature Review

Liu et al. constructed a two-stage supply chain to examine the pricing strategy of green product supply chains based on behavioral pricing. They found that when consumers are less sensitive to green products, as green product market share increases, green product retailers will increase their loyalty prices, and consumers' emphasis on green products will lead to higher profits for green product manufacturers and retailers [17]. Heydari et al. analyzed the coordination of green channels in secondary supply chains, where demand is a function of the sales price and product green quality. They found that green cost-sharing contracts and revenue-sharing contracts can achieve channel coordination, improve product green quality, reduce prices, and stimulate market demand [18]. However, the literature above does not consider information asymmetry between green product sellers and buyers. Information asymmetry in the market affects consumers' purchasing decisions, green product supply chain production, and sales decisions. Shao and Unal studied the sustainable information attributes that consumers pay attention to in green purchasing, and how these attributes promote consumers' willingness to pay a premium [19]. Hong et al. studied the pricing of green products by considering consumers' environmental awareness and non-green product references. The results show that the pricing strategy for green products is significantly affected by information asymmetry. Compared with information symmetry, enterprises should apply differentiated pricing strategies by considering their green production costs [20].

The above studies only considered the pricing of green products from the market perspective. Since green production has a strong positive externality, the government often needs to promote green production in the initial development stage of the green market. Meng et al. constructed a two-stage green supply chain price decision model composed of a manufacturer and a retailer and studied four types of price decisions: no government subsidies, government subsidies to the manufacturer, government subsidies to the retailer, and government subsidies to green product consumers. Compared with no government subsidies, government subsidies to the manufacturer will reduce the wholesale and sales prices of green products, whereas subsidies to the retailer will lead to higher wholesale and sales prices of green products. Regardless of which object is subsidized by the government, the wholesale price of common products remains unchanged, and the sales price decreases. Government subsidies promote the sales of green products, thereby expanding the market share of green products [21].

Based on the above literature, our research considers green product prices as a way of information transmission from sales to consumers. Through the information game, we analyze the game model between consumers and manufacturers, retailers, and the government under information asymmetry from the perspective of the supply chain. In addition, we explore how the producers and sellers of green products can help consumers correctly distinguish between green and non-green products in the market through a price strategy.

8.2.3 Pricing for Green Product Model of Game Between the Manufacturer and Consumers Under Information Asymmetry

(1) Problem Description and Assumptions

Suppose that the main players of the game are the green product manufacturer and consumers, the manufacturer is a signal sender and consumers are signal receivers, and the manufacturer has absolute advantages in information. According to the trading characteristics of the green product market, a signal game is applied, and the following assumptions are made.

It is assumed that both parties of green product transactions are strictly rational and committed to pursuing the maximization of their own interests. There are two types of manufacturers θ: manufacturer h produces qualified green products and manufacturer l produces unqualified green products. The utilities of consumers purchasing qualified and unqualified green products are u_h and u_l, respectively, and $u_h > u_l$ [22]. At the same time, whether the green products produced by the manufacturer are qualified is private information, and consumers only know the price of the product and can only judge the type of product based on its price. If the manufacturer produces qualified green products, they need to pay high cost c_h; otherwise, they pay a low-cost c_l [20]. Qualified or non-qualified manufacturers can choose to sell green products at a high price of p_h or low price of p_l [23]. Suppose that the consumer either accepts the manufacturer's pricing or does not purchase it. To simplify the analysis, we assume $u_h - p_h > u_l - p_l > 0 > u_l - p_h$, that is, buying qualified green products at a high price is more cost-effective than buying non-qualified green products at a low price, and buying non-qualified green products at a low price will not result in negative returns.

According to the representation method of the signal game, the game can be expressed as: (a) "Nature" first chooses the type of the manufacturer, and the prior probabilities are $\mu(\theta = h) = q$ and $\mu(\theta = l) = 1 - q$, respectively; (b) after the enterprise understands its type, it selects the price level p_θ as the signal to be sent; (c) after the consumer observes the price level p_θ, they use the Bayesian rule to obtain the posterior probability $\mu(\theta|p_\theta)$, and then choose to buy; (d) the manufacturer realizes their own benefit and consumers realize their own utility.

According to the above assumptions, the expected income of consumers choosing to buy is $E_{M1} = (u_h - p_h)\mu(h|p_h) + (u_l - p_h)\mu(l|p_h) + (u_l - p_l)\mu(l|p_l) + (u_h - p_l)\mu(h|p_l)$; the expected benefit of consumers not buying is $E_{M2} = 0$.

If $E_{M1} > E_{M2}$, consumers buy green products; otherwise, they give up buying. The signal game model of green product manufacturers and consumers is shown in Fig. 8.1.

(2) Equilibrium Analysis

Since $p_h - c_l > p_l - c_l$, unqualified green product manufacturers always wanted to sell products at a high price. There is no separating equilibrium in this game; but

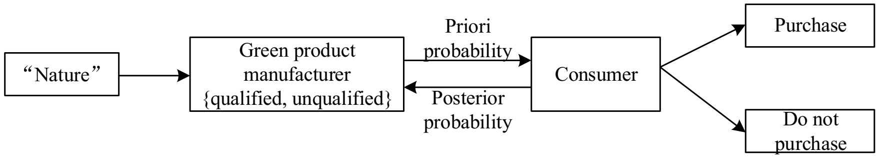

Fig. 8.1 The signal game model of green product manufacturers and consumers

when $q > \frac{(p_h - u_l)(1-q)}{(u_h - p_h)}$, there is a pooling equilibrium. Pooling equilibrium implies that manufacturers of qualified green products, regardless of being qualified or not, offer the same price (high price). Therefore, the consumers' posterior judgment of the manufacturer is $\mu(h|p_h) = q$, $\mu(l|p_h) = 1 - q$, $\mu(l|p_l) = 0$, and $\mu(h|p_l) = 0$. At this point, the expected benefit of the consumer's purchase is $E_{M1} = (u_h - p_h)q + (u_l - p_h)(1 - q) > 0$ and the consumer chooses to buy the product.

(3) Conclusion

The analysis results show that when only the manufacturers and consumers play the game, the unqualified green products sell at a high price. This is because the unqualified green product manufacturers are not constrained by the outside world and are in information advantage; thus, they do not need to pay any cost for counterfeiting behavior. Qualified green product manufacturers can only sell their qualified green products at a high price; therefore, there is no separating equilibrium in the game. Market forces cannot effectively distinguish between qualified and unqualified green products, and consumers can only buy in a market where unqualified and qualified green products are sold together, which reduces consumers' trust in the green market.

8.2.4 Pricing for Green Product Model from the Perspective of Supply Chain Under Information Asymmetry

(1) Problem Description and Assumptions

Assuming that the game subject is the manufacturer and retailer of green products, the green products produced by the manufacturer are sold to consumers through the retailer. However, the retailer does not know whether the green products are qualified, and will decide whether to test the green products according to the wholesale price of the manufacturer. The assumptions of the model are as follows.

The manufacturer and retailer of green products are strictly rational and committed to maximizing their own interests. There are two types of manufacturers θ: manufacturer h produces qualified green products; manufacturer l produces unqualified green products. If the manufacturer produces qualified green products, they need to pay high cost c_h, and if the manufacturer produces unqualified green products, they need to pay low cost c_l [20]. Both qualified and non-qualified manufacturers can choose to wholesale green products to retailers at the high wholesale price of

w_h or the low wholesale price of w_l. The market price of green products set by the retailer is p, and the final sales volume of qualified and non-qualified green products is Q_h and Q_l respectively [24]. Suppose the retailer either tests the green products from the manufacturer to assess whether they are qualified or not. If the retailer chooses to test, it will definitely detect non-qualified products, but it will cost c_r. The unit compensation of the unqualified manufacturer is L_θ. And the manufacturer who makes high wholesale price will bear high compensation, who makes low wholesale price will bear low compensation If the non-qualified green products flow into the market without testing, the loss to the retailer is D.

According to the representation method of the signal game, the game can be expressed as: (a) “Nature” first chooses the type of the manufacturer, and the prior probabilities are $\mu(\theta = h) = q$ and $\mu(\theta = l) = 1 - q$, respectively; (b) after the manufacturer understands its type, they select the wholesale price w_θ as the signal to be sent; (c) after the retailer observes the price level w_θ, they uses the Bayesian rule to obtain the posterior probability $\mu(\theta|w_\theta)$, and then choose whether to test; (d) the manufacturer and retailer realize their own benefits.

According to the above assumptions, the expected revenue of the retailer’s choice of test is:

$$
\begin{aligned}
E_J = {} & (p - w_h - c_r)Q_h\mu(h|w_h) + (p - w_h - c_r + L_h)Q_l\mu(l|w_h) \\
& + (p - w_l - c_r + L_l)Q_l\mu(l|w_l) + (p - w_l - c_r)Q_h\mu(h|w_l);
\end{aligned}
$$

The expected benefit of choosing not to test is:

$$
\begin{aligned}
E_B = {} & (p - w_h)Q_h\mu(h|w_h) + (p - w_h - D)Q_l\mu(l|w_h) \\
& + (p - w_l - D)Q_l\mu(l|w_l) + (p - w_l)Q_h\mu(h|w_l).
\end{aligned}
$$

If $E_J > E_B$, the retailer chooses to test, otherwise, does not test. The signal game model of green product manufacturer and retailer is shown in Fig. 8.2.

(2) Equilibrium Analysis

When

$$(w_h - c_l - L_h)Q_h < (w_l - c_l - L_l)Q_l$$

and

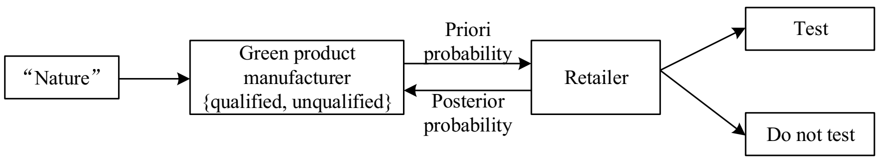

Fig. 8.2 The signal game model of green product manufacturer and retailer

$(p - w_h - c_r)Q_h + (p - w_l - c_r + L_l)Q_l > (p - w_h)Q_h + (p - w_l - D)Q_l$, a separating equilibrium is reached. The strategy combination under the separating equilibrium is high wholesale price agreed upon by qualified green product manufacturers, low wholesale price agreed upon by unqualified manufacturers, and retailer selection testing. Therefore, the posterior probability judgments of the retailer to the manufacturer are $\mu(h|w_h) = 1$, $\mu(l|w_h) = 0$, $\mu(l|w_l) = 1$, and $\mu(h|w_l) = 0$. Thus, the expected revenue of the retailer choosing the test is $E_J = (p - w_h - c_r)Q_h + (p - w_l - c_r + L_l)Q_l$, and the expected benefit of choosing not to test is $E_B = (p - w_h)Q_h + (p - w_l - D)Q_l$ and $E_J > E_B$.

When

$$(w_h - c_l - L_h)Q_h > (w_l - c_l - L_l)Q_l$$

and

$(p - w_h - c_r)Q_h q + (p - w_h - c_r + L_h)Q_l(1 - q) > (p - w_h)Q_h q + (p - w_h - D)Q_l(1 - q)$, the result is pooling equilibrium. The strategy combination of the pooling equilibrium is that both qualified and non-qualified green product manufacturers set high wholesale prices, and retailers choose testing. Therefore, the posterior judgment of the retailer on the manufacturer is $\mu(h|w_h) = q$,$\mu(l|w_h) = 1 - q$, $\mu(l|w_l) = 0$, and $\mu(h|w_l) = 0$. The expected revenue of the retailer choosing to test is $E_J = (p - w_h - c_r)Q_h q + (p - w_h - c_r + L_h)Q_l(1 - q)$; the expected revenue of choosing not to test is $E_B = (p - w_h)Q_h q + (p - w_h - D)Q_l(1 - q)$, and because $E_J > E_B$, the retailer chooses to test.

(3) Conclusion

The manufacturer's production behavior is supervised by the internal members of the supply chain when the retailer chooses whether to test the manufacturer's products according to the wholesale price. In this case, there is a separating and pooling equilibrium in the game. Since the manufacturers of both qualified and non-qualified green products set high wholesale prices under the pooling equilibrium, it is impossible to distinguish qualified green products from non-qualified green products by relying on the wholesale price. Retailers should reasonably adjust the retail price and the compensation charged to manufacturers to achieve the conditions $(w_h - c_l - L_h)Q_h < (w_l - c_l - L_l)Q_l$ and $(p - w_h - c_r)Q_h + (p - w_l - c_r + L_l)Q_l > (p - w_h)Q_h + (p - w_l - D)Q_l$ of separating equilibrium. Hence, the wholesale price can accurately reflect whether the manufacturer's green products are qualified, that is, qualified green product manufacturers can set a high wholesale price, whereas unqualified green product manufacturers can set a low wholesale price to ensure the interests of qualified green product manufacturers.

8.2.5 Pricing for Green Product Model with Information Asymmetry Under Government Supervision

(1) Problem Description and Assumptions

Assume that the main players in the game are the green product manufacturer and the government, the green product manufacturer is the signal sender, while the government is the signal receiver. The model assumptions are as follows.

The manufacturer and government are both rational and committed to maximizing their own benefits. There are two types of manufacturers θ: manufacturer h produces qualified green products; manufacturer l produces unqualified green products. The social benefits of the production of qualified green products are V_h, and the social benefits of the production of unqualified green products are V_l, and $V_h > V_l$ [25]. If the manufacturer produces qualified green products, they need to pay a high cost c_h; otherwise, they pay a low-cost c_l [20]. Both the qualified and non-qualified manufacturers can choose to sell green products at a high price p_h or a low price p_l. The government either regulates or does not regulate. Under the supervision of the government, a subsidy αp_θ will be given to the qualified green product manufacturer based on pricing, and a penalty $\beta_\theta p_\theta$ ($\beta_h > \beta_l$) will be imposed on the unqualified green product manufacturer.

The game can be expressed as: (a) "Nature" first chooses the type of the manufacturer, and the priori probability are $\mu(\theta = h) = q$, $\mu(\theta = l) = 1 - q$; (b) after the manufacturer understands its type, it selects the price level p_θ as the signal to be sent; (c) after the government observes the price level p_θ, it uses the Bayesian rule to get the posterior probability $\mu(\theta | p_\theta)$, and then chooses whether to monitor the manufacturer; (d) the manufacturer and the government realize their own benefits.

According to the above assumptions, the expected benefit of the government's choice of regulation is $E_G = (V_h - \alpha p_h)\mu(h|p_h) + (V_l + \beta_h p_h)\mu(l|p_h) + (V_l + \beta_l p_l)\mu(l|p_l) + (V_h - \alpha p_l)\mu(h|p_l)$, while the expected benefit of the government's non-regulation is $E_N = V_h\mu(h|p_h) + V_l\mu(l|p_h) + V_l\mu(l|p_l) + V_h\mu(h|p_l)$. When $E_G > E_N$ occurs, the government chooses to regulate, and if vice versa, it does not regulate. The signal game model of green product manufacturer and the government is shown in Fig. 8.3.

(2) Equilibrium Analysis

If $p_h - c_l - \beta_h p_h < p_l - c_l - \beta_l p_l$ and $(V_h - \alpha p_h) + (V_l + \beta_l p_l) > V_h + V_l$, we obtain a separating equilibrium. The strategic combination under separating equilibrium is that qualified green product manufacturers set high prices, unqualified manufacturers set low prices, and the government chooses supervision. Therefore, the manufacturer's posterior probability judgment is $\mu(h|p_h) = 1$, $\mu(l|p_h) = 0$, $\mu(l|p_l) = 1$, and $\mu(h|p_l) = 0$. Thus, the expected benefit of the government choosing to regulate is $E_G = (V_h - \alpha p_h) + (V_l + \beta p_l)$; the expected benefit of the government not regulating is $E_N = V_h + V_l$ $(E_G > E_N)$, and the government chooses to regulate.

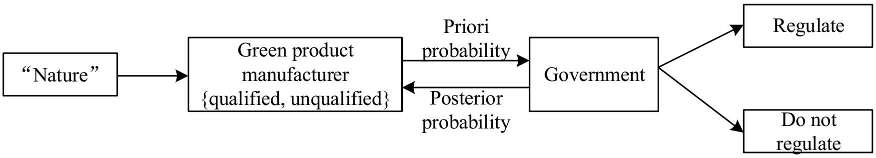

Fig. 8.3 The signal game model of green product manufacturer and the government

For $p_h - c_l - \beta_h p_h > p_l - c_l - \beta_l p_l$ and $(V_h - \alpha p_h)q + (V_l + \beta_h p_h)(1 - q) > V_h q + V_l(1 - q)$, the result of the game is a pooling equilibrium. The strategic combination under the pooling equilibrium is as follows: both qualified and unqualified green product manufacturers set a high price and the government chooses to regulate. Therefore, the government's a posteriori judgment of the manufacturer includes $\mu(h|p_h) = q$, $\mu(l|p_h) = 1-q$, $\mu(l|p_l) = 0$, and $\mu(h|p_l) = 0$. The expected benefit of the government's choice of regulation is $E_G = (V_h - \alpha p_h)q + (V_l + \beta_h p_h)(1 - q)$; the expected benefit of the government's non-regulation is $E_N = V_h q + V_l(1 - q)$ $(E_G > E_N)$, and the government chooses to regulate.

(3) Conclusion

When the external government regulates the manufacturer's production and sales behavior, the game results also have separating and pooling equilibriums. In turn, the equilibrium result is ultimately determined by the conditions satisfied by the relevant parameters. Since manufacturers of both qualified and unqualified green products set high prices in the pooling equilibrium market, consumers cannot distinguish green products accurately based on the product price. To ensure that the result of the game reaches separating equilibrium, the government needs to mandate reasonable punishment for unqualified green product manufacturers and appropriate subsidies for qualified green product manufacturers. It doesn't mean that the more punishment the government mandate, the better. When $p_h - c_l - \beta_h p_h < p_l - c_l - \beta_l p_l$ and $(V_h - \alpha p_h) + (V_l + \beta_l p_l) > V_h + V_l$ are satisfied, the government can separate qualified manufacturer from unqualified manufacturer according to market price. By doing so, consumers can correctly distinguish qualified green products from non-qualified green products based on their price, thus enhancing their trust in the green market.

8.3 Summary

Green product prices affect market demand and enterprise profits. Reasonable green prices can encourage more consumers to convert their green consumption intentions into actual purchasing behaviors, and provide a guarantee for enterprises to implement green growth models. Compared with common products, green products require enterprises to invest significant green costs, and their prices are usually higher than common products. This makes enterprises lose part of their price-sensitive consumers. However, the green market also possesses opportunities that are not available to common products, such as the growing trend in green consumption and government policies. Consumption and policy environments provide favorable conditions for enterprises to produce green products. However, the interior of a green market is a typical decision-making environment with limited and vague information. If there is no guidance and constraint of system and mechanism, bad money drives out good, which is not conducive to enterprises' implementation of the green growth model. Therefore, government or upstream and downstream supervision of the supply chain is particularly important for creating a healthy and green production and consumption environment. The game analysis between manufacturers, retailers, and the government from the perspective of the supply chain and government supervision also shows that if the pricing of green products meets certain conditions, consumers can separate qualified and unqualified green products to ensure healthy operation of the green market.

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Chapter 9
Green Procurement and Outsourcing

Bin Wei, Nengmin Wang, Qi Jiang, and Zhengwen He

Abstract Procurement and outsourcing are essential links in enterprises' production and operation. They have varying impacts on value chain structures, enterprises' profits, and environmental sustainability. Government environmental regulations and the growing consumer demand for green consumption have prompted enterprises to choose green procurement models. Accordingly, this chapter discusses the relationship between procurement and outsourcing and enterprises' green growth. It analyzes the strategic decision of enterprises to choose direct procurement or procurement outsourcing based on the motivation and risk factors of outsourcing. Following the theoretical analysis, a procurement game model comprising the original equipment manufacturer, contract manufacturer, and suppliers is constructed. The results show that when enterprises choose direct procurement, the wholesale price of suppliers is lower but the processing price is higher than that for outsourcing; when the market scale is small, enterprises opt for direct procurement. Moreover, procurement outsourcing is more environmentally sustainable than direct procurement.

9.1 Relationships Between Procurement, Outsourcing, and Enterprises' Green Growth Model

9.1.1 Procurement and Outsourcing

Procurement is the process whereby a company obtains raw materials, components, products, services, or other resources from suppliers to conduct its business [1]. The effective procurement of goods or services has a significant impact on a company's

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competitive advantage. The procurement process connects members of the value chain and ensures its quality of supply. The procurement function is vital to a company because purchased materials or commodities account for a large proportion of the value chain transaction costs [2]. Each unit (1%) reduction in procurement costs can directly contribute to the net profit by one unit (1%); the lower the profit margin, the greater the importance of reducing procurement costs. With increased globalization and advances in information technology, enterprises now have access to an ever-larger supply base for better cost and quality materials. However, the procurement process can be complex and time-consuming because of longer geographic distances, more extensive supply networks, and different geopolitical circumstances. Consequently, many enterprises outsource purchasing activities to agents such as Accenture, Global Sources, and ICG Commerce [3]. Outsourcing implies that an enterprise dynamically configures its functions and services and those of other enterprises and utilizes external resources to facilitate its internal production and operations.

Nike and UNIQLO are well-known clothing enterprises with mature procurement systems. The two companies' production and logistics services are outsourced to professional third-party companies, and the commodity labels generally mention the origin as "made in China" or "made in Vietnam." In contrast, the company itself focuses on product design and brand operation. Unlike Nike and UNIQLO, ZARA, one of the most important fashion companies worldwide, integrates design, production, distribution, and retail through its extensive retail channels. ZARA purchases most of its products from suppliers in more than 50 markets, and more than 50% of its products are made internally or in nearby factories.[1] This production model allows ZARA to respond more quickly to the market sales situation through its factories, modify the manufacturing plan, and realize more effective control. A similar situation exists in the automobile industry as well. China's NIO Automobile outsources its production activities to JAC Automobile.[2] NIO is mainly responsible for key technology research and development (R&D) and brand operation, saving on the substantial fixed costs of building factories. Owing to the low-end brand of the foundry and annual loss of performance, providing foundry services for new energy vehicle manufacturers can achieve a win–win situation for NIO and JAC Automobile. Traditional car manufacturers, such as the BYD Company, have attached importance not only to design but also to manufacturing in establishing their entire industry chain system. BYD grew sales of its "new energy" (hybrid or all-electric) passenger vehicles by more than 231% year over year in 2021, selling nearly 600,000 new energy passenger cars.[3]

Procurement and outsourcing are everyday operational decision-making activities in the global production industry. Enterprises should choose their procurement or outsourcing strategies based on their industry characteristics and competitive advantages.

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[1] https://www.inditex.cn/en/how-we-do-business/our-model/sourcing.

[2] https://seekingalpha.com/article/4429867-nio-vs-li-auto-stock-better-buy.

[3] https://www.fastcompany.com/90724485/most-innovative-companies-transportation-2022.

9.1.2 Green Procurement

Green procurement is an indispensable part of enterprises' green growth model. Unlike ordinary procurement, green procurement requires enterprises to manage all aspects of the value chain's upstream components to maximize coordination for environmental, social, and economic sustainability [4].

(1) Reasons for Enterprises to Implement Green Procurement Strategies
(a) Government Regulations

Green transformation is an essential strategy for achieving sustainable development [5]. To achieve this goal, governments worldwide have implemented environmental regulation systems to encourage enterprises to implement green production methods. The United States was the first country to embark on Government Green Procurement, mainly using federal laws and presidential executive orders as the legal basis for promoting such procurement. For example, the Resource Conservation and Recycling Act (RCRA) was promulgated by the US in 1976.[4] Executive Order 13,101 of the President of the US in 1991 "Greening the Government Through Waste Prevention, Recycling, and Federal Acquisition" requires procurement agencies to prioritize the purchase of green products and use of recycled products.[5] In April 2016, the European Commission issued a fully revised version of "Buying Green!—A Handbook" on green public procurement. This Handbook is a guidance document of the European Commission and aims to help public authorities purchase goods and services with less impact on the environment. It is also a useful reference for policy makers and companies responding to green tenders.[6] Although the Chinese government's green procurement started relatively late compared to that of developed countries, the scale of procurement has expanded year by year. With the successive introduction and continuous improvement of government procurement laws and regulations, Chinese government departments at all levels and state-owned enterprises and institutions are expanding the demand-side proportion of green procurement to promote green innovation, transformation, and upgradation of enterprises. In March 2015, China implemented the revised "Government Procurement Law of the People's Republic of China," which stipulates the development goals of protecting the environment, achieving sustainable development and building an ecological civilization. These procurement policies aim to encourage supplier R&D innovation to reduce costs and stimulate private demand for green products [6]. Wang et al. argued that the level of green technology adoption by enterprises is related to the intensity of government regulations [7]. Considering industrial compliance, supervision can promote the development of new green technologies more effectively. However, given fierce market competition, excessive radical supervision would stifle enterprises' green innovation.

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[4] https://www.epa.gov/history/epa-history-resource-conservation-and-recovery-act.

[5] https://www.wbdg.org/ffc/fed/executive-orders/eo-13101.

[6] https://ec.europa.eu/environment/gpp/buying_handbook_en.htm.

(b) Consumers' Green Preferences

Owing to the continuous deterioration of the environment and the promotion of environmental protection by governments or NGOs, an increasing number of consumers are focusing on green consumption; consumers' green preferences are the key market drivers that promote value chain sustainability [8]. According to a global survey by Accenture, more than 80% of respondents consider the greenness of a product when making a purchasing decision; therefore, companies choosing to source green raw materials can enhance their brand image and expand their market share [9]. Consequently, enterprises are motivated to choose green suppliers.

Hong et al. proposed a two-echelon supply chain model comprising manufacturers who design and produce green products and retailers who promote green products. They concluded that with an increase in consumers' green preferences, cooperation between participants can improve supply chain sustainability but is not necessarily optimal for participants [10]. Lin et al. investigated a company's best quality and pricing decisions for its by-products. They found that when green consumers emphasize the material-saving aspects of the product, the company may strategically abandon traditional consumers [11].

(2) Selection and Evaluation of Green Suppliers

Supplier selection is a critical activity in the green procurement process and crucial for reducing procurement costs and risks. Suppliers' technical level, competitive advantage, and corporate culture can affect the final product's performance. He et al. designed a hybrid e-procurement mechanism, which implements a multi-attribute combinatorial auction. They found that compared to the classical Vickrey-Clarke-Groves mechanism, the proposed mechanism improves the transactional social surplus [12]. Koh et al. investigated an auction contest for innovation procurement and showed that it is optimal for buyers to invite multiple companies under high randomness; moreover, fixed-prize tournaments may outperform auctions [13]. However, in the absence of randomness, it is optimal to invite only two companies. He et al. further explored a buyer's optimal procurement mechanism when facing two potential suppliers with capacity constraints and private cost information [14]. Birulin et al. discussed the procurement auction problem for a project with cost overruns after the production cost is affected and stated that the lowest bid auction procurement mechanism can result in an optimal combination of the lowest bid auction and the guaranteed bond to minimize the expected cost [15]. Hosseini et al. first adopted a hybrid BWM-ER method to evaluate and rank suppliers, subsequently proposing a dual-objective mathematical optimization model to address the trade-off between sustainability and economic cost under uncertain demand, capacity, and inventory [16]. Villenade et al. studied the sustainability of extended supply chains by collaborating with a sustainable development electronics company "Tronics." They concluded that having an integrated management system comprising economic, environmental, and social elements or collaborating with a network of key stakeholders of

Chinese suppliers increases the likelihood of adopting sustainable sourcing strategies [17].

In the process of enterprise's green operation, it is necessary to select suitable suppliers and evaluate whether they can bring about an increase in their performance. Aksoy et al. proposed a neural network-based supplier selection and performance evaluation system to help just-in-time production agents select the most suitable suppliers and evaluate supplier performance [18]. Dey et al. proposed the leading factors such as organizational practice, risk management, environmental, and social practice, and lagging factors of supplier evaluation and demonstrated a systematic method of identifying these factors with stakeholder participation [19]. Liu et al. indicated that supplier sustainability is crucial for supply chain sustainability, proposing a fuzzy decision-making tool for supplier sustainability performance evaluation based on TBL and testing its effectiveness in the sustainable agricultural food value chain [20]. Giannakis et al. established a sustainability performance evaluation framework for supplier evaluation and selection using the analytic network process. They found that socioeconomic indicators play the most important role in sustainable supplier selection [21]. In addition, technologies such as blockchain and the Internet of Things are widely used in green procurement activities involving supplier selection, logistics, packaging, and distribution [22]. Evaluating green suppliers is especially important for enterprise procurement and outsourcing decisions. Enterprises may switch from traditional to green procurement models only when the benefits of choosing green suppliers outweigh those of manufacturing outsourcing.

9.1.3 Impact of Procurement and Outsourcing on Enterprises' Green Growth Model

Enterprises' growth model refers to the way that enterprises achieve their goals including increasing sales, maximizing profits, or increasing market share through internal and external expansion. Green growth model requires enterprises to achieve optimal profits and coordinate economic and environmental sustainability. The primary motivation for procurement outsourcing is to improve brand owners' operational efficiency and lower procurement costs, thereby expanding production and increasing corporate profits, which represent the same goals as enterprises' growth. However, the most severe obstacle to the development of business outsourcing is the lack of suitable contract operation mechanisms upstream and downstream of the value chain, which makes it difficult to effectively coordinate the costs, risks, and incomes of the value chain members under procurement outsourcing. This results in the unsustainable operation of enterprises and hinders the formation of green growth model. In addition, the specific path, value chain reconstruction, and integration strategy direction vary across enterprises in the process of green transformation of the growth model. Procurement and outsourcing choices involve critical decision-making processes, and innovative enterprises face rapid market demand updates that are prone to inventory backlogs. Consequently, enterprises' independent procurement and manufacturing choices may result in redundant inventory production and inventory losses. Most enterprises thus outsource production activities to professional tripartite enterprises to focus on new technologies and product development. Functional products mainly reduce operating costs through economies of scale, enabling enterprises to coordinate through long-term procurement contracts to achieve green growth.

9.2 Procurement and Outsourcing Decisions

Enterprises in different industries adopt flexible procurement or outsourcing strategies in different periods in complex and changeable external environments. For example, as the world's largest chain, Walmart Inc. once relied on the Hong Kong purchasing agent Li & Fung Group to provide comprehensive procurement services. However, in 2015, a Walmart bulletin announced that it would adjust its cooperation with the Li & Fung Group, transferring part of the procurement functions to Walmart's internal departments, but continue to use the Li & Fung Group's other services, such as quality inspection. In the same year, Kate Spade, the US handbag and clothing brand, also announced that their handbags and accessories procurement activities would be carried out by the company from the spring of 2016, with only the clothing component handed over to the Li & Fung Group to cut outsourcing orders.[7] Therefore, in pursuing green and sustainable growth, enterprises must often carry out procurement cost and profit analyses to confirm whether outsourcing is beneficial for enterprises in the long term, which determines whether they should adopt a procurement outsourcing strategy.

This section analyzes the strategic decisions of independent procurement and procurement outsourcing from the perspective of the motivation factors and risks of outsourcing.

[7] https://insideretail.asia/2015/05/27/walmart-reduces-li-fung-reliance-2/.

9.2.1 Motivation for Outsourcing

In enterprise value chain operations, it is necessary to reasonably evaluate the risks and benefits of independent procurement and outsourcing. Enterprises choose to outsource only when it increases customer value or reduces the cost of value chain operations relative to independent procurement. The main motivations for outsourcing are as follows.

(1) Capacity Concentration

Third-party enterprises can improve the value chain's profit by concentrating on the needs of multiple companies and acquiring economies of scale that a single company cannot obtain. Apple Inc. and most other mobile phone manufacturers, such as Xiaomi Corporation and Huawei Company, outsource the assembly and production of mobile phones to the Foxconn Group. Foxconn has incomparable competitive advantage in terms of electronic design and manufacturing. Outsourcing can save costs and improve product competitiveness.

(2) Risk Pooling

Outsourcing may transfer demand uncertainty to contract manufacturers. The advantage of using contract manufacturers is that they can integrate demand from different buyers, thereby reducing demand uncertainty through risk sharing. This further allows them to reduce parts inventories while maintaining or improving service levels. Especially for small and medium-sized enterprises, outsourcing can diversify the risks arising from economic, market, and financial factors through outward resource allocation. As enterprises' procurement resources and capabilities are limited, they can become more flexible and adapt to the changing external environment through the outward allocation of resources and risk sharing with external outsourcing suppliers.

(3) Focus on the Core Competitiveness of Enterprises

By carefully selecting outsourced content, an enterprise can focus on improving its core competencies such as unique talents, skills, and knowledge structures, which set them apart from competitors and can be identified by consumers. Owing to globalization, different countries and regions have diverse comparative advantages that need to be rationally utilized. The key components of electric vehicles are their power batteries. Tesla outsources power batteries to China's CATL, the largest battery manufacturer worldwide. Therefore, Tesla focuses on the power management system design. The final vehicle manufacturing is outsourced to the Tesla Super Factory in Shanghai. This efficient outsourcing model led Tesla's stock market value to exceed $1 trillion in 2021, surpassing the sum of the market values of 11 established automobile companies, including Toyota, Volkswagen, and GM, in the same period.[8]

[8] https://www.cnbc.com/2021/10/25/tesla-stock-passes-1-trillion-market-cap-traders-bet-on-more-gains.html.

(4) Improved Production Flexibility

Outsourcing can better respond to changes in consumer demand and use suppliers' technical expertise to shorten the product R&D cycle. In addition, enterprises can also obtain new technologies and innovation capabilities from suppliers. For example, Xiaomi Corporation, the fastest-growing mobile phone brand in China and the world in recent years, integrates the competitive advantages of suppliers in value chain operations, by combining Samsung's screen, Qualcomm's processor (CPU), and Sony's lens module. Through its contract agreement, Xiaomi Corporation can also obtain the starting privilege of new technologies from suppliers to improve its product demand. Owing to its excellent value chain integration ability, Xiaomi Corporation ranked third worldwide in terms of global smartphone shipments in 2021, below Samsung Electronics and Apple Inc.[9]

9.2.2 Outsourcing Risks

The uncertainty of the environment and conditions of outsourcing activities and the influencing factors that outsourcing stakeholders cannot accurately predict or control affect the operations of enterprises. Despite the many advantages of outsourcing, enterprises must realize the necessity of accounting for risk measures in outsourcing decisions. The following are the five common risk factors for outsourcing activities.

(1) Decision-Making Risks

Decision-making risks stem from two aspects. First, when making outsourcing decisions, enterprises must define which projects or functions are suitable for outsourcing, that is, the technologies that constitute their core competitiveness and those that are non-core technologies. If the selection of outsourcing projects is inappropriate, outsourcing may not achieve the expected goals and may even threaten the business security of the enterprise. Second, enterprises inevitably face supplier selection problems when conducting outsourcing activities. According to the theory of information economics, a "principal-agent" relationship is formed between enterprises and outsourcing service providers in service outsourcing. Owing to information asymmetry in the industry, companies cannot truly understand outsourcing service providers' business performance, social reputation, development status, cost structure, and other information, rendering them unable to accurately screen suitable service providers before outsourcing.

(2) Disclosure Risks

In the process of outsourcing cooperation, enterprises must disclose a large amount of information to service providers, including enterprise strategy, business indicators,

[9] https://omdia.tech.informa.com/pr/2022-feb/omdia-research-shows-galaxy-a12-is-the-most-shipped-smartphone-in-2021.

and patented technology, of which a considerable part forms the business secrets of the enterprise. As the enterprise's information is widely transmitted, the "infidelity" of outsourcing service providers may lead to the loss of enterprise information resources and disclosure of core technologies and trade secrets. For example, with the development of information technology, the financial business has gradually transformed into an information management business. Financial institutions are increasing their investments in information technology systems, considering customer demand, competitive pressure, and cost-effectiveness. Security vulnerabilities exist in outsourcing services provided by information security system providers to financial institutions. These security loopholes can easily lead to leakage, loss, and damage to customers' personal information and even to corporate reputation and legal risks, causing financial institutions and consumers to suffer substantial economic losses.

(3) Contract Risks

An outsourcing contract is an agreement between an enterprise and a third party without an affiliated relationship. The term validity of outsourcing contracts is usually five to ten years, which is a long period. It is difficult to accurately predict business needs and environmental changes during this period. Therefore, whether the outsourcing provider can complete the agreed tasks in time and while maintaining quality is uncertain. As the world's second-largest electronics manufacturing service (EMS) provider after Foxconn, the Flextronics group announced the cessation of cooperation with Huawei in May 2021 and retained Huawei's equipment and materials worth hundreds of millions of dollars because the US Department of Commerce's Bureau of Industry and Security (BIS) listed Huawei on their "entity list" and prohibited US enterprises from selling relevant technologies and products to Huawei.[10] The termination of cooperation temporarily halted Huawei's production. Businesses originally contracted by Flextronics, including Huawei's mobile phones, notebooks, tablets, and telecommunications base stations, were gradually undertaken by Chinese domestic manufacturers.

(4) Disruption Risks

With the continuous development of the global value chain, several uncertain factors inside and outside the value chain make enterprises vulnerable to disruption. The rise of offshore outsourcing has allowed multinational enterprises to enjoy the diverse comparative advantages of other regions fully. However, the long-distance industrial chain makes it difficult for enterprises to control their production and operations. Once a disruption occurs, the transmission of time and distance leads the enterprise into operational difficulties and even bankruptcy because of interrupted cash flow. Chakraborty et al. analyzed the impact of the COVID-19 pandemic on the textile industry by considering the Bangladeshi garment-manufacturing industry as a case study [23]. They concluded that the disruption of raw materials caused by the

[10] https://www.gizchina.com/2019/07/26/huawei-cut-ties-with-flextronics-for-seizing-its-equipment-worth-over-100-million/.

COVID-19 pandemic has led to a sharp increase in the production costs of clothing manufacturers, affecting clothing exports and global textile sales.

(5) Conflict of Interest Risks

Although there is a strategic partnership between outsourcing enterprises and service providers, they are two separate legal entities that seek to maximize their interests. Therefore, in real life, enterprises outsource to service providers to provide more services and reduce costs. In contrast, outsourcing service providers want to increase costs and reduce business requirements, which results in a mutual conflict of interest. In addition, because outsourcing service providers also have the technology and ability to produce similar products, enterprises' profits are likely to suffer if outsourcing service providers use their brands to compete for a market share. Niu et al. analyzed the price competition game model of original equipment manufacturers (OEMs) and their competitive original design manufacturers (ODMs). They concluded that different market environments and pricing sequences have other effects on enterprises' cooperation and competition status [24].

In conclusion, risks and benefits are interrelated. In the face of uncertain outsourcing risks, enterprises must choose outsourcing companies reasonably, sign service agreements, and introduce tripartite institutional supervision or real-time feedback mechanisms to achieve the goal of green growth.

9.2.3 Procurement Outsourcing

Choosing whether to outsource a specific set of activities or business functions is one of the most critical strategic decisions faced by companies [25]. Companies tend to outsource operations that do not have core competitive advantages in the contemporary business environment. The most discussed themes in academia and industry are procurement outsourcing. Procurement requires enterprises to fully control all purchase processes, including supplier selection, evaluation, and purchases. Fully controlled procurement can help enterprises protect core technology and better control quality, leading to stronger resilience of enterprise value chains in the face of upstream and downstream uncertainty. Procurement outsourcing means that enterprises outsource procurement functions to third-party companies. Kayis et al. found that when the supplier's production cost is private information, procurement outsourcing may be better than direct procurement if there are two layers of information distortion [26]. Wang et al. compared two outsourcing structures under three contracts: push, pull, and two-wholesale-price, and found that OEMs prefer control over the delegation structure, regardless of the type of contract [27]. Bolandifar et al. discussed the optimal component procurement strategies of two competing OEMs. They demonstrated that a larger OEM always uses delegation in equilibrium under a strategic supplier, whereas a smaller OEM may use either delegation or control [28].

In addition, consumers' green preferences and government regulations are the main factors affecting corporate procurement and outsourcing decisions. Consumers' increasing awareness of green environmental protection urges enterprises to choose green suppliers and adopt green technologies to expand the market for their products. The government's environmental pollution regulations and green technology subsidies can also guide companies to optimize production processes, choose technical routes, and achieve the goal of green growth.

These decisions are based on a relatively stable external environment. However, as the global geopolitical situation becomes increasingly tense, tariff disputes and trade protectionism are spreading worldwide. Many multinational companies are facing unprecedented challenges in international supply, and the continuously increasing tariff costs have attracted the attention of corporate management. For the daily operation of international trade services, such as the classification of customs goods, the applicable conditions of preferential measures such as free trade agreements, and import and export compliance, these tasks are complex but crucial to controlling enterprise operating costs. The successful performance of these tasks requires companies to equip different regions of the global network with various professional skills and information systems. Therefore, outsourcing such businesses to a professional third party can significantly improve the efficiency of the enterprise. However, if the anti-globalization trend intensifies, multinational companies should seriously consider the location of suppliers, strive to increase the proportion of local production, and balance direct procurement and offshore outsourcing.

9.3 Strategic Decisions of Direct Procurement and Procurement Outsourcing

9.3.1 Introduction

Owing to the intensification of government environmental regulations, enhancement of consumers' awareness of green environmental protection, and development of innovative green technologies, an increasing number of OEMs are actively developing green products or cooperating with suppliers using green raw materials to capture the green consumer market. Improvements in green technology promote the enterprises' brand image, augmenting market demand and product sales. The garment-manufacturing industry is closely related to procurement and outsourcing. As the second-largest industry globally, the garment industry is also the second-largest polluter worldwide, second only to the petrochemical industry. For every ton of textile product, 200 tons of water are polluted; for every kilogram of cloth produced, 23 kg of carbon dioxide are emitted. Furthermore, approximately 2500 chemicals, including harmful heavy metals and some unknown persistent organic pollutants, are used in the dyeing and finishing processes of different textiles. However, the diversity of clothing products leads to apparent demand uncertainty. In the face of volatile market demand, brands often order more clothing than there is actual demand for to ensure supply. Excessive order quantities lead to the overproduction of upstream manufacturers and may result in excess inventory owing to brands' low actual demand, thereby undermining the sustainability of the value chain. Therefore, designing reasonable procurement and outsourcing strategies can alleviate the environmental damage caused by garment manufacturing and achieve the goal of green enterprise growth.

Nike has no manufacturing plants but chooses to outsource the work to contractors in the China, Philippines, Vietnam and Indonesia. Nike relies on Daphne to purchase upstream raw materials for sports shoes and outsources processing and manufacturing services to Daphne in the Chinese market. Simultaneously, Daphne sells its footwear brand in the market, forming a competitive and cooperative relationship with Nike [29]. In addition, Nike sometimes purchases its raw materials and tends to use green, renewable, and environmentally friendly materials, which are generally more expensive than ordinary materials. When enterprises adopt green technology to obtain greater market share, their sales volume will also increase. Because environmental pollution is often positively correlated with output, the increase in sales may be contrary to the goal of sustainable development. Therefore, the impact of green procurement on the coordination of environmental and economic sustainability requires rigorous theoretical analysis and practical summary. Combined with the actual situation, this section mainly focuses on the decision-making of direct procurement and procurement outsourcing in the operation of enterprises, analyzes the sustainability of the economy and environment under the two modes, and provides a reference for business decision-making.

9.3.2 Mathematical Modeling

This section establishes a simple game model to describe the decision-making process of direct procurement and procurement outsourcing in enterprise operations. Consider a three-tier supply chain comprising a component supplier, a contract manufacturer (CM), and an OEM. The CM is a professional manufacturer. The OEM (denoted as O) has no production capacity but can choose to purchase raw materials to meet green standards or hand over all production and procurement to the CM (denoted as M). Simultaneously, because of its ability to integrate the entire industry chain, the CM can also sell its own branded goods and compete with the OEM in the downstream market. Therefore, this section divides the procurement model into two structures:

(a) Procurement Outsourcing

The OEM outsources all procurement and manufacturing activities to the CM. The CM purchases raw materials from the upstream supplier S1 at a unit wholesale price

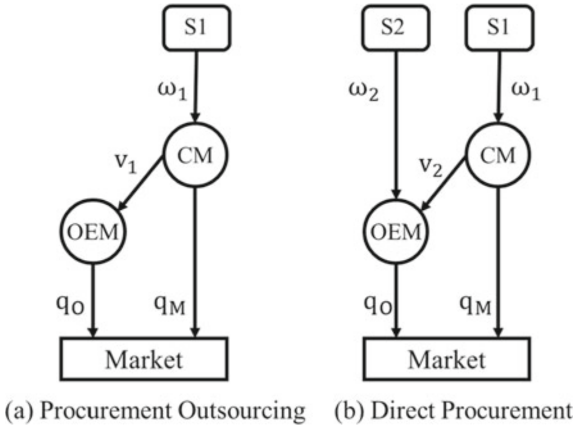

Fig. 9.1 Illustration of two procurement structures

of ω_1. The raw materials can be used for itself and for the OEM. Finally, the OEM buys the finished products from the CM at unit price v_1.

(b) Direct Procurement

To meet the requirements of government environmental regulations or consumers' green preferences, the OEM purchases green raw materials and entrusts them to the CM for processing. The unit purchase cost of raw materials independently purchased by the OEM from upstream green suppliers is ω_2, and the processing cost paid by the OEM to the CM is v_2.

The structure of the model is shown in Fig. 9.1.

The sequence of events is described as follows:

In the first stage of the game, the OEM chooses its procurement strategy. In the second stage, upstream suppliers set the unit wholesale price of their components or materials. It is worth noting that if the OEM chooses direct procurement, the two suppliers set their unit wholesale prices simultaneously. In the third stage, the CM decides the processing cost or the price of finished products, and the OEM and CM engage in quantity competition in the same market.

The firm faces a typical linear inverse demand function given by [30]

$$p_i = a - q_i - b_i q_j,$$

where p_i represents selling price of the firm i, $i, j \in \{M, O\}$, $i \neq j$; q_i and q_j are the selling quantities for the end market. The above inverse demand function can be derived from utility functions that are quadratic in product quantities. Specifically, parameter b_i represents the cross-effect of the change in firm i's product demand caused by a change in that of firm j. This can also represent the substitutability of the OEM's and CM's products. Without loss of generality, we assume that the OEM's products can completely replace the CM's products; however, the reverse is not true [31]. Therefore, $b_M = 1$, and $b_O = b \leq 1$. The total market potential of the CM is a.

The OEM is a strong-brand firm, and it continues to invest in green technologies and products. Therefore, the OEM can improve the consumers' willingness to pay for its products. We assume that the total market potential of the OEM is $(\theta + 1)a, \theta \in \left[0, \overline{\theta}\right)$; note that $\theta < \overline{\theta} = \frac{48-26b+3b^2}{2(22-7b)}$ to guarantee all players positive profits. The marginal manufacturing cost of the CM is standardized to zero. To summarize, the inverse demand functions of the OEM and CM are

$$p_O = (1+\theta)a - q_O - bq_M$$
$$p_M = a - q_O - q_M$$

The objective function of the decision maker is as follows:

(1) Procurement Outsourcing

$$\pi_O^a = (p_O - v_1)q_O$$
$$\pi_M^a = (p_M - \omega_1)q_M + (v_1 - \omega_1)q_O$$
$$\pi_{S1}^a = \omega_1(q_O + q_M)$$

(2) Direct Procurement

$$\pi_O^b = (p_O - \omega_2 - v_2)q_O$$
$$\pi_M^b = (p_M - \omega_1)q_M + v_2 q_O$$
$$\pi_{S1}^b = \omega_1 q_M$$
$$\pi_{S2}^b = \omega_2 q_O$$

9.3.3 Model Analysis and Conclusions

Using backward induction, the game equilibrium results for the OEM and CM are as follows:

(1) Equilibrium Outcomes Under Procurement Outsourcing

Sales quantities:

$$q_O^a = \frac{a\left(8 - 11b + 3b^2 + (30 - 10b)\theta\right)}{2(7-2b)(8-3b)},\ q_M^a = \frac{a\left(48 - 26b + 3b^2 - (44 - 14b)\theta\right)}{4(7-2b)(8-3b)}$$

Profits:

$$\pi_O^a = \frac{a^2\left(8 - 11b + 3b^2 + (30 - 10b)\theta\right)^2}{4(8-3b)^2(7-2b)^2}$$

$$\pi_M^a = \frac{a^2\left[\begin{array}{l}\left(512 - 640b + 328b^2 - 84b^3 + 9b^4\right) + \left(256 - 672b + 376b^2 - 60b^3\right)\theta \\ + \left(928 - 608b + 100b^2\right)\theta^2\end{array}\right]}{16(8-3b)^2(7-2b)}$$

Unit manufacturing price:

$$v_1^a = \frac{a\left(192 - 152b + 38b^2 - 3b^3 + \left(104 - 64b + 10b^2\right)\theta\right)}{4(7-2b)(8-3b)}$$

Unit material wholesale price:

$$\omega_1^a = \frac{a(8 - 3b + 2\theta)}{16 - 6b}$$

(2) Equilibrium Outcomes Under Direct Procurement

Sales quantities:

$$q_O^b = \frac{a\left(22 - 13b + b^2 + (30 - 6b)\theta\right)}{(7-2b)(31-5b)},\ q_M^b = \frac{a(8-b)(13 - 3b - 2\theta)}{2(7-2b)(31-5b)}$$

Profits:

$$\pi_O^b = \frac{a^2\left(22 - 13b + b^2 + (30 - 6b)\theta\right)^2}{(31-5b)^2(7-2b)^2}$$

$$\pi_M^b = \frac{a^2\left[\begin{array}{l}2752 - 1724b + 385b^2 - 34b^3 + b^4 + \left(1824 - 1244b + 232b^2 - 12b^3\right)\theta \\ + \left(928 - 368b + 36b^2\right)\theta^2\end{array}\right]}{4(31-5b)^2(7-2b)}$$

Unit manufacturing price:

$$v_2^b = \frac{a\left(192 - 111b + 20b^2 - b^3 + \left(104 - 52b + 6b^2\right)\theta\right)}{2(7-2b)(31-5b)}$$

Unit material wholesale prices:

$$\omega_2^b = \frac{a\left(22 - 13b + b^2 + (30 - 6b)\theta\right)}{62 - 10b},\ \omega_1^b = \frac{a(13 - 3b - 2\theta)}{31 - 5b}$$

From the above analysis of sales quantities, unit wholesale raw material prices, unit manufacturing prices, and profits, we can draw the following conclusions:

(1) In equilibrium, the CM lowers the wholesale price from supplier S1 under direct procurement, regardless of any values of θ and b, that is, $\omega_1^b < \omega_1^a$. In addition,

during $0 \leq \theta < \frac{72+37b-32b^2+3b^3}{2(89-64b+9b^2)}$, the OEM also lowers the wholesale price from supplier S2, that is, $\omega_2^b < \omega_1^a$. This conclusion shows that, under procurement outsourcing conditions, the wholesale prices of raw materials are always high, even if the CM orders larger quantities from supplier S1. When procurement outsourcing occurs, there is only one monopoly supplier S1, which allows it to charge a higher monopoly price, thus affecting the CM. Through further analysis, we can obtain $\omega_2^b > \omega_1^a$, when $\frac{72+37b-32b^2+3b^3}{2(89-64b+9b^2)} < \theta < \frac{48-26b+3b^2}{2(22-7b)}$. Product substitutability and market size can affect wholesale prices; therefore, the OEM can design products with different properties to avoid high purchase prices when outsourcing. This conclusion also implies that more OEMs tend to purchase independently.

(2) When $0 < \theta < \min\left\{\frac{(8-3b)(74+14b-21b^2+3b^3)}{2(346-330b+91b^2-7b^3)}, \overline{\theta}\right\}$, the unit manufacturing price of direct procurement is higher than that of procurement outsourcing, i.e., $v_2^b > v_1^a - \omega_1^a$. Note that only when b is sufficiently small, $\frac{(8-3b)(74+14b-21b^2+3b^3)}{2(346-330b+91b^2-7b^3)} < \overline{\theta}$. That means that inequality $v_2^b > v_1^a - \omega_1^a$ is always true in general. The result shows that in the case of direct procurement, the CM can only charge processing fees. To generate more profits, the CM can only charge higher manufacturing prices. Therefore, to improve the OEM's procurement outsourcing motivation, the CM can choose to reduce processing costs. In a real-world context, enterprises focusing on brand operations, such as Nike and Adidas, outsource all production and procurement activities to professional manufacturing plants to play to their unique advantages. Foxconn Group works for Apple's mobile phone business, charging only $5 per assembly fee. Through low-cost processing, it is also objectively profitable to obtain hundreds of millions of orders per year for Apple's mobile phones, thereby leading to a win–win situation.

(3) The processing price charged by the CM is an increasing function of OEM's market potential, and the growth rate of direct procurement is lower than that of outsourcing i.e., $\frac{\partial(v_1^a-\omega_1^a)}{\partial\theta} > \frac{\partial v_2^b}{\partial\theta} > 0$. This shows that huge OEM's market potential expands the flexibility of pricing. The CM is the only manufacturer in the market. In the direct procurement mode, the CM mainly charges processing fees from OEM orders, whereas the CM can benefit from manufacturing and procurement services in procurement outsourcing. As the wholesale price of raw materials increases, the CM is motivated to charge higher manufacturing prices.

(4) The sales quantities of the CM under direct procurement are greater than those under procurement outsourcing. In the case of direct procurement, the existence of an alternative supplier S2 significantly weakens the pricing ability of S1. Supplier S1 loses an upstream monopoly; therefore, raw material suppliers can only reduce wholesale prices. Thus, the CM orders more at low prices. This shows that although the OEM's direct procurement strategy can control the

source of raw materials, it may face the risk of increasing downstream market competition.

The above concerns sales and wholesale price analyses. However, enterprises are often more concerned about total profits. By comparing the profits of the OEM and CM under the two structures, we obtain:

(5) When $\theta \in \left(0, \frac{104+41b-54b^2+9b^3}{450-184b+14b^2}\right)$, the OEM tends to engage in direct procurement, and when $\theta \in \left(\frac{104+41b-54b^2+9b^3}{450-184b+14b^2}, \overline{\theta}\right)$, the OEM tends to outsource procurement. This result shows that larger market size does not imply higher profits. Only when θ is relatively small will the OEM choose direct procurement. A larger θ will lead to higher manufacturing and wholesale raw material prices, which offset the competitive benefits of new suppliers. Therefore, when choosing direct procurement or outsourcing procurement decisions, enterprises should reasonably evaluate factors such as market size and raw material prices and comprehensively consider choosing appropriate procurement modes.

The above research mainly analyzes the economic goals of enterprises. However, as government and people's awareness of environmental protection increases, enterprises should pay more attention to environmental sustainability. Referring to Krass et al. [32], we use the environmental impact (EI) index to measure environmental sustainability. Practice shows that the number of products is closely related to production, resource consumption, waste, and pollution such as packaging. Under the conditions of direct procurement and procurement outsourcing, if the OEM makes additional efforts to make products green, the pollution generated by each unit product is less, that is, $n_O < n_M$. For simplicity, we normalize n_M to 1; therefore, $n_O = 1 - e, e \in (0, 1)$. Therefore, $EI = (1 - e)q_0 + q_M$. Finally, we draw the following conclusions 6.

(6) The environmental sustainability of procurement outsourcing is always better than that of direct procurement; that is,

$$EI^a = (1 - e)q_O^a + q_M^a < EI^b = (1 - e)q_O^b + q_M^b$$

Combined with Conclusion 5, when θ is in a small range, the OEM tends to shift from procurement outsourcing to direct procurement, which reduces environmental sustainability. For both economic and environmental development, the government can appropriately subsidize enterprises to encourage them to outsource manufacturing or introduce new technologies to reduce the pollution of unit products.

9.4 Summary

The procurement process is a critical step in connecting the value chain members and ensuring the supply quality of the value chain. The key to the procurement decision is to decide whether to engage in direct procurement or procurement outsourcing. Procurement outsourcing can improve enterprises' operational efficiency and reduce procurement costs, thereby expanding production and increasing profit. Direct procurement can meet the green preferences of consumers and the requirements of government environmental regulation because the firm can choose more environmentally friendly suppliers. OEMs choosing the direct procurement mode can reduce the wholesale price of suppliers; however, the processing price paid is higher than that of procurement outsourcing. For CMs, an increase in OEM's market potential can increase the processing price; when OEMs choose direct procurement, CMs can sell more products. Regardless of market size, the sustainability of procurement outsourcing is better than that of direct procurement. Therefore, the government should provide subsidies for enterprises or implement environmental regulation measures to encourage enterprises to choose greener growth models. To summarize, this chapter analyzes the advantages and risks of outsourcing. It establishes a model comprising OEMs, CMs, and suppliers, which provides recommendations for enterprise procurement or outsourcing decision-making.

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Chapter 10
Green Manufacturing

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Abstract Green manufacturing is an important part of enterprises' implementation of the green growth mode, and remanufacturing is one of the specific forms of green manufacturing. The development of the next generation Internet recycling model has increased the recycling channel of raw materials for remanufacturing and provided an effective guarantee for the effective implementation of remanufacturing. This chapter focuses on the relationship between green manufacturing and the enterprise green growth mode, and analyses the impact of obtaining remanufactured products from traditional channels and dual channels in enterprises' green growth model. Dual channel refers to considering both traditional channels and online channels. Then, this chapter construct a single-channel that only considering traditional channels and dual-channel remanufacturing recycling network model. These two models determined the location decisions of the distribution centre and recycling centre, distribution route, recycling route, online order distribution route and inventory decision of the remanufacturing supply chain under the two channels. To solve these two models, a genetic algorithm with local search is proposed. Through a sensitivity analysis of key parameters, it is concluded that the dual-channel recycling mode not only increases the recycling cost in the value chain but also increases the utilization rate of waste products, reduces the inventory cost and transportation cost of the distribution centre, and promotes the effective implementation of the green growth mode of enterprises.

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10.1 Green Manufacturing and Enterprises' Green Growth Model

10.1.1 Concept of Green Manufacturing

Green manufacturing is developed along the value chain of products. Through new technologies and control measures, this approach creates manufactured products in the way of "using materials and processing processes with minimal negative environmental impact, saving energy and natural resources, ensuring the safety of employees, society and consumers, and economically reasonable" [1] by comprehensively considering environmental impact and resource efficiency so that enterprises can improve their business performance while improving their green growth [2]. Focusing on the environmental problems in the manufacturing process, this paper proposes the concept of green manufacturing, which includes four aspects.

First, the problem areas involved in green manufacturing include manufacturing (including the entire process of the product life cycle), environmental protection and optimal utilization of resources [3].

Second, green manufacturing is a fully considered modern manufacturing mode and the embodiment of the circular economy mode in the modern manufacturing industry [4].

Third, the manufacturing process in green manufacturing mainly refers to the green production activities involved in the enterprise value chain [5].

Fourth, green manufacturing is an effective way to achieve green growth and economic performance of enterprises [6].

10.1.2 Basic Features of Green Manufacturing

There are essential differences between green manufacturing and traditional manufacturing, as shown in Table 10.1. The characteristics of green manufacturing can be summarized in the following four aspects: first, the goal is to achieve the economic performance and green growth of enterprises at the same time [6]; second, the means by which to achieve the goal is to innovate relevant production and service activities along the product value chain [5]; third, the main body of innovation consists of organizations and individuals dominated by enterprises and involved in relevant production and service activities on the product value chain [7]; fourth, through the synergy and complementarity of relevant subjects in the value chain, the entire manufacturing system can maintain its rapid response and good adaptability to the complex and changeable market environment [8].

Table 10.1 Differences between traditional manufacturing and green manufacturing

	Traditional manufacturing	Green manufacturing
The ultimate goal	Traditional manufacturing management mainly aims to realize the profit of enterprises, meet the requirements of consumers, and expand market share. These objectives ultimately aim to realize the economic interests of a core enterprise	The goal of management is not only to achieve economic benefits but also to pursue environmental protection, energy conservation and emission reduction, which not only have economic performance but also include the goal of green growth of enterprises
Range of activity	Traditional manufacturing usually designs, produces, and sells products according to market information and rarely considers the scrapping and recycling of products	Each activity will cause harm to the environment, from the acquisition of raw materials to the use of waste products and services. Therefore, the scope of green manufacturing activities is to innovate related production and service activities along the product value chain
Subject of action	Mainly include consumers and node enterprises in the value chain, not involving scrap and recycling	Including consumers, the government, and the node enterprises of the supply chain, the manufacturing enterprises that are in leading positions of the value chain should cooperate with other enterprises, ranging from the goal of saving resources and protecting the environment to formulating a model plan for green supply chain management, so that both the enterprises and the value chain can gain a sustainable competitive advantage

10.1.3 The Relationship Between Green Manufacturing and Enterprises' Green Growth

With the promotion of the green manufacturing mode, enterprises urgently need to build a green and sustainable value chain system to cope with the large amount of pressure placed of them due to energy conservation and environmental protection [9, 10]. As the front end of the enterprise value chain, green manufacturing is of great significance for building a green value chain system.

Although many enterprises have made many efforts in green manufacturing and have achieved good results, some enterprises are still relatively weak in regard to green manufacturing, which will limit the implementation effect of the green development of these enterprises and hinder their competitive position in the market. This is not conducive to the green growth of these enterprises [11]. Enterprises should develop an overall plan to improve all manufacturing activities involved in the value chain. Otherwise, the business performance, green growth and future competitiveness of the enterprise will be adversely affected. For example, recently, the clothes of a garment factory in Zhejiang Province were returned by the United States because the nickel content in the zipper exceeded the standard threshold, which resulted in a direct economic loss of US $1 million [2]. Previously, an international nonprofit organization conducted a survey on the environmental protection of China's garment industry. The survey results showed that there were environmental problems present in the green manufacturing process of these enterprises, which had a significant adverse impact on many world-leading garment brands predominantly made in China and further affected the synergy between green manufacturing and the growth of enterprises. These brands need to change their value chain system and reduce the use of pollutants in the production process. Therefore, many enterprises have realized the seriousness of environmental problems in the manufacturing process.

The implementation of green manufacturing will bring a certain amount of pressure to enterprises in the short term, such as rising costs and limited production capacity [12]. However, green manufacturing also provides opportunities for the future development of enterprises. If enterprises can actively promote the construction of green value chains, then they can improve market competitiveness, improve their green brand image, and achieve enterprise performance and green growth. At present, many scholars have studied the quantitative relationship between green manufacturing and enterprise performance; through green manufacturing, enterprises can achieve environmental protection production, improve their self-image, and improve their business performance while improving their green growth [6, 13, 14]. Many scholars believe that enterprises should not regard green manufacturing as a burden on economic activities. Instead, it should be seen as a prerequisite for sustainable economic development. The green growth of enterprises and the economic growth of enterprises should develop harmoniously and are mutually supportive and mutually reinforcing [15–17]. In other words, to maintain sustainable profitability and green growth, green manufacturing should be the bottom line of relevant enterprises. In turn, green manufacturing puts pressure on enterprises to pay more attention to resource efficiency and environmental impact [18].

As the direct executor of green manufacturing, enterprises should focus on the management of their green value chain to ensure the further development of enterprises [19]. The literature shows that enterprises need to take the following measures to actively promote green manufacturing to the green growth model [2]. (1) Enhance the environmental awareness of managers in the value chain and combine the responsibilities of managers with the environmental benefits of enterprises. (2) Base all business activities in the value chain on environmental benefits and eliminate nonenvironmental behaviours. (3) Strengthen the evaluation and audit of the environmental benefits of all activities in the value chain. (4) Use information technology to track the management process of the green value chain in real-time.

Based on the abovementioned advantages of green manufacturing, many enterprises, especially in high-polluting industries, have transformed their manufacturing processes into green manufacturing. Among them, a typical representative is the Tangshan Iron and Steel Group in the steel industry. In 2020, Tangsteel New District put forward the development concept of a green manufacturing general layout in

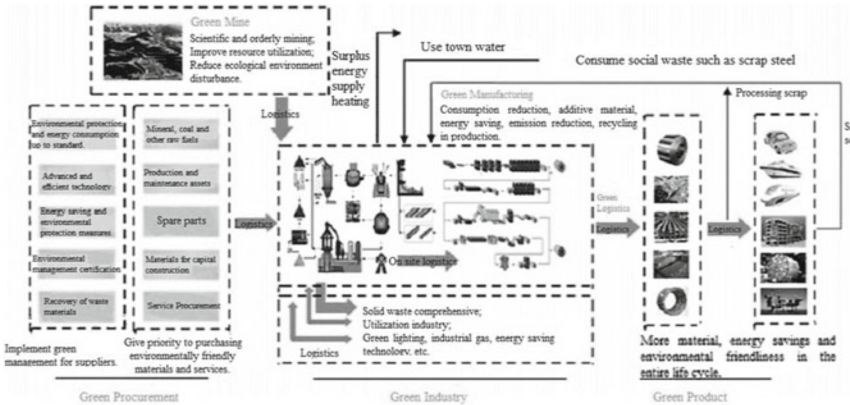


Fig. 10.1 Tang steel group's green manufacturing general layout development concept[1]

regard to planning, design, construction, and production and operation, as shown in Fig. 10.1. It has subsequently assembled a number of advanced environmental protection technologies at home and abroad and integrated them into all processes, as well as the overall process. More than 230 advanced environmental protection technologies and processes and more than 130 green manufacturing technologies in the steel industry are used for process and equipment configuration. In terms of energy, environmental protection and power, these processes focus on remote coverage and the centralized control of the entire process and the entire region to achieve carbon emission reduction in the entire process. Adhering to scientific and technological innovation, coordinating the research and development of key low-carbon technologies and low-carbon products, and implementing green manufacturing greatly reduce the environmental hazards in the production process of enterprises and achieve enterprise performance and green growth.

10.1.4 Typical Form of Green Manufacturing—Remanufacturing

The development of green manufacturing has become a consensus among enterprises [20]. Although the green manufacturing activities of each enterprise have their own characteristics; generally speaking, they are realized by reducing the waste of resources involved in the production and manufacturing activities in the enterprise value chain and improving the utilization rate of energy. Remanufacturing is based on the perspective of the enterprise value chain. One of the most effective ways to achieve green manufacturing is by recycling, processing and disposing of waste products to achieve resource conservation and energy utilization [21]. Remanufacturing is not a simple refurbishment process but rather a series of professional repairs, such

[1] http://www.cmisi.com.cn/default/index/newsDetails?newsId=888.

as dismantling, cleaning, repairing, reassembling, and testing the recovered products and components so that the quality of the recovered products can be restored to the same quality as new products [22]. In developed countries, the concept of remanufacturing was first proposed for economic considerations in the 1990s. With the continuous development of remanufacturing, remanufacturing has been broadly used in two major industries, namely, the auto parts and electronic/electrical industry sectors. For example, the remanufacturing of electronics such as copiers and disposable cameras is fairly common in Japan, and the U.S. auto parts remanufacturing industry has also grown steadily since the 1990s. In China, remanufacturing is still an emerging industry. The development of China's remanufacturing industry is carried out under the guidance of the Chinese government, and a pilot and demonstration system has been adopted to guide the large-scale development of remanufacturing enterprises. Remanufacturing is the development and extension of green manufacturing. Therefore, it is crucial to green development and the efficient use of resources [23].

For remanufacturing, the most important thing is to have a sufficient amount of recycled products to form a scale effect, thereby reducing the investment cost in the early stage of remanufacturing and improving the profitability of the enterprise while realizing the green growth of the enterprise. Next generation Internet recycling is the product of the deep integration of Internet technology and the recycling industry, which provides a new way for remanufacturing to increase the number of recycled products. Online channels can not only increase the total amount of recycling in the recycling market but also significantly improve the economic profits of enterprises. Professional recycling centres that dismantle and decompose waste products can also obtain more resources, reduce harmful emissions to the ecological environment, and improve enterprises' green growth. In recent years, with next generation Internet, an increasing number of recycling enterprises have built online recycling channels based on Internet technologies such as big data, cloud computing and artificial intelligence, relying on terminal platforms such as PC websites and mobile apps; they have then performed the integration of online and traditional offline recycling channels, such as the O2O recycling model represented by "Aihuishou,"[2] and the intelligent recycling machine recycling mode are represented by the Beijing "Yingchuang" company.[3] This recycling mode with both online and offline channels is called the dual-channel recycling mode.

10.2 Dual-Channel Remanufacturing

The emergence of the dual-channel model has broadened the traditional channels for remanufacturing to obtain waste products. The raw materials of remanufactured products can be obtained not only from traditional offline recycling channels but also from online platforms, which directly results in the demand for remanufactured raw

[2] https://www.aihuishou.com/.

[3] http://en.incomrecycle.com/.

materials and has an impact on the remanufacturing logistics network. An efficient remanufacturing logistics network is important for the successful implementation of remanufacturing. Remanufacturing logistics include the reverse logistics of transporting waste products from the place of consumption back to the place of production and the forward logistics of transporting remanufactured products from the place of production to the place of consumption, thereby forming a closed-loop logistics system. Most enterprises that have established traditional production and distribution logistics networks tend to expand on the basis of traditional production and distribution logistics networks to increase remanufacturing logistics functions. This saves costs without having too much impact on the existing network. The research in this chapter is also based on this remanufacturing logistics network.

Due to the sales and recycling carried out in traditional channels, manufacturers mainly focus on the demand and recycling of products from retailers (large customers), and the needs and recycling of customers (small customers) are met by retailers. However, the introduction of the dual-channel model allows online channels to segment and expand market demand and the number of products recycled by the original traditional retailers. This allows the original small customer needs and products to be recycled and directly completed by the manufacturer. As a result, enterprises adopting a dual-channel model need to redesign their value chain network and determine the location of individual facilities.

At present, there are few studies on logistics network optimization for remanufacturing. Optimizing the logistics network is an effective way to improve the operation efficiency of the enterprise supply chain and reduce the cost of the enterprise [24]. Different from traditional logistics design, remanufacturing logistics design should not only consider the distribution logistics of forward new products but also consider the reverse recycling logistics of waste products, thus forming a closed-loop supply chain system. Remanufacturing logistics network optimization problems include the production of new and remanufactured products, the establishment of distribution centres, the inventory of new and used products, the distribution of new products and the recycling route of used products, and the detection and disposal of used products. In summary, studying the optimization problem of remanufacturing logistics networks is actually studying the location-path-inventory problem of a closed-loop supply chain.

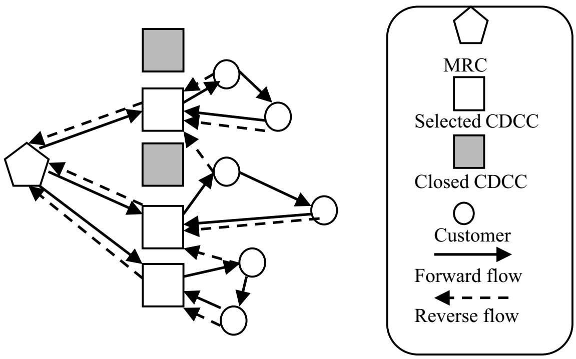
This chapter studies the location-inventory-routing problem in a multicycle closed-loop supply chain based on the new mode of remanufacturing and next generation Internet. To investigate the impact of adopting online channels into the remanufacturing integrated logistics network, two models are considered in this chapter. The first model is a single-channel model in which the manufacturer does not adopt a dual-channel model, and the system only includes traditional retail channels. The other model is a dual-channel model in which manufacturers adopt a dual-channel model, and the system includes both traditional retail channels and online channels. Both systems have the following commonalities. They both consist of a manufacturing remanufacturing centre (MRC), multiple potentially capacity-constrained distribution-collection centres (CDCCs), and a group of customers. The MRC produces both new products and remanufactured recycled products. This section assumes that remanufactured products and new products do not share the same sales channel. To save costs, CDCCs act not only as distribution centres but also as collection centres. In other words, a CDCC not only delivers new and remanufactured products to customers but also collects used products from customers. Recycling and remanufacturing rates for recycled items are known and assumed to be constant. To increase the company's flexibility in the supply chain, the logistics of recycled products collected from customers to CDCCs are undertaken by third-party logistics. The purpose of this chapter is to integrate and optimize facility location-allocation, inventory control, and vehicle routing in a multicycle closed-loop supply chain to minimize the overall system cost.

10.2.1 Manufacturers Do Not Adopt a Dual-Channel Model

To define the problem of the single-channel mode more clearly, this section expounds the decisions to be solved by forward logistics and reverse logistics. For systems in single-channel mode, in forward logistics, customer demand for new and remanufactured products is produced at the MRC and delivered to customers via CDCCs. Both requirements are deterministic but variable per cycle. To facilitate product tracking, each customer is assigned only one CDCC. Furthermore, customer needs are served by a homogeneous set of capacity-constrained vehicles, each of which departs from and returns to the same CDCC to which it belongs. In reverse logistics, recycled products are collected from customers and checked at CDCCs to determine if they can be remanufactured. If the returned product is remanufacturable, it will be shipped to the MRC, remanufactured at the MRC, and then resold through the CDCC to customers who need it at a lower price. The remanufacturing integrated logistics network of the studied single-channel mode is shown in Fig. 10.2.

To easily convert this problem into a model, this section uses the following notation. This section defines q as the remanufacturing cost of MRC. J is defined as the candidate CDCC set. The fixed setup cost of each CDCC $j, j \in J$ is f_j, and the capacity

Fig. 10.2 Remanufacturing integrated logistics network under single channel mode



of each CDCC j is C_j. The inspection fee at CDCC $j, j \in J$ is e_j, and the processing fee at CDCC $j, j \in J$ is g_j. The transportation cost from MRC to CDCC $j, j \in J$ is a_j. I is used to represent a collection of customers. In this chapter, m represents different commodity types (n = new product retail, r = retail remanufactured product, on = online new product, or = online remanufactured product). T is the set of cycles. Each customer i, $i \in I$ has a certain nonconstant demand d_{itm} for m product in each period, $t \in T$, and the inventory carrying cost of customer i, $i \in I$ for m product is h_{im}. Customer i, $i \in I$ m has a recovery rate of α_{im} and a remanufacturable rate of product m of β_m. K is a set of vehicles with loading capacity U. For the convenience of notation, this section denotes the set of customers and potential CDCCs as S. In forward logistics, the transportation cost from node i to node j, $i \in S, j \in S$ is c_{ij}. In reverse logistics, the transportation cost between customer i, $i \in I$ and CDCC $j, j \in J$ is b_{ij}.

To obtain the optimal solution, the following variables need to be determined. The variable u_{ipkt} represents the quantity of product m delivered to customer i, $i \in I$ by vehicle k, $k \in K$ in period t, $t \in T$ in single-channel mode. The auxiliary variable l_{itpm} represents the quantity of product m delivered to customer i, $i \in I$ in period p, $p \in T$ to satisfy its demand in period t, $t \in T$ under single-channel mode. Decision variable $z_j = 1$ if CDCC $j, j \in J$ is established in single-channel mode; otherwise, $z_j = 0$. In the single-channel mode, if customer i, $i \in I$ is served by the established CDCC $j, j \in J$, the decision variable $y_{ij} = 1$; otherwise, it is 0. If the recycling activity of customer i, $i \in I$, is assigned to the open CDCC $j, j \in J$, the decision variable $w_{ji} = 1$. Otherwise, $w_{ji} = 0$. If vehicle k visits node j in cycle t, $t \in T, j \in s$ immediately visits node i, $i \in S$, and then $x_{ijkt} = 1$. Otherwise, $x_{ijkt} = 0$.

(1) Cost analysis under the single-channel mode. Under the single-channel mode, the total cost of the closed-loop supply chain system consists of the following costs.

   (a) Location cost. The cost of establishing CDCCs is $LC = \sum_{j \in J} f_j \cdot z_j$.
   (b) Inventory cost. The inventory holding cost of CDCCs is

$$IC = \sum_{t \in T} \sum_{i \in I} \left[\frac{1}{2}(h_{in} \cdot d_{\text{int}} + h_{ir} \cdot d_{irt}) + \sum_{p \in T, p < t} \left(h_{in} \cdot l_{inpt} + h_{ir} \cdot l_{irpt}\right)(t-p) \right.$$
$$\left. + \sum_{p \in T, p > t} \left(h_{in} \cdot l_{inpt} + h_{ir} \cdot l_{irpt}\right)(t-p+T) \right]$$

   (c) Transportation costs. The total transportation cost includes the transportation cost from MRC to CDCCs, transportation cost from CDCCs to customers, transportation costs from customers to CDCCs, and transportation cost from CDCCs to MRC.

- The transportation cost from MRC to CDCCs is $\sum_{t\in T}\sum_{j\in J}\sum_{i\in I} a_j \cdot (d_{\text{int}} + d_{irt}) \cdot y_{ij}$.
- The transportation cost from CDCCs to customers is $\sum_{i\in S}\sum_{j\in S}\sum_{k\in K}\sum_{t\in T} c_{ij} \cdot x_{ijkt}$.
- Transportation costs from customers to CDCCs. Due to the uncertainty of recycled products, CDCCs will use third-party logistics to collect waste products at a cost of $\sum_{t\in T}\sum_{j\in J}\sum_{i\in I} b_{ij} \cdot (\alpha_{in} \cdot d_{\text{int}} + \alpha_{ir} \cdot d_{irt}) \cdot w_{ji}$.
- Transportation cost from CDCCs to MRC. Waste products that can be used for remanufacturing are transported from customers to MRC for remanufacturing through CDCCs. Therefore, the cost is $\sum_{t\in T}\sum_{j\in J}\sum_{i\in I} a_j \cdot (\alpha_{in} \cdot \beta_n \cdot d_{\text{int}} + \alpha_{ir} \cdot \beta_r \cdot d_{irt}) \cdot w_{ji}$.

  Therefore, the total transportation cost is

$$TC = \sum_{i\in S}\sum_{j\in S}\sum_{k\in K}\sum_{t\in T} c_{ij} \cdot x_{ijkt} + \sum_{t\in T}\sum_{j\in J}\sum_{i\in I} \big(b_{ij} \cdot (\alpha_{in} \cdot d_{\text{int}} + \alpha_{ir} \cdot d_{irt}) \cdot w_{ji} + a_j \cdot (d_{\text{int}} + d_{irt}) \cdot y_{ij}\big) + \sum_{t\in T}\sum_{j\in J}\sum_{i\in I} a_j \cdot (\alpha_{in} \cdot \beta_n \cdot d_{\text{int}} + \alpha_{ir} \cdot \beta_r \cdot d_{irt}) \cdot w_{ji}.$$

- Inspection fee. The returned products are inspected in CDCCs, and the cost is

$$INC = \sum_{t\in T}\sum_{j\in J}\sum_{i\in I} e_j \cdot (\alpha_{in} \cdot d_{\text{int}} + \alpha_{ir} \cdot d_{irt}) \cdot w_{ji}.$$

- Disposal costs. Waste products that cannot be used for remanufacturing are discarded in CDCCs. The cost is

$$DC = \sum_{t\in T}\sum_{j\in J}\sum_{i\in I} g_j \cdot (\alpha_{in} \cdot (1-\beta_n) \cdot d_{\text{int}} + \alpha_{ir} \cdot (1-\beta_r) \cdot d_{irt}) \cdot w_{ji}$$

- Remanufacturing cost. The products that can be used for remanufacturing are remanufactured in MRC at a cost of

$$RC = \sum_{t\in T}\sum_{j\in J}\sum_{i\in I} q \cdot (\alpha_{in} \cdot \beta_n \cdot d_{\text{int}} + \alpha_{ir} \cdot \beta_r \cdot d_{irt}) \cdot w_{ji}$$

(2) Optimization model under single-channel mode. The model of the single-channel closed-loop location path inventory problem can be expressed as follows.

$$\min C_{single-channel} = LC + IC + TC + INC + DC + RC \tag{10.1}$$

subject to

$$\sum_{j\in S} x_{ijkt} - \sum_{j\in S} x_{jikt} = 0 \quad \forall i \in S, \forall k \in K, \forall t \in T \tag{10.2}$$

$$\sum_{j\in S}\sum_{k\in K} x_{ijkt} \le 1 \quad \forall t \in T, \forall i \in I \tag{10.3}$$

$$\sum_{j\in S}\sum_{k\in K} x_{jikt} \le 1 \quad \forall t \in T, \forall i \in I \tag{10.4}$$

$$\sum_{i\in I}\sum_{j\in J} x_{ijkt} \le 1 \quad \forall t \in T, \forall k \in K \tag{10.5}$$

$$x_{ijkt} = 0 \quad \forall i, j \in J, \forall t \in T, \forall k \in K, i \ne j \tag{10.6}$$

$$\sum_{i\in I} (u_{inkt} + u_{irkt}) \le U \; \forall t \in T, \forall k \in K \tag{10.7}$$

$$\sum_{i\in V}\sum_{j\in V} x_{ijkt} \le |V| - 1 \quad \forall k \in K, \forall t \in T, \forall V \subseteq I \tag{10.8}$$

$$\sum_{j\in J} y_{ij} = 1 \quad \forall i \in I \tag{10.9}$$

$$y_{ij} \le z_j \quad \forall i \in I, \forall j \in J \tag{10.10}$$

$$\sum_{j\in J} w_{ji} = 1 \quad \forall i \in I \tag{10.11}$$

$$w_{ji} \le z_j \quad \forall i \in I, \forall j \in J \tag{10.12}$$

$$\sum_{i\in I} w_{ji} \le M \sum_{i\in I} y_{ij} \quad \forall j \in J, M \text{ is a big number} \tag{10.13}$$

$$\sum_{i\in I}\left(y_{ij}\sum_{t\in T}(d_{\text{int}} + d_{irt})\right) \le C_j \quad \forall j \in J \tag{10.14}$$

$$\sum_{v\in I} x_{vjkt} - \sum_{v\in S\setminus\{i\}} x_{ivkt} \le 1 + y_{ij} \quad \forall i \in I, \forall j \in J, \forall k \in K, \forall t \in T \tag{10.15}$$

$$\sum_{i\in I}\sum_{k\in K}\sum_{t\in T} x_{ijkt} \ge z_j \quad \forall j \in J \tag{10.16}$$

$$\sum_{i\in I} x_{jikt} \le z_j \quad \forall j \in J, \forall k \in K, \forall t \in T \tag{10.17}$$

$$\sum_{p\in T} \left(l_{inpt} + l_{irpt}\right) = d_{\text{int}} + d_{irt} \quad \forall i \in I, \forall t \in T \tag{10.18}$$

$$\sum_{p\in T} \left(l_{inpt} + l_{irpt}\right) = \sum_{k\in K} \left(u_{inkt} + u_{irkt}\right) \forall i \in I, \forall t \in T \tag{10.19}$$

$$\left(u_{inkt} + u_{irkt}\right) \le M \sum_{j\in S} x_{ijkt} \quad \forall i \in I, \forall k \in K, \forall t \in T \tag{10.20}$$

$$\sum_{j\in S} x_{ijkt} \le M\left(u_{inkt} + u_{irkt}\right) \quad \forall i \in I, \forall k \in K, \forall t \in T \tag{10.21}$$

$$\left(u_{inkt} + u_{irkt}\right) \le \min\left\{U, \sum_{p\in T} \left(d_{\text{int}} + d_{irt}\right)\right\} \quad \forall i \in I, \forall k \in K, \forall t \in T \tag{10.22}$$

$$\left(l_{inpt} + l_{irpt}\right) \le d_{\text{int}} + d_{irt} \quad \forall i \in I, \forall t, p \in T \tag{10.23}$$

$$x_{ijkt} \in \{0, 1\} \quad \forall i \in I, \forall j \in J, \forall k \in K, \forall t \in T \tag{10.24}$$

$$y_{ij} \in \{0, 1\} \quad \forall i \in I, \forall j \in J \tag{10.25}$$

$$w_{ji} \in \{0, 1\} \quad \forall i \in I, \forall j \in J \tag{10.26}$$

$$z_{ji} \in \{0, 1\} \quad \forall j \in J \tag{10.27}$$

$$l_{inpt} \in \mathrm{R}^{+},\ l_{irpt} \in \mathrm{R}^{+} \quad \forall i \in I, \forall t, p \in T \tag{10.28}$$

The total cost of the remanufacturing integrated logistics network in single-channel mode is Eq. (10.1). Constraint (10.2) ensures that the vehicle must leave from a node after entering it. Constraints (10.3) and (10.4) ensure that each vehicle can only serve one node for a period of time. Each vehicle only accesses one route at a time, guaranteed by constraint (10.5). Constraint (10.6) has only one CDCC on a path. Constraint (10.7) is the capacity constraint of the vehicle. Constraint (10.8) ensures that each path must contain a CDCC to avoid subpaths. Constraints (10.9) and (10.10) show that, in forward logistics, each customer must be served by an open CDCC. Constraints (10.11) and (10.12) indicate that only open CDCCs can recycle customer products in reverse logistics. Constraint (10.13) states that, in reverse logistics, if and only if a CDCC has been opened as a distribution centre in forward logistics can the CDCC can be opened as a recycling centre. Constraint (10.14) is the capacity constraint of CDCCs. Constraint (10.15) means that, if customer i is assigned to CDCC j, there must be a vehicle k starting its journey from CDCC j and visiting customer i. Constraints (10.16) and (10.17) ensure that vehicles will access a CDCC when and only when that CDCC is opened. The satisfaction of each customer's demand is guaranteed by constraints (10.18) and (10.19), and constraint (10.19) states that the sum of the quantity delivered from other periods to meet the customer in a certain period is equal to the quantity delivered by the vehicle. Constraints (10.20–10.22) ensure that, if vehicle k supplements a customer in cycle t, the corresponding vehicle should also visit the customer in this cycle. Constraint (10.23) ensures that the number of replenishment cycles t from cycle p is less than the customer's demand in cycle t. Constraints (10.24–10.28) represent the properties of decision variables and auxiliary variables.

10.2.2 *The Manufacturer Adopts the Dual-Channel Mode*

Online retail channels are added to the single-channel mode to form a dual-channel mode. The needs of customers' online retail channels are directly met by the MRC and provided to customers through third-party logistics. In addition, customers who buy products online recycle their waste products to CDCCs. Although the structure of the traditional retail industry remains unchanged in the dual-channel model, the online demand of customers may erode the number of some traditional retailers. The objective of this section is to reoptimize the decision-making of facility location, allocation, inventory control and vehicle routing in the dual-channel mode. The remanufacturing supply chain in dual-channel mode is shown in Fig. 10.3. This

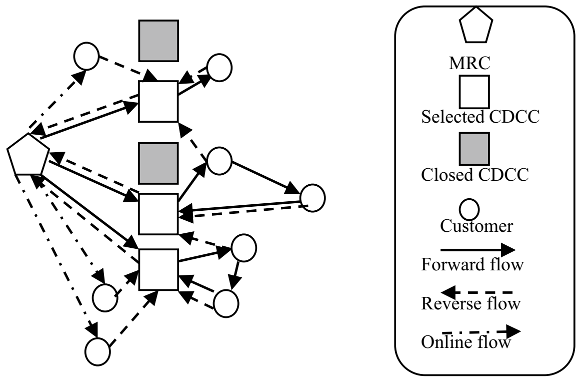


Fig. 10.3 Remanufacturing integrated logistics network under dual channel mode

supply chain mode is also a Location-routing-inventory problem under dual-channel in closed-supply chain (LIRP-CLDC).

Considering the addition of online retail channels, some new symbols and variables need to be introduced. In the online channel, the transportation cost from MRC to customer i, $i \in I$ is s_i. The variable representing the quantity of product m delivered to customer i, $i \in I$ by vehicle k, $k \in K$ in cycle t, $t \in T$ under dual channels is $u_{ipktdual}$. The auxiliary variable representing the quantity of product m passed to customer i, $i \in I$ in cycle p, $p \in T$ to meet its demand in cycle t, $t \in T$ is $l_{itpmdual}$. If CDCC j, $j \in J$ is established under dual channels, then $z_{jdual} = 1$; otherwise, it is 0. If customer i, $i \in I$ is served by the established CDCC j, $j \in J$, the decision variable $y_{ijdual} = 1$; otherwise, it is 0. If the recycling activity of customer i, $i \in I$, is assigned to the open CDCC j, $j \in J$, the decision variable $w_{jidual} = 1$. Otherwise, it is 0. If vehicle k accesses node j in cycle t, $t \in T$ and $j \in s$ immediately accesses node i, $i \in s$, then $x_{ijktdual} = 1$. Otherwise, $x_{ijktdual} = 0$.

(1) Cost analysis of the dual-channel model. As mentioned earlier in this section, this section posits that the demand of online channels may erode the demand of the original retail channels. Therefore, when using online channels, customers' needs for new products and remanufactured products are as follows.

$$d_{\text{int}dual} = (1-\chi)\cdot d_{\text{int}};\ d_{irtdual} = (1-\chi)\cdot d_{irt};$$
$$d_{iontdual} = \chi\cdot d_{\text{int}};\ d_{iortdual} = \chi\cdot d_{irt}.$$

In the dual-channel mode, the total cost of the supply chain system consists of the following costs.

(a) Location cost. The cost of establishing CDCCs in this chapter is

$$LC_{dual} = \sum_{j\in J} f_j \cdot z_{jdual}.$$

(b) Inventory cost. The inventory cost under dual-channel mode is

$$\begin{aligned} IC_{dual} = \sum_{t\in T}\sum_{i\in I}\Bigg[&\frac{1}{2}(h_{in}\cdot d_{\text{int}dual} + h_{ir}\cdot d_{irtdual}) \\ &+ \sum_{p\in T, p<t}\big(h_{in}\cdot l_{inptdual} + h_{ir}\cdot l_{irptdual}\big)(t-m) \\ &+ \sum_{p\in T, p>t}\big(h_{in}\cdot l_{inptdual} + h_{ir}\cdot l_{irptdual}\big)(t-p+H)\Bigg]. \end{aligned}$$

(c) Transportation costs. The total transportation cost includes the transportation cost from MRC to CDCCs, transportation costs from CDCCs to customers, transportation costs from customers to CDCCs, transportation costs from CDCCs to MRC, and transportation costs from MRC to customers.

- Transportation cost from MRC to CDCCs is

$$\sum_{t\in T}\sum_{j\in J}\sum_{i\in I} a_j \cdot (d_{\text{int}dual} + d_{irtdual}) \cdot y_{ijdual}.$$

- Transportation cost from CDCCs to customers is

$$\sum_{i\in S}\sum_{j\in S}\sum_{k\in K}\sum_{t\in T} c_{ij} \cdot x_{ijktdual}.$$

- Transportation costs from customers to CDCCs is

$$\sum_{t\in T}\sum_{j\in J}\sum_{i\in I} b_{ij} \cdot (\alpha_{in} \cdot d_{\text{int}dual} + \alpha_{ir} \cdot d_{irtdual} + \alpha_{io} \cdot (d_{iontdual} + d_{iortdual})) \cdot w_{jidual}.$$

- Transportation cost from CDCCs to MRC is

$$\sum_{t\in T}\sum_{j\in J}\sum_{i\in I} a_j \cdot (\alpha_{in} \cdot \beta_n \cdot d_{\text{int}dual} + \alpha_{ir} \cdot \beta_r \cdot d_{irtdual} + \alpha_{io} \cdot \beta_o \cdot (d_{iontdual} + d_{iortdual})) \cdot w_{jidual}.$$

- Transportation cost from customers to MRC is

$$\sum_{t\in T}\sum_{i\in I} (d_{iontdual} + d_{iortdual}) \cdot s_i.$$

Therefore, the total transportation cost is

$$\begin{aligned} TC_{dual} = {} & \sum_{i\in S}\sum_{j\in S}\sum_{k\in K}\sum_{t\in T} c_{ij} \cdot x_{ijktdual} + \sum_{j\in J}\sum_{i\in I} b_{ij} \cdot \left[\alpha_{in} \cdot d_{\text{int}dual} + \alpha_{ir} \cdot d_{irtdual} \right. \\ & \left. + \alpha_{io} \cdot (d_{iontdual} + d_{iortdual})\right] \cdot w_{jidual} + \sum_{t\in T}\sum_{j\in J}\sum_{i\in I} \left[a_j \cdot (\alpha_{in} \cdot \beta_n \cdot d_{\text{int}dual} \right. \\ & + \alpha_{ir} \cdot \beta_r \cdot d_{irtdual} + \alpha_{io} \cdot \beta_o \cdot (d_{iontdual} + d_{iortdual})) \cdot w_{jidual} \\ & \left. + a_j \cdot (d_{\text{int}dual} + d_{irtdual}) \cdot y_{ijdual}\right] + \sum_{t\in T}\sum_{i\in I} (d_{iontdual} + d_{iortdual}) \cdot s_i \end{aligned}$$

(d) Inspection cost. The inspection cost is

$$INC_{dual} = \sum_{t\in T}\sum_{j\in J}\sum_{i\in I} e_j \cdot (\alpha_{in} \cdot d_{\text{int}dual} + \alpha_{ir} \cdot d_{irtdual} + \alpha_{io} \cdot (d_{iontdual} + d_{iortdual})) \cdot w_{ji}$$

(e) Discard cost. The discard cost is

$$DC_{dual} = \sum_{t \in T} \sum_{j \in J} \sum_{i \in I} g_j \cdot (\alpha_{in} \cdot (1 - \beta_n) \cdot d_{\text{int}dual} + \alpha_{ir} \cdot (1 - \beta_r) \cdot d_{irtdual} + \alpha_{io} \cdot (1 - \beta_o) \cdot (d_{iontdual} + d_{iortdual})) \cdot w_{jidual}$$

(f) Remanufacturing cost. The remanufacturing cost is

$$RC_{dual} = \sum_{t \in T} \sum_{j \in J} \sum_{i \in I} q \cdot (\alpha_{in} \cdot \beta_n \cdot d_{\text{int}dual} + \alpha_{ir} \cdot \beta_r \cdot d_{irtdual} + \alpha_{io} \cdot \beta_o \cdot (d_{iontdual} + d_{iortdual})) \cdot w_{jidual}$$

(2) Optimization model of the dual-channel mode. Therefore, for the dual-channel mode, the remanufacturing integrated logistics network optimization model is as follows.

$$\min\ C_{dual-channel} = LC_{dual-channel} + IC_{dual-channel} + TC_{dual-channel} + INC_{dual-channel} + DC_{dual-channel} + RC_{dual-channel} \tag{10.29}$$

subject to

$$\sum_{j \in S} x_{ijktdual} - \sum_{j \in S} x_{jiktdual} = 0 \quad \forall i \in S, \forall k \in K, \forall t \in T \tag{10.30}$$

$$\sum_{j \in S} \sum_{k \in K} x_{ijktdual} \le 1 \quad \forall t \in T, \forall i \in I \tag{10.31}$$

$$\sum_{j \in S} \sum_{k \in K} x_{jiktdual} \le 1 \quad \forall t \in T, \forall i \in I \tag{10.32}$$

$$\sum_{i \in I} \sum_{j \in J} x_{jiktdual} \le 1 \quad \forall t \in T, \forall k \in K \tag{10.33}$$

$$x_{ijktdual} = 0 \quad \forall i, j \in J, \forall t \in T, \forall k \in K, i \ne j \tag{10.34}$$

$$\sum_{i \in I} (u_{inktdual} + u_{irktdual}) \le U \quad \forall t \in T, \forall k \in K \tag{10.35}$$

$$\sum_{i \in V} \sum_{j \in V} x_{ijkt} \le |V| - 1 \quad \forall k \in K, \forall t \in T, \forall V \subseteq I \tag{10.36}$$

$$\sum_{j \in J} y_{ijdual} = 1 \quad \forall i \in I \tag{10.37}$$

$$\sum_{j \in J} w_{jidual} = 1 \quad \forall i \in I \tag{10.38}$$

$$y_{ijdual} \leq z_{jdual} \quad \forall i \in I, \forall j \in J \tag{10.39}$$

$$w_{jidual} \leq z_{jdual} \quad \forall i \in I, \forall j \in J \tag{10.40}$$

$$\sum_{i \in I} w_{jidual} \leq M \sum_{i \in I} y_{ijdual} \quad \forall j \in J, M \text{ is a big number} \tag{10.41}$$

$$\sum_{i \in I} \left(y_{ijdual} \sum_{t \in T} (d_{\text{int}dual} + d_{irtdual}) \right) \leq C_j \quad \forall j \in J \tag{10.42}$$

$$\sum_{v \in I} x_{vjktdual} - \sum_{v \in S \setminus \{i\}} x_{ivktdual} \leq 1 + y_{ijdual} \, \forall i \in I, \forall j \in J, \forall k \in K, \forall t \in T \tag{10.43}$$

$$\sum_{i \in I} \sum_{k \in K} \sum_{t \in T} x_{ijktdual} \geq z_{jdual} \quad \forall j \in J \tag{10.44}$$

$$\sum_{i \in I} x_{jiktdual} \leq z_{jdual} \quad \forall j \in J, \forall k \in K, \forall t \in T \tag{10.45}$$

$$\sum_{p \in T} \left(l_{inptdual} + l_{irptdual} \right) = d_{\text{int}dual} + d_{irtdual} \quad \forall i \in I, \forall t \in T \tag{10.46}$$

$$\sum_{p \in T} \left(l_{inptdual} + l_{irptdual} \right) = \sum_{k \in K} (u_{inktdual} + u_{irktdual}) \quad \forall i \in I, \forall t \in T \tag{10.47}$$

$$(u_{inktdual} + u_{irktdual}) \leq M \sum_{j \in S} x_{ijktdual} \quad \forall i \in I, \forall k \in K, \forall t \in T \tag{10.48}$$

$$\sum_{j \in S} x_{ijktdual} \leq M(u_{inktdual} + u_{irktdual}) \quad \forall i \in I, \forall k \in K, \forall t \in T \tag{10.49}$$

$$(u_{inktdual} + u_{irktdual}) \leq \min \left\{ U, \sum_{t \in T} (d_{\text{int}dual} + d_{irtdual}) \right\} \quad \forall i \in I, \forall k \in K, \forall t \in T \tag{10.50}$$

$$\left(l_{inptdual} + l_{irptdual} \right) = d_{inpdual} + d_{irpdual} \quad \forall i \in I, \forall t, p \in T \tag{10.51}$$

$$x_{ijktdual} \in \{0, 1\} \quad \forall i \in I, \forall j \in J, \forall k \in K, \forall t \in T \tag{10.52}$$

$$y_{ijdual} \in \{0, 1\} \quad \forall i \in I, \forall j \in J \tag{10.53}$$

$$w_{jidual} \in \{0, 1\} \quad \forall i \in I, \forall j \in J \tag{10.54}$$

$$z_{jidual} \in \{0, 1\} \quad \forall j \in J \tag{10.55}$$

$$l_{inptdual} \in \mathrm{R}^+, \; l_{irptdual} \in \mathrm{R}^+ \quad \forall i \in I, \forall t, p \in T \tag{10.56}$$

The objective function of the dual-channel model is Eq. (10.29). Adding online channels to the single-channel model forms a dual-channel model, while the traditional retail structure remains unchanged. In addition, customers' online channel needs are met by the MRC and provided to customers through third-party logistics (3PL). Therefore, there are no additional constraints in the dual-channel model. Constraints (10.30–10.56) have the same meaning as constraints (10.2–10.28).

10.2.3 Solution of the Model

The location inventory path problem is an NP-hard problem. Reverse logistics and the online mode are also added to the research problems in this chapter, which further increases the difficulty of solving the model. It is difficult to solve NP-hard problems in a reasonable time; thus, heuristic methods are widely used to solve location inventory path problems. In this part, we propose a genetic algorithm combined with a local search process (GALS). The genetic algorithm has good global search ability but weak local search ability, so it adopts local search to avoid local optimization.

The GALS algorithm proposed in this section starts with a set of initial solutions called group (P). Every solution in the population is represented by a chromosome. The main process of GALS is to perform chromosome evolution through continuous iteration (*it*). This process is called generation. In each generation process, chromosome (*i*) is evaluated by *fitness (i)*. The fitness function proposed in this paper is the objective function. The next generation is generated using a crossover operator, mutation operator and local search program. The generation used to generate the next generation is called the parent generation. The next generation is called offspring. The algorithm uses the mutation rate (p_{mutation}) and local search rate (p_{ls}) to selectively accept mutation and local search. In addition, in each generation, the best solution is stored (if found). When the stop condition is met, the iteration ends. Table 10.2 outlines the pseudocode of the proposed GALS.

The GALS algorithm proposed in this chapter improves the performance of the genetic algorithm in the following three aspects: first, the algorithm applies the anti-learning algorithm (OBL) to produce a better initialization solution; second, a path crossover operator (RCX) is adopted; third, a memory operator is proposed to prevent the loss of good solutions.

Table 10.2 Overall flow of the GALS algorithm

Algorithm 1: Overall flow of the GALS algorithm
Steps 0: //Initialize
Generating chromosomes with population size p by Algorithm 2;
for $i = 1$ to P do
Computing chromosomes i fitness(i) by using Theorem 1;
end for
fitness(bestsolution) = min{fitness(i)};
bestsolution = {i | fitness(i) = fitness(bestsolution)}
Steps 1: //Main process
While($it \leq \alpha_{max}$ or $it \leq iter_{max}$)
// Crossover
Select two collateral by binary competition parent 1 and parent 2
Apply the crossover operation to generate two children 1 and children 2
Add children 1 and children 2 to that population P
Move out the two worst from P
for $i = 1$ to P do
// Mutation
if random < $p_{mutation}$
Perform mutation operation (i)
end if
//Local search
if random < p_{ls} then LSswap(i) end if
If random < p_{ls} then LSinsert(i) end if
If random < p_{ls} then LS2-opt(i) end if
Feasibility repair
//Memory
if fitness(i) < fitness(Best Solution) then
Fitness(bestsolution): = fitness(i)
Best Solution: = i
α: = 0
else α: = $\alpha + 1$
$iter = iter + 1$
end for
end while
Step 2: Output that optimal solution

10.2.4 Sensitivity Analysis

In this section, we analyse the parameters used in LIRP-CLDC that affect the optimal value of both channels. Thus, parameters b_{ij}, e_j, g_j, h_{in}, h_{ir}, q, s_i, α_{in}, α_{ir}, β_{in}, β_{ir} and χ are considered. In Table 10.3, these parameters are changed by the percentages within the range of $[-50\%, 50\%]$. OBJ1 is the objective value of LIRP-CLDC under a single channel, and OBJ2 is the objective value of LIRP-CLDC under dual channels. GAP1 is calculated by (the objective value of LIRP-CLDC under a single channel after the parameters change—the objective value of LIRP-CLDC under a single channel without changing the parameters)/the objective value of LIRP-CLDC under

Table 10.3 Sensitivity analysis of parameters of LIRP-CLDC under both strategies

		b_{ij}	e_j	g_j	h_{in}	h_{ir}	Q	s_i
50%	OBJ1	1,333,080.85	1,213,327.90	1,210,541.7	1,329,335.96	1,210,650.28	1,209,727.11	–
	GAP1	11.20	1.21	0.98	10.89	0.99	0.91	–
	OBJ2	631,996.66	601,473.80	602,594.12	631,255.61	607,425.63	601,629.97	631,695.15
	GAP2	6.07	0.95	1.14	5.95	1.95	0.98	6.02
40%	OBJ1	1,257,016.67	1,212,839.89	1,209,850.69	1,279,183.22	1,211,359.69	1,208,647.55	–
	GAP1	4.86	1.17	0.92	6.71	1.05	0.82	–
	OBJ2	622,858.37	601,305.52	601,202.05	621,045.18	603,349.27	600,866.46	622,908.98
	GAP2	4.54	0.92	0.90	4.23	1.26	0.85	4.55
30%	OBJ1	1,234,993.00	1,209,542.07	1,206,523.02	1,220,815.1	1,209,538.17	1,205,479.35	–
	GAP1	3.02	0.90	0.65	1.84	0.90	0.56	–
	OBJ2	612,954.65	600,216.77	598,620.27	611,046.4	603,265.93	599,986.06	614,672.65
	GAP2	2.88	0.74	0.47	2.56	1.25	0.70	3.16
20%	OBJ1	1,227,283.93	1,204,922.16	1,204,354.11	1,209,929.32	1,203,425.98	1,201,943.32	–
	GAP1	2.38	0.51	0.46	0.93	0.39	0.26	–
	OBJ2	609,248.07	596,985.66	596,752.23	602,987.22	602,040.06	599,368.99	607,860.85
	GAP2	2.25	0.20	0.16	1.20	1.04	0.60	2.02
10%	OBJ1	1,218,279.89	1,204,504.72	1,198,810.88	1,202,580.98	1,203,038.30	1,202,100.78	–
	GAP1	1.63	0.48	0.00	0.32	0.35	0.28	–
	OBJ2	608,175.40	596,165.88	597,755.11	599,597.67	596,563.31	598,716.74	598,693.65
	GAP2	2.07	0.06	0.33	0.63	0.13	0.49	0.48
0%	OBJ1	1,198,786.94	1,198,786.94	1,198,786.94	1,198,786.94	1,198,786.94	1,198,786.94	–
	GAP1	0.00	0.00	0.00	0.00	0.00	0.00	–
	OBJ2	595,816.96	595,816.96	595,816.96	595,816.96	595,816.96	595,816.96	595,816.96
	GAP2	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(continued)

Table 10.3 (continued)

		b_{ij}	e_j	g_j	h_{in}	h_{ir}	Q	s_i
−10%	OBJ1	1,193,491.96	1,198,527.26	1,195,123.87	1,192,858.93	1,194,951.10	1,196,394.56	–
	GAP1	−0.44	−0.02	−0.31	−0.49	−0.32	−0.20	–
	OBJ2	585,601.97	593,744.16	595,580.51	580,245.61	595,461.52	594,490.08	587,012.22
	GAP2	−1.71	−0.35	−0.04	−2.61	−0.06	−0.22	−1.48
−20%	OBJ1	1,179,683.78	1,192,231.08	1,190,245.59	1,175,902.87	1,183,881.86	1,196,153.86	–
	GAP1	−1.59	−0.55	−0.71	−1.91	−1.24	−0.22	–
	OBJ2	570,466.06	592,308.74	592,571.34	579,594.53	590,784.73	594,385.74	576,044.47
	GAP2	−4.25	−0.59	−0.54	−2.72	−0.84	−0.24	−3.32
−30%	OBJ1	1,162,217.25	1,195,241.18	1,188,047.2	1,162,956.62	1,188,138.82	1,191,321.19	–
	GAP1	−3.05	−0.30	−0.90	−2.99	−0.89	−0.62	–
	OBJ2	565,796.90	591,598.68	586,105.60	570,466.06	590,117.25	592,930.23	571,863.52
	GAP2	−5.04	−0.71	−1.63	−4.25	−0.96	−0.48	−4.02
−40%	OBJ1	1,120,648.70	1,190,805.57	1,186,783.77	1,131,601.25	1,180,749.36	1,189,882.76	–
	GAP1	−6.52	−0.67	−1.00	−5.60	−1.50	−0.74	–
	OBJ2	555,414.29	589,500.37	586,068.68	565,931.21	589,805.52	591,454.96	566,201.48
	GAP2	−6.78	−1.06	−1.64	−5.02	−1.01	−0.73	−4.97
−50%	OBJ1	1,117,511.8	1,177,339.94	1,180,978.48	1,109,098.18	1,179,560.94	1,188,883.44	–
	GAP1	−6.78	−1.79	−1.49	−7.48	−1.60	−0.83	–
	OBJ2	548,590.75	588,902.30	584,909.85	558,312.53	585,022.1	589,815.94	558,729.04
	GAP2	−7.93	−1.16	−1.83	−6.29	−1.81	−1.01	−6.22

a single channel after the parameters change*100%. GAP2 is calculated similarly. In this table, the objective value of LIRP-CLDC under a single channel is increased by 11.2% when b_{ij} increases by 50% and increased by 10.89% when h_{in} increases by 50%. Moreover, when b_{ij} and h_{in} decrease by 50%, the objective value decreases by 6.78% and 7.48%, respectively. s_i is the per transportation cost from the MRC to the customer, which only influences the cost of LIRP-CLDC under dual channels. s_i also represents the 3PL cost. Then, when b_{ij} increases by 50%, the objective value of LIRP-CLDC under dual channels is increased by 6.07%, when h_{in} increases by 50%, the objective value is increased by 5.95% and when s_i increases by 50%, the objective value is increased by 6.02%. When b_{ij}, h_{in} and s_i decrease by 50%, the objective value decreases by 7.93%, 6.29% and 6.22%, respectively. The remaining parameters have little effect on the objective values. In addition, the objective values under a single channel cost more than the objective values under dual channels. This indicates that, if the company adopts the dual-channel strategy, the company can reduce the cost. Moreover, all the parameters considered in this table influence the objective value of both strategies. Company managers should take them into consideration when making decisions.

The parameters α_{in} and α_{ir} influence the quantity of returned products, and the parameters β_{in} and β_{ir} affect the quantity of repairable products. These parameters are changed within the range [0, 1]. The sensitivity analysis of these parameters is shown in Tables 10.4 and 10.5. Tables 10.4 and 10.5 depict the changes in costs under a single channel. The costs of the dual-channel strategy have the same trend as those of a single channel. From Table 10.4, we can see that the cost of establishing CDCCs is not changed when parameters α_{in} and α_{ir} change. The inventory cost is decreased when α_{in} and α_{ir} increase, while the transportation cost, inspection cost, disposal cost and repair cost are increased when parameters α_{in} and α_{ir} increase. Then, the objective values are increased when α_{in} and α_{ir} increase. In Table 10.5, the location cost is also unchanged, the inventory cost is also decreased when β_{in}

Table 10.4 Sensitivity analysis of parameters α_{in} and α_{ir}

α_{in}	α_{ir}	LC	IC	TC	INC	DC	RC	OBJ1
0	0	6562	701,293.00	388,240.00	0	0	0	1,096,095.00
0.1	0.2	6562	700,492.46	419,206.00	9663.7	14,478.42	4848.98	1,155,251.56
0.2	0.3	6562	677,682.01	444,181.86	17,009.0	23,437.96	8360.84	1,167,516.29
0.3	0.4	6562	675,009.66	453,566.20	31,798.8	23,456.60	8393.68	1,198,786.94
0.4	0.5	6562	674,510.22	462,037.02	77,854.6	25,234.96	8785.92	1,258,156.51
0.5	0.6	6562	674,316.00	481,032.76	78,373.4	57,709.22	10,332.09	1,309,019.13
0.6	0.7	6562	667,964.63	546,540.16	92,799.0	67,824.12	14,274.06	1,402,315.34
0.7	0.8	6562	661,192.00	591,416.33	107,893.2	78,984.88	24,622.48	1,470,670.89
0.8	0.9	6562	660,613.38	614,061.89	122,152.4	89,755.04	32,532.96	1,525,677.67
0.9	1	6562	600,504.97	686,138.11	137,222.2	100,851.34	36,446.86	1,567,725.48
1	1	6562	600,237.00	785,990.76	147,150.0	107,677.20	39,314.80	1,686,931.76

Table 10.5 Sensitivity analysis of parameters β_{in} and β_{ir}

β_{in}	β_{ir}	LC	IC	TC	INC	DC	RC	OBJ1
0	0	6562	705,755.58	389,785.67	24,394.0	24,394.00	0	1,150,891.25
0.1	0	6562	683,811.38	424,366.56	24,394.0	23,057.87	2997.72	1,165,189.57
0.2	0.1	6562	679,665.87	447,567.76	24,399.8	23,143.06	3944.00	1,185,282.49
0.3	0.2	6562	675,009.66	453,566.20	31,798.8	23,456.60	8393.68	1,198,786.94
0.4	0.3	6562	655,926.91	494,562.96	48,942.4	11,731.56	8896.68	1,226,622.51
0.5	0.4	6562	648,320.63	498,206.83	49,117.4	10,750.48	22,708.26	1,235,665.60
0.6	0.5	6562	643,178.50	526,391.45	49,213.4	6791.68	27,547.88	1,259,684.91
0.7	0.6	6562	641,043.52	540,895.67	49,247.4	3617.30	32,461.74	1,273,827.63
0.8	0.7	6562	637,336.39	555,412.68	49,276.0	3401.39	37,385.84	1,289,374.30
0.9	0.8	6562	624,000.15	572,805.67	49,304.4	3126.40	42,452.28	1,298,250.90
1	0.9	6562	611,963.74	609,381.97	49,355.0	1886.40	47,436.60	1,326,585.71

and β_{ir} increase, and the transportation cost, inspection cost and repair cost are also increased when β_{in} and β_{ir} increase. However, the disposal cost is decreased when β_{in} and β_{ir} increase. The objective values are increased when β_{in} and β_{ir} increase.

The parameter χ represents the proportion of customers who buy products from online channels. This parameter only affects the cost under dual channels, and the parameter changes from 0 to 0.8. The results are shown in Table 10.6. In Table 10.6, $\chi = 0$ indicates that the company adopts the single-channel model. $\chi > 0$ means that the company adopts the dual-channel model. It can be seen from Table 10.6 that, with the increase in χ, the cost of site selection remains unchanged, the cost of inventory, transportation and disposal decreases, and the cost of inspection and remanufacturing increases with the increase in χ. As χ increases, the total cost of dual channels decreases. This suggests that enterprises adopting dual channels can reduce operating costs.

Table 10.6 Sensitivity analysis of parameter χ

χ	LCdual	ICdual	TCdual	INCdual	DCdual	RCdual	OBJ2
0	6562	675,009.66	453,566.20	31,798.8	23,456.60	8393.68	1,198,786.94
0.1	6562	558,720.99	411,380.41	95,734.9	23,187.08	11,694.36	1,107,279.74
0.2	6562	530,018.58	401,221.59	105,902.1	23,143.06	12,110.76	1,078,958.09
0.3	6562	516,901.41	347,941.52	143,209.6	23,082.86	12,202.28	1,049,899.67
0.4	6562	496,219.80	336,431.42	160,236.2	23,003.76	12,300.20	1,034,753.38
0.5	6562	392,426.86	335,668.45	181,472.0	21,447.18	12,341.98	949,918.47
0.6	6562	357,481.74	331,745.68	190,413.0	21,392.82	12,351.62	919,946.86
0.7	6562	175,796.97	306,802.43	246,434.2	21,343.61	12,376.92	769,316.13
0.8	6562	89,652.55	108,915.71	357,020.8	21,274.00	12,391.90	595,816.96

In summary, the above sensitivity analysis can be summarized into the following two aspects.

(1) Because the dual-channel mode will directly distribute the customers originally distributed by the retailer to the manufacturer, and this portion of the customers directly distributed by the manufacturer will reduce the links of the retailer and reduce the inventory cost and transportation cost, the dual-channel mode can bring higher profits to the enterprise than the single-channel mode.

(2) If the proportion of recycled products is greater than the proportion of recycled products that cannot be used for remanufacturing, remanufacturing enterprises can obtain more profits. This is because recycled products that can be used for remanufacturing provide additional profit means for remanufacturing, although the production cost is now high. In contrast, if the recycled products are not suitable for remanufacturing, it will cause losses to the remanufacturer because the waste products can only be discarded. Therefore, decision-makers can invest in quality improvement actions to increase the proportion of remanufactured products in the production process to achieve a higher proportion of remanufactured products.

10.3 Summary

This chapter first defines the basic concept of green manufacturing and clarifies the connotation, characteristics, and relationship with the green growth of enterprises. Then, the most direct and effective way to realize green manufacturing, namely, remanufacturing, is introduced. Finally, this chapter models analyses the remanufacturing problem under the traditional retail channel and the dual-channel configuration, and uses a new genetic algorithm combined with local search to solve the problem. The solution shows that, for enterprises, customers with less demand and recycling volume will be diverted to online channels, and these customers can be directly delivered to by manufacturers, which reduces transportation costs and inventory due to the reduction of retailers' links. Enterprises can reduce their total operating costs by adopting a dual-channel model. In addition, through the implementation of the dual-channel model, enterprises can improve their recycling rate of waste products, thereby increasing their ratio of remanufactured products and enabling themselves to obtain more profits compared to the profits obtained under the single-channel model.

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Chapter 11
Inventory Management

Dandan Gao, Nengmin Wang, Qi Jiang, and Bin Jiang

Abstract Efficient inventory management is an important component of enterprises' green growth model. By reducing the inventory levels and inventory costs and lessening resource waste, enterprises can efficiently achieve green growth. To realize green transformation, enterprises need to form a closed-loop system from product design to resource recovery and utilization and then implement the coordination of "green" and "growth". Therefore, inventory management and control in a closed-loop system plays an important role in the green growth model and value chain reconstruction. Demand information mutation or the bullwhip effect of the supply chain is one of the important reasons for a high inventory level. It refers to the transmission of the market demand information from the downstream retailer to the upstream supplier throughout the value chain in the course of the fluctuation and variation. The bullwhip effect will cause higher inventory levels and inventory costs for the supplier. And the demand information distortion increases the risk of production and inventory management for upstream suppliers in the value chain and even can lead to the disruption of production and supply. To efficiently achieve the green growth of enterprises through efficient inventory management, this chapter focuses on the impact of the product return, remanufacturing, and different value chain structures on the bullwhip effect and inventory costs based on statistical theory and methods. We analyze the coordinated control measures of the bullwhip effect under different scenarios to lower the inventory levels and inventory costs of the enterprises. The analysis will help enterprises better achieve the green growth model and the green transformation of the value chain.

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11.1 Inventory Management and Enterprises' Green Growth Model

11.1.1 Concept of Inventory Management

Inventory management, also known as inventory control, is to manage and control the finished products and other resources in the whole process of production and operation in the manufacturing or service industry. The aim of inventory management is to keep the reserves at an economically reasonable level. Inventory management includes two parts: warehouse management and inventory control. The content of warehouse management refers to the scientific storage of stock materials to reduce losses and facilitate access. Inventory control is required to control a reasonable inventory level. A reasonable inventory level should meet the demand use and reduce the stock loss through the minimum input of materials and the lowest overhead. The content of the inventory management includes materials in and out of storage, the movement management of materials, inventory checking and the information analysis of inventory materials.

The objective of inventory management is to control the operation costs of the inventory system by adjusting the timing and quantity of replenishment. The target is to determine the optimal replenishment time and the optimal replenishment batch to minimize the operation costs of the inventory system. Effective inventory management can improve service levels, reduce the occupancy of inventory space, and decrease overall inventory costs. It will rationalize the allocation of stock capital and resources and accelerate the capital turnover of enterprises. A reasonable inventory mode or inventory management mode can help enterprises achieve more effective inventory control. How to balance the inventory level and the demand quantity is the key problem to be studied and solved by inventory management. Enterprises should minimize the inventory costs and the inventory levels on the premise of achieving the service levels expected by customers by selecting the reasonable inventory mode. The inventory mode includes various inventory management strategies, storage strategies and stock classification methods [1, 2], as shown in Table 11.1.

11.1.2 Inventory Management for Green Growth

The goal of inventory management under enterprises' green growth model is to reduce inventory levels and inventory costs and realize resource savings. The realization methods include the zero inventory strategy and the cross-dock operation. The zero inventory strategy refers to purchasing through a just-in-time system, which means enterprises will purchase goods in accordance with the required quantity and quality to achieve zero inventory. The strategy can reduce inventory holding capital, decrease inventory management costs and timely avoid market risks. The cross-dock operation means that the finished vehicle goods provided by each supplier are not put into the

Table 11.1 The definition and classification of inventory mode

Inventory mode	Classification	Definition
Inventory management strategy	Just-in-time	It refers an inventory management strategy where enterprises will purchase goods in accordance with the required quantity and quality to achieve zero inventory [1]
	Lateral transfer	It is an inventory management strategy where distributors or retailers at the same horizon of the supply chain share inventory with each other. It means the player with insufficient stock can require the player with rich stock to laterally transfer [2]
	Vendor managed inventory	It is an inventory management strategy where the manufacturers or retailers hand over the inventory to suppliers to reduce costs and improve service levels [3]
	Jointly managed inventory	It is an inventory management strategy developed on the VMI, which balances power and responsibility and shares risks between upstream and downstream enterprises. It emphasizes that both sides should participate in making the inventory plan together [4]
Storage strategy	Fixed quantity ordering system	It generally refers to the storage strategy of deriving the ordering alarming points and quantities through formula calculation or experience, whenever the inventory level drops to the alarming points [5]
	Fixed period ordering system	It refers to the storage strategy of replenishing orders at fixed intervals to bring the inventory up to a certain level [6]
Stock classification method	ABC control method	It refers to the quantitative management method where the management style is differentially adopted to grasp the main contradictions and distinguish between the key and general materials, carry out statistics, arrangement, and analysis [7]. The method uses mathematical statistics to make statistics, arrangement, and analysis according to the main characteristics of the economy, technology, etc.

(continued)

Table 11.1 (continued)

Inventory mode	Classification	Definition
	Critical value analysis	It refers to a classification method of dividing supplies into 3–5 categories and adopting different inventory methods for each type of material, according to the criticality of materials for the enterprise management [8]

warehouse after receipt but are immediately disassembled, sorted, stacked, loaded, and delivered to the customer delivery point according to the customer demand and the delivery location. All goods in cross-docking are kept out of the storage space of the warehouse. Overstock operations are especially suitable for the rapid processing of urgent orders and retailers directly delivering to customers. In the cross-dock operation, goods flow through a warehouse or distribution center rather than being stored. Through the strategy of cross-dock operations, the inventory levels can be greatly reduced to decrease the inventory management costs and the loss rate and speed up capital turnover. Efficient inventory management can lower the inventory levels and inventory costs and reduce the waste of resources to better realize the green growth of enterprises. Promoting a zero inventory strategy or low inventory strategies of nodal enterprises in the value chain including manufacturers, distributors and distribution centers, is an important component of implementing a green growth model. It plays an important role in realizing green growth.

The green growth of enterprises needs to effectively deal with the new requirements of inventory management in the value chain, the environmental issues with stock and the energy reuse problem in inventory control. The green value chain is a low entropy manufacturing mode to achieve the lowest harm of the raw materials, industrial production, product use, scrapping and secondary raw material on the environment. It is devoted to realize the highest resource efficiency in the whole life cycle from designing, manufacturing, and using to product scrapping and recycling. The green value chain considers the environmental attributes of products from the point of view of system integration in the whole life cycle of products and can change the original environmental protection method of end processing. It aims at environmental protection from the source and considers the basic attributes of the product. The product meeting the requirements of environmental objectives at the same time can ensure that the product should have basic performance, service life and quality. Achieving green growth requires enterprises to further reduce resource waste and lower inventory levels and costs. It indicates that a reasonable inventory management mode has important environmental and economic significance.

Inventory management for enterprises' green growth model forms a closed-loop system to reduce pollution emissions and waste residues. The closed-loop system includes recycling and remanufacturing activities besides the processes of traditional procurement, production, and marketing. The green value chain requires enterprises to realize closed-loop management to achieve the efficient reuse of resources. It can be implemented through the complete supply chain cycle, from procurement, production, sales, and recycling to remanufacturing. Simultaneously, it is of great significance for the sustainable development of enterprises to provide services for customers at a lower cost and form effective closed-loop management. Inventory management is an important component of activities in reverse logistics and plays an important role in the transformation of the green value chain. Producers in green value chains must meet consumer demand for products and accept the recycling of used products. Manufacturers can order raw materials from outside to make finished products and reproduce products by repairing recycled products. The inventory management of the green value chain needs to coordinate the relationship between ordering and remanufacturing to achieve the established service level at the lowest cost. Inventory control can reduce resource waste and improve operational efficiency, which plays an important role in optimizing the green value chain.

11.2 Inventory Management and Bullwhip Effect

11.2.1 Bullwhip Effect

The bullwhip effect refers to the phenomenon of amplified demand information disturbance throughout the supply chain when each nodal enterprise makes the order decision only according to the demand data of adjacent subordinate enterprises. The bullwhip effect will result in damage to the interests of companies, inventory backlog, occupancy of capital and disrupted operation schedules [9–13]. Forrester [14] first proposed the amplification effect of demand information and proved its existence through system dynamics simulation modeling. The analysis put forward that the main reason for the bullwhip effect is irrational decisions among organizational subjects in supply chains, which leads to a distorted transmission of demand information among upstream node enterprises. Burbidge [15] observed that the bullwhip effect is generated from the isolated decision-making, management and implementation of enterprises and analyzed the causes of demand information variation and the restraining measures. Sterman [16] proved that the bullwhip effect is caused by the irrational behaviors of participants in the supply chain and the incorrect judgment of feedback information. Information volatility in the value chain can be controlled by cultivating managers' systematic thinking. An important milestone in the field of the bullwhip effect is in Lee et al. [11–13], who made a systematic quantitative analysis of demand information distortion for the first time. The analysis indicated that the main causes of the bullwhip effect are batching order, price fluctuation, shortage gaming and demand signal processing.

The restraining and coordinating measures of the bullwhip effect mainly include information sharing, stable price control, limited supply, shortening lead time, accurate forecasting technology, adjusting ordering strategy and so on. Information sharing: The bullwhip effect is essentially the distortion and disturbance of market information and demand data throughout the supply chain. The bullwhip effect can be effectively restrained by encouraging nodal enterprises in the supply chain to strengthen cooperation and share demand and inventory information. In addition, the management model integrating modern information technology is widely applied in the supply chain, which has a significant effect on reducing the inventory backlog and smoothing the information fluctuation in the supply chain. Stable price control: Consumers' prediction of future prices and their purchase behavior in advance will result in a bullwhip effect. The corresponding solution is to appropriately reduce the frequency and amplitude of product discounts and maintain price stability. Limited supply: Shortage gaming between downstream retailers and upstream suppliers is another important cause of the bullwhip effect. The game behavior in ordering can be restrained by suppliers adopting a reasonable allocation mechanism to limit the supply quantity. Shortening lead time: Chen et al. [17] proved that the lead time between organizational entities in the supply chain would amplify the bullwhip effect. Promoting the negotiation between downstream retailers and upstream suppliers and formulating an appropriate lead time can coordinate information variation in the supply chain. Accurate forecasting techniques and adjusting ordering strategies: Encouraging enterprises in the supply chain to select the optimal forecasting method and inventory strategy can reduce the forecasting error and the expected cost. The minimum mean square error prediction technique and the order-up-to inventory policy are widely adopted to effectively mitigate the information distortion in the supply chain [18]. However, the above measures can suppress the bullwhip effect only to a certain extent and cannot completely eliminate the fluctuation of order information in the supply chain. In particular, with the development of modern information technology and the emergence of new business models, the market environment, supply chain structure, and interaction of logistics and information flow in a supply chain will become more complex. How to coordinate the bullwhip effect in complex supply chain contexts has significant research value.

11.2.2 Bullwhip Effect and Inventory Management

By restraining the bullwhip effect, enterprises can reduce inventory levels and inventory costs to achieve more effective inventory management and control. The bullwhip effect of the supply chain will directly lead to inventory overstocking and misleading production plans for upstream enterprises, increase inventory costs and reduce the efficiency of the supply chain. Therefore, coordinated control measures should be adopted to restrain the bullwhip effect in the supply chain. When suppliers at all levels of the supply chain make supply decisions based only on the demand information from their neighboring subvendors, the distortion of demand information transfers upstream throughout the supply chain. When the distorted ordering information reaches the source supplier, such as the general seller or the manufacturer, there will be a huge deviation between the obtained demand information and the customer demand information. The coefficient of variation of demand is much larger than that of distributors and retailers. As a result of the demand amplification effect, upstream suppliers tend to maintain higher inventory levels than downstream retailers to cope with the uncertainty of orders. Thus, it artificially increases the risks of upstream suppliers in the supply chain and even leads to the distortion of production, supply and marketing.

Reasonable inventory management strategies also can reduce the bullwhip effect in supply chains. Different inventory strategies will have significant impacts on demand information mutation. The bullwhip effect of manufacturers and retailers can be minimized by adopting optimal inventory strategies. In the research field of the bullwhip effect, the widely used inventory strategies include the order-up-to inventory policy, (s, Q) policy and (s, S) policy. Therefore, the order-up-to inventory policy is widely used in supply chain analysis, has been proven to be a locally optimal inventory strategy, and can minimize the total discounted holding and shortage costs [11]. Order-up-to inventory policy: The retailer sets the corresponding order-up-to level according to the expected lead-time demand of consumers and places orders to upstream suppliers according to the order-up-to level and the actual inventory level in each period. In addition, each node enterprise in the supply chain independently manages inventory and sets inventory control targets and corresponding strategies. A lack of information communication and exclusive inventory information between each other will inevitably produce demand information distortion and time delays. Thus, suppliers cannot meet market demand quickly and accurately. The vendor managed inventory (VMI) policy can effectively mitigate the bullwhip effects of enterprises. Suppliers should make accurate predictions of demand according to real-time sales data, determine order quantity more accurately and reduce the uncertainty of prediction, thus decreasing the safety inventory and supply costs. At the same time, the VMI policy allows suppliers to respond to the user demand more quickly, improve the service level, and effectively lower the inventory level. The VMI policy promotes the sharing of information about enterprises in the supply chain so that the bullwhip effect can be inhibited significantly.

In summary, the coordinated control of the bullwhip effect can reduce the inventory levels and inventory costs in the supply chain, thus achieving more effective inventory management. However, adopting a reasonable inventory management strategy can mitigate the bullwhip effect. Therefore, it plays an important role in realizing the green growth of enterprises to reduce inventory costs and resource waste by restraining the bullwhip effect.

11.3 Bullwhip Effect in Green Value Chain

The green value chain realizes the circular and efficient utilization of resources by establishing a closed-loop system from procurement to resource recovery. In addition to the activities of the traditional supply chain, the recycling, remanufacturing and distribution of recycled products also should be considered [19]. The processes of product recovery and remanufacturing in reverse logistics supplement the traditional supply chain [20]. The inventory control and management of the value chain is an important component of all reverse activities. The coordinated control of the bullwhip effect in the value chain can decrease inventory costs and inventory levels, reduce enterprise resource waste, and improve operation efficiency. It plays an important role in optimizing the green value chain.

For environmental protection and resource conservation, most of the research on the bullwhip effect in the value chain mainly focuses on the recovery and reuse of products. Product return in the value chain will directly affect the retailer's inventory levels and ordering decisions, thus affecting the retailer's ordering information transfer to upstream suppliers and the bullwhip effect. The bullwhip effect in traditional offline retail has been extensively studied. Scholars have proven that product return in the value chain can restrain the bullwhip effect and improve the operation efficiency through statistics, simulation, and empirical research methods [21, 22]. The process of reverse logistics in the green value chain mainly includes product recovery, product return and exchange, reuse, and remanufacturing. Therefore, the bullwhip effect in the green value chain is mainly focused on product recycling and remanufacturing. Based on statistical theories and methods, this chapter focuses on the impact of new factors, such as product return, remanufacturing and different value chain structures, on bullwhip effects and their coordination strategies. We establish the demand function and the ordering model based on the characteristics of the green value chain. Then, we study the bullwhip effect and the expected cost of retailers under different value chain scenarios, and analyze the impact of product return on value chain performance [23–30].

We measure the impacts of different retail policies on the bullwhip effect and inventory costs. The research design is as follows:

(1) Build a closed-loop supply chain system network by comparing the differences with the traditional supply chain. The supply chain system is usually composed of three or more parties, such as manufacturers, remanufacturers, retailers, logistics service providers and consumers. Identify the interaction relationships and the transmission processes of logistics and information flow among the organization subjects in the supply chain system.
(2) Determine the market demand process, which will directly affect the retailer's ordering decision and the bullwhip effect of the closed-loop supply chain. Constructing the demand function depends on the supply chain complexity, market environment and research objectives. The demand function in bullwhip modeling is more complicated due to the drastic fluctuation of demand information in the retail market and the complexity of the supply chain. Select the optimal demand forecasting technology and inventory strategy to make the retailer's order decision based on the market demand information. Different forecasting techniques will lead to different forecasting accuracies. Meanwhile, different inventory strategies also will have significant impacts on ordering decisions. Therefore, adopting the optimal forecasting method and inventory strategy plays an important role in suppressing information distortion. When

modeling the bullwhip effect, the minimum mean square error prediction technique and order-up-to inventory strategy are widely identified as the optimal demand forecasting technique and inventory strategy, respectively. Quantify the bullwhip effect and the expected cost of the retailer according to the ordering decisions in different supply chain contexts. The quantitative expression of the bullwhip effect is derived as the ratio or the difference between the order variance and the demand variance. To simplify its quantitative expression, scholars usually directly adopt the order variance as a substitute. In addition, the bullwhip effect usually leads to inventory overstocking of upstream suppliers, thus increasing the inventory costs. Therefore, analyzing the bullwhip effect and inventory costs are mutually reinforcing in measuring information fluctuation in the supply chain.

(3) Make simulations and sensitivity analyses according to the bullwhip effect and expected costs of the supply chain. Measure the impacts of parameters in the supply chain on the information fluctuation, such as the replenishment lead time, delivery lead time, return lead time and return rate, etc. Draw the research conclusions and the management enlightenment based on the analytical results.

The parameters of the models in this chapter are shown in Table 11.2:

Considering a closed-loop supply chain with a manufacturer, a remanufacturer, a logistics center and a retailer, the external demand of a single product is expressed in Eq. 11.1:

Table 11.2 Notations of parameters

Parameter	Definition	Parameter	Definition
C_t	Expected cost	M_t	Remanufacture quantity
D_t^L	Lead-time demand	P	Unit penalty cost
$\hat{D}_t^L$	Prediction of lead-time demand	p_t	Market price
d_t	Demand	q_t	Order quantity
$\hat{d}_t$	Prediction of demand	y_t	Order-up-to level
H	Unit holding cost	Z	Safety factor
I_t	inventory level	ε_t	Demand disturbance term
K	Historical observation period	$\hat{\sigma}_t^L$	Demand forecasting error
L	Lead time of manufacturer	Σ	The standard deviation
L_r	Lead time of remanufacturer	σ_d^2	Variance of demand
L_t	Random lead time	σ_q^2	Order quantity variance
l	Return lead time	BWE	Bullwhip effect

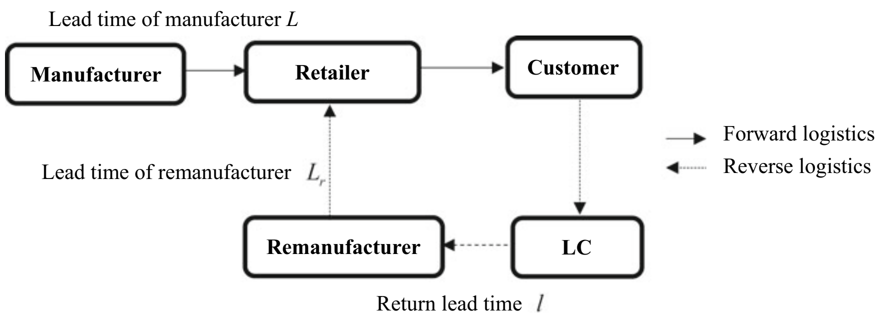

Fig. 11.1 The closed-loop supply chain network with product return

$$d_t = \mu + \varepsilon_t \tag{11.1}$$

where μ is the constant term of the market demand and ε_t $N(0, \sigma^2)$ is the demand shock, an independently and normally distributed random variable. In addition, the inappreciable probability of negative demand is due to a large constant term of demand.

Consider a green value chain system for recycling and remanufacturing, as shown in Fig. 11.1. The total lead time in the reverse logistics in Fig. 11.1 is defined as the indirect return period. Thereinto, L_r is the lead time of the remanufacturer and l is the return lead time of the consumers, which refers to the delivery lead time from the consumers to the remanufacturer. Since there is only one return channel, both intact and defective products will be delivered to the remanufacturer by the logistics center. Then, after l periods, the remanufacturer receives the total returned products from the consumers. The remanufacturer receives the returned products from the logistics center as $r_{t,1}$:

$$r_{t,1} = \theta_1 d_{t-l-1} + \zeta_{t,1} \tag{11.2}$$

where $0 \le \theta_1 \le 1$ is the defective rate, and $\zeta_{t,1}$ $N\left(0, \sigma_{\xi_1}^2\right)$ is the random disturbance, an independently and normally distributed random variable. Assume that shock term $\zeta_{t,1}$ has no relation with market demand d_t. Then, the covariance is zero as $Cov\left(d_t, \zeta_{t',1}\right) = 0, \left(\forall t, t'\right)$.

This research adopts the assumption that the time delay of the remanufacturing process is neglected to simplify the supply chain model. When a remanufacturer receives defective returns $r_{t,1}$ at period t to undergo the remanufacturing process, the actual output in the remanufacturing process will be M_t:

$$M_t = \xi r_{t,1} + \varsigma_t \tag{11.3}$$

where ξ is the average yield rate of the remanufacturer and $\varsigma_t \; N\left(0, \sigma_\varsigma^2\right)$ is the random term irrelevant with the demand shock. Therefore, we obtain the covariance $Cov\left(\varsigma_t, r_{t',1}\right) = 0$, $\left(\forall t, \forall t'\right)$. The total quantity delivered by the remanufacturer to the retailer M_t, the remanufacturing lead time L_r and the manufacturing lead time L are well known by the retailer. The remanufacturer informs the retailer as soon as the remanufacturing process is finished. Thus, there is no asymmetric information between the remanufacturer and the retailer. The reproduced items are then sent into the retailer's stock to partially satisfy the market demand supposing that those reproduced products function as well as new products. Therefore, the returned products received by the retailer in period t are r_t:

$$r_t = M_{t-L_r} = \xi r_{t-L_r,1} + \varsigma_{t-L_r} \tag{11.4}$$

To derive the order-up-to level, retailers need to use forecasting techniques to predict the mean lead-time demand. The three most commonly used forecasting techniques in bullwhip modeling are minimum mean square error (MMSE), moving average (MA) and exponential smoothing (ES). Among them, MMSE has the smallest error. The MMSE is provided by the conditional expectation given to previous observations and is considered an optimal forecasting procedure that minimizes the mean-squared forecasting error. Thus, this paper uses the MMSE forecasting technique and the order-up-to policy to analyze the bullwhip effect in the value chain. It will be conducive to comparative analysis of the bullwhip effect and expected costs under different value chain scenarios and thus not affected by different inventory strategies and forecasting techniques in the value chain. We suppose that the retailer in the value chain has adopted the optimal inventory policy and the optimal forecasting technique [11]. Accordingly, the prediction of the market demand $\hat{d}_{t+i}$ is $\hat{d}_{t+i} = E(d_{t+i}|d_{t-1})$ made at the end of period $t-1$. L is the manufacturing lead time or the retailer's replenishment lead time, and the estimated lead-time demand during $[t, t+L)$ is:

$$D_t^L = \sum_{i=0}^{L-1} d_{t+i} = L\mu + \sum_{i=0}^{L-1} \varepsilon_{t+i} \tag{11.5}$$

We adopt the following sequence of events during the replenishment period. The retailer observes consumer demand d_{t-1} and return data r_{t-1} at the end of period $t-1$, calculates the order-up-to level y_t, and then places an order of quantity q_t to the manufacturer at the beginning of period t according to its current inventory level. After lead time L, the retailer receives the product from the manufacturer at the beginning of period $t+L$.

The order-up-to policy is one of the most widely studied policies of supply chain models. When demands are stationary, resupply is infinite, product purchase cost is stationary, and there is no fixed order cost, the order-up-to policy is considered as the locally optimal inventory policy. The policy can minimize the total discounted holding and shortage costs [11]. Assuming that the retailer adopts the order-up-to inventory policy, the ordering decision is as follows:

$$q_t = y_t - (y_{t-1} - d_{t-1}) \tag{11.6}$$

The order-up-to level consists of an anticipation stock that is retained to meet the expected lead-time demand and a safety stock for hedging against unexpected demand. Therefore, the order-up-to level is updated in every period according to the following:

$$y_t = \hat{D}_t^L + z\hat{\sigma}_t^L \tag{11.7}$$

where $\hat{D}_t^L$ is the lead-time demand equal to the sum of the demands of L periods, z is a constant that has been set to meet a desired service level and is often referred to as the safety factor, and the estimate of the standard deviation of the L period forecasting error is $\hat{\sigma}_t^L = \sqrt{Var\left(D_t^L - \hat{D}_t^L\right)}$.

In a traditional supply chain without product returns, the retailer's ordering decision is $q_t = y_t - (y_{t-1} - d_{t-1})$ with the order-up-to replenishment policy. However, in a green value chain, items returned from the remanufacturer can partly satisfy the actual demand of the retailer, assuming that the remanufactured products function as well as new products. Thus, the practical lead-time demand should be the total demand short of the total return quantity, as $\hat{D}_t^L - \hat{R}_t^L$. Therefore, the actual order-up-to level of the green value chain is:

$$y_t = \hat{D}_t^L - \hat{R}_t^L + z\hat{\sigma}_t^L \tag{11.8}$$

where $\hat{D}_t^L = E\left(\sum_{i=0}^{L-1} d_{t+i}\right)$ is a prediction of lead-time demand during the time interval $[t, t+L)$, and $\hat{R}_t^L = E\left(\sum_{i=0}^{L-1} r_{t+i}\right)$ is an estimate of the total return quantity of L periods from the remanufacturer during interval $[t, t+L)$. $\hat{\sigma}_t^L = \sqrt{Var\left(\left(D_t^L - \hat{D}_t^L\right) - \left(R_t^L - \hat{R}_t^L\right)\right)}$ is the prediction for the standard deviation of the forecasting error during L periods. In addition, $z = \Phi^{-1}[P/P + H]$ is a safety factor with the standard normal distribution Φ [11, 13]. P and H denote the penalty and holding costs of the retailer, respectively. Accordingly, the ordering decision of the retailer in period t is:

$$q_t = y_t - (y_{t-1} - (d_{t-1} - r_{t-1})) \tag{11.9}$$

where r_{t-1} is the return volume received by the retailer at $t - 1$.

Substituting (11.8) into (11.9), the ordering level of the retailer is rewritten as:

$$q_t = \hat{D}_t^L - \hat{D}_{t-1}^L - \left(\hat{R}_t^L - \hat{R}_{t-1}^L\right) + d_{t-1} - r_{t-1} + z\left(\hat{\sigma}_t^L - \hat{\sigma}_{t-1}^L\right) \tag{11.10}$$

Apparently, because the total return quantity of L periods R_t^L is different in different value chain contexts, the expected costs of the retailer also are different. When the manufacturing lead time is larger than that of the remanufacturer, the product returns contain unknown information that needs to be estimated and considered in the ordering decisions for the retailer. The estimate of the total return quantity of the retailer during $[t, t + L)$ is:

$$\hat{R}_t^L = E\left(\sum_{i=0}^{L-1} r_{t+i}\right) = E\left(\sum_{i=1}^{L_r} M_{t-i}\right) + E\left(\sum_{i=0}^{L-L_r-1} M_{t+i}\right) \tag{11.11}$$

When $L > L_r$, the total return quantity from the remanufacturer during periods $[t, t + L)$ includes the remanufactured quantity $\sum_{i=1}^{L_r} M_{t-i}$ and the future yield $\sum_{i=0}^{L-L_r-1} M_{t+i}$. Because $\sum_{i=1}^{L_r} M_{t-i}$ is the known information, we have:

$$E\left(\sum_{i=1}^{L_r} M_{t-i}\right) = \sum_{i=1}^{L_r} M_{t-i} \tag{11.12}$$

In addition, the retailer has to forecast the future returns from the remanufacturer during $[t, t + L)$:

$$\sum_{i=0}^{L-L_r-1} M_{t+i} = \theta_1 \xi \sum_{i=0}^{L-L_r-1} d_{t+i-l-1} + \xi \sum_{i=0}^{L-L_r-1} \zeta_{t+i,1} + \sum_{i=0}^{L-L_r-1} \varsigma_{t+i} \tag{11.13}$$

The expect of future return from the remanufacturer during $[t, t + L)$ is:

$$E\left(\sum_{i=0}^{L-L_r-1} M_{t+i}\right) = \begin{cases} \theta_1 \xi \sum_{i=0}^{L-L_r-1} d_{t+i-l-1}, & l \geq L - L_r - 1 \\ \theta_1 \xi \sum_{i=0}^{1} d_{t+i-l-1} + \theta_1 \xi (L - L_r - l - 1)\mu, & L - L_r - 1 > l \end{cases} \tag{11.14}$$

When the lead time of the manufacturer is smaller than that of the remanufacturer, which means $L \leq L_r$, the total return quantity of L periods of retailer R_t^L is known information. The estimate of the total return quantity during $[t, t + L)$ is:

$$\hat{R}_t^L = E\left(\sum_{i=0}^{L-1} r_{t+i}\right) = \sum_{i=L_r-L+1}^{L_r} M_{t-i} \tag{11.15}$$

Because $\sum_{i=L_r-L+1}^{L_r} M_{t-i}$ is known information, the estimate of the output is:

$$E\left(\sum_{i=L_r-L+1}^{L_r} M_{t-i}\right) = \sum_{i=L_r-L+1}^{L_r} M_{t-i} \tag{11.16}$$

Thus, the prediction error of total return quantity under different value chain scenarios can be expressed as follows:

$$\begin{aligned} & R_t^L - \hat{R}_t^L \\ & = \begin{cases} \xi \sum_{i=0}^{L-Lr-1} \zeta_{t+i,1} + \sum_{i=0}^{L-Lr-1} \varsigma_{t+i}, & L > L_r \wedge l \geq L - L_r - 1 \\ \theta_1 \xi \sum_{i=l+1}^{L-Lr-1} \varepsilon_{t+i-l-1} + \xi \sum_{i=0}^{L-Lr-1} \zeta_{t+i,1} + \sum_{i=0}^{L-Lr-1} \varsigma_{t+i}, & L > L_r \wedge L - L_r - 1 > l \\ 0, & L \leq L_r \end{cases} \end{aligned} \tag{11.17}$$

Therefore, the differences in estimated total returns at period t and period $t-1$ are expressed as:

$$\begin{aligned} & \hat{R}_t^L - \hat{R}_{t-1}^L \\ & = \begin{cases} M_{t-1} - M_{t-L_r-1} + \theta_1 \xi \left(d_{t+L-L_r-l-2} - d_{t-l-2}\right), & L > L_r \wedge l \geq L - L_r - 1 \\ M_{t-1} - M_{t-L_r-1} + \theta_1 \xi (d_{t-1} - d_{t-l-2}), & L > L_r \wedge L - L_r - 1 > l \\ M_{t+L-L_r-1} - M_{t-L_r-1}, & L \leq L_r \end{cases} \end{aligned} \tag{11.18}$$

Lemma 11.1 *Variances of the forecasting error of lead-time demand in two return modes and policies under different business contexts remain constant.*

Proof:

When $L > L_r \wedge l \geq L - L_r - 1 \wedge l_1 \geq L - 1$, variances of the forecasting error of lead-time demand are:

$$\begin{aligned} \left(\hat{\sigma}_t^L\right)^2 &= Var\left(\sum_{i=0}^{L-1} \varepsilon_{t+i} - \xi \sum_{i=0}^{L-L_r-1} \zeta_{t+i,1} - \sum_{i=0}^{L-L_r-1} \varsigma_{t+i}\right) \\ &= L\sigma^2 + (L - L_r)\xi^2 \sigma_{\zeta_1}^2 + (L - L_r)\sigma_{\varsigma}^2 \end{aligned} \tag{11.19}$$

When $\mathrm{L} > \mathrm{L_r} \wedge \mathrm{L} - \mathrm{L_r} - 1 > 1 \wedge \mathrm{L} - 1 > \mathrm{l_1}$, variances of the forecasting error of lead-time demand are:

$$\begin{aligned} \left(\hat{\sigma}_t^L\right)^2 &= Var\left(\sum_{i=0}^{L-1} \varepsilon_{t+i} - \left(\theta_1 \xi \sum_{i=0}^{L-L_r-l-2} \varepsilon_{t+i} + \xi \sum_{i=0}^{L-L_r-1} \zeta_{t+i,1} + \sum_{i=0}^{L-L_r-1} \varsigma_{t+i}\right)\right) \\ &= Var\left(\begin{array}{l} (1 - \theta_1 \xi) \sum_{i=0}^{L-L_r-l-2} \varepsilon_{t+i} + \sum_{i=L-L_r-l-1}^{L-l_1-2} \varepsilon_{t+i} + \sum_{i=L-l_1-1}^{L-1} \varepsilon_{t+i} \\ -\xi \sum_{i=0}^{L-L_r-1} \zeta_{t+i,1} - \sum_{i=0}^{L-L_r-1} \varsigma_{t+i} \end{array}\right) \end{aligned}$$

$$= (L - L_r)\xi^2\sigma_{\zeta_1}^2 + (L - L_r)\sigma_{\varsigma}^2 + (1 - \theta_1\xi)^2(L - L_r - l - 1)\sigma^2 + (L_r + l - l_1)\sigma^2 + (l_1 + 1)\sigma^2 \tag{11.20}$$

When $L > L_r \wedge L - L_r - 1 > l \wedge l_1 \geq L - 1$, variances of the forecasting error of lead-time demand are:

$$\begin{aligned}\left(\hat{\sigma}_t^L\right)^2 &= Var\left(\sum_{i=0}^{L-1} \varepsilon_{t+i} - \left(\theta_1\xi \sum_{i=0}^{L-L_r-l-2} \varepsilon_{t+i} + \xi \sum_{i=0}^{L-L_r-1} \zeta_{t+i,1} + \sum_{i=0}^{L-L_r-1} \varsigma_{t+i}\right)\right) \\ &= Var\left((1-\theta_1\xi) \sum_{i=0}^{L-L_r-l-2} \varepsilon_{t+i} + \sum_{i=L-L_r-l-1}^{L-1} \varepsilon_{t+i} \right. \\ &\quad \left. -\xi \sum_{i=0}^{L-L_r-1} \zeta_{t+i,1} - \sum_{i=0}^{L-L_r-1} \varsigma_{t+i}\right) \\ &= (L - L_r)\xi^2\sigma_{\zeta_1}^2 + (L - L_r)\sigma_{\varsigma}^2 + (1 - \theta_1\xi)^2(L - L_r - l - 1)\sigma^2 \\ &\quad + (L_r + l + 1)\sigma^2 \end{aligned} \tag{11.21}$$

When $L > L_r \wedge l \geq L - L_r - 1 \wedge L - 1 > l_1$, variances of the forecasting error of lead-time demand are:

$$\begin{aligned}\left(\hat{\sigma}_t^L\right)^2 &= Var\left(\sum_{i=0}^{L-1} \varepsilon_{t+i} - \xi \sum_{i=0}^{L-L_r-1} \zeta_{t+i,1} - \sum_{i=0}^{L-L_r-1} \varsigma_{t+i}\right) \\ &= Var\left(\sum_{i=0}^{L-l_1-2} \varepsilon_{t+i} + \sum_{i=L-l_1-1}^{L-1} \varepsilon_{t+i} - \xi \sum_{i=0}^{L-L_r-1} \zeta_{t+i,1} - \sum_{i=0}^{L-L_r-1} \varsigma_{t+i}\right) \\ &= L\sigma^2 + (L - L_r)\xi^2\sigma_{\zeta_1}^2 + (L - L_r)\sigma_{\varsigma}^2 \end{aligned} \tag{11.22}$$

When $L \leq L_r \wedge l_1 \geq L - 1$, variances of the forecasting error of lead-time demand are:

$$\begin{aligned}\left(\hat{\sigma}_t^L\right)^2 &= Var\left(\sum_{i=0}^{L-1} \varepsilon_{t+i}\right) \\ &= L\sigma^2 \end{aligned} \tag{11.23}$$

When $L \leq L_r \wedge L - 1 > l_1$, variances of the forecasting error of lead-time demand are:

$$\begin{aligned}\left(\hat{\sigma}_t^L\right)^2 &= Var\left(\sum_{i=0}^{L-1} \varepsilon_{t+i}\right) \\ &= L\sigma^2 \end{aligned} \tag{11.24}$$

Lemma 11.1 proves that $\hat{\sigma}_t^L = \hat{\sigma}_{t'}^L, (\forall t, t')$. Substituting (11.5) and (11.18) into (11.10), the ordering quantity of the retailer in period t is derived as:

$$q_t = \begin{cases} d_{t-1} - \theta_1 \xi d_{t+L-L_r-l-2} \\ \quad - \xi \zeta_{t-1,1} - \varsigma_{t-1}, & L > L_r \wedge l \geq L - L_r - 1 \\ (1-\theta_1\xi) d_{t-1} - \xi \zeta_{t-1,1} - \varsigma_{t-1}, & L > L_r \wedge L - L_r - 1 > l \\ d_{t-1} - \theta_1 \xi d_{t+L-L_r-l-2} \\ \quad - \xi \zeta_{t+L-L_r-1,1} - \varsigma_{t+L-L_r-1}, & L \leq L_r \end{cases} \tag{11.25}$$

This section analyzes the bullwhip effect expression of retailers under different value chain scenarios, which depends on the variance of the order quantity of retailers $\sigma_q^2 = Var(q_t)$. When the retailer adopts the MMSE prediction method and order-up-to inventory strategy, the order quantity expression under different value chain scenarios can be expressed by (11.25) as $\sigma_{q,r}^2$:

$$\sigma_{q,r}^2 = \begin{cases} \left(1 + (\theta_1\xi)^2\right)\sigma^2 + \xi^2\sigma_{\zeta_1}^2 + \sigma_\varsigma^2, & L > L_r \wedge l \geq L - L_r - 1 \\ (1-\theta_1\xi)^2\sigma^2 + \xi^2\sigma_{\zeta_1}^2 + \sigma_\varsigma^2, & L > L_r \wedge L - L_r - 1 > l \\ \left(1 + (\theta_1\xi)^2\right)\sigma^2 + \xi^2\sigma_{\zeta_1}^2 + \sigma_\varsigma^2, & L \leq L_r \end{cases} \tag{11.26}$$

This section deduces the analytical expression of the bullwhip effect in the green value chain. Determining the order level of retailers is an important prerequisite step to derive the bullwhip effect. The bullwhip effect is calculated as the ratio of the retailer's order variance to the market demand variance [11, 13]. When the ratio is greater than one, the bullwhip effect exists in the value chain. Such disturbance of information usually leads to potential costs in the value chain, including large overstocking of inventory, loss of profit and disordered capacity planning. Therefore, the bullwhip effect in the value chain should be restrained and coordinated. When the retailer adopts the MMSE prediction method and order-up-to inventory strategy, the order quantity expression under different value chain scenarios can be expressed as:

$$BWE = \frac{Var(q_t)}{Var(d_t)} = \begin{cases} 1 + (\theta_1\xi)^2 + \left(\xi^2\sigma_{\zeta_1}^2 + \sigma_\varsigma^2\right)/\sigma^2, & L > L_r \wedge l \geq L - L_r - 1 \\ (1-\theta_1\xi)^2 + \left(\xi^2\sigma_{\zeta_1}^2 + \sigma_\varsigma^2\right)/\sigma^2, & L > L_r \wedge L - L_r - 1 > l \\ 1 + (\theta_1\xi)^2 + \left(\xi^2\sigma_{\zeta_1}^2 + \sigma_\varsigma^2\right)/\sigma^2, & L \leq L_r \end{cases} \tag{11.27}$$

As the shipment inventory during the replenishment lead time is normally distributed with mean $\hat{D}_t^L - \hat{R}_t^L$ and standard deviation $\hat{\sigma}_t^L$, the expected inventory cost for the retailer in period t is given as:

$$C_t = E\left[P \int_{y_t}^{\infty} \left(D_t^L - R_t^L - y_t\right) d\bar{F}_t\left(D_t^L - R_t^L\right)\right.$$

$$+H\int_{-\infty}^{y_t}\left(y_t-\left(D_t^L-R_t^L\right)\right)d\bar{F}_t\left(D_t^L-R_t^L\right)\Big]$$
$$=\hat{\sigma}_t^L[(H+P)L(z)+Hz] \tag{11.28}$$

where $\overline{F}_t\left(D_t^L-R_t^L\right)$ is the true distribution of $D_t^L-R_t^L$ with variance $\left(\hat{\sigma}_t^L\right)^2$. y_t is the optimal order-up-to level of the retailer $y_t=\hat{D}_t^L-\hat{R}_t^L+z\hat{\sigma}_t^L$. $L(x)$ is $L(x)=\int_x^{\infty}(\mathrm{y}-x)d\Phi(y)$ convex and decreasing in x, and $H(z+L(z))+PL(z)\leq H(x+L(x))+PL(x)\forall x\geq z$.

The following two conclusions can be drawn by solving the models:

(1) Relationships between the manufacturer/remanufacturer's lead times and return lead time have a remarkable effect on operational efficiency, i.e., expected costs and bullwhip effect, and optimizing the decisions of return polies under different value chain situations.
(2) Product recycling cannot always restrain the order information fluctuation in the value chain. Consumers' product return behavior can diminish the information mutation of the value chain only if the ordering lead time is larger than the return period, which means that the total return period is enclosed in an ordering period. Returned products will be delivered into the retailer's inventory to partly balance out the fluctuation of current demand and thus can alleviate the information mutation. In addition, retailers can timely adjust the forecast of future actual demand to improve the accuracy of ordering decisions when the return period is included in an ordering period.

11.4 Summary

The green growth of enterprises requires optimizing the inventory control strategy in the value chain and improving the efficiency of inventory management. Promoting a zero inventory strategy or low inventory strategies of nodal enterprises in the value chain is an important component of implementing a green growth model, which plays an important role in realizing green growth. To realize green transformation, enterprises need to form a closed-loop system from product design to resource recovery and utilization, promote the efficient reuse and sustainable development of resources, and then implement the coordination of "green" and "growth". Therefore, inventory management and control play an important role in the green growth model and value chain reconstruction. Inventory control of the value chain can reduce resource waste and improve operational efficiency, which is an important component of the green growth model. To achieve green growth and a green value chain of enterprises through efficient inventory management, this chapter studies the significant influence of product return on the bullwhip effect and inventory costs under different value chain scenarios. We analyze the coordinated control measures of the bullwhip effect of the green value chain to decrease the inventory levels and inventory costs of enterprises. The analysis helps managers improve the efficiency of the green value chain and realize the green growth of enterprises.

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Chapter 12
Green Logistics

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Abstract Logistics is an important link connecting all operational activities of enterprises and has a significant impact on their growth and green initiatives. In contrast to traditional logistics, green logistics in enterprises' green growth model focus on achieving environmental friendliness while pursuing optimal efficiency of resource allocation in logistics and distribution activities. This chapter mainly covers four aspects. First, it briefly introduces the connotation and main implementation path of green logistics. Second, it presents the split routing optimization problem of low-carbon distribution with the optimization goal of reducing carbon emissions. And then, it presents the routing optimization problem of collaborative distribution in forward and reverse logistics considering multiple types of depots under complete information sharing. Finally, the routing optimization problem for hazardous materials distribution based on the principles of fatal incident avoidance is proposed.

12.1 Basic Framework and Implementation Paths of Green Logistics

12.1.1 Basic Framework of Green Logistics

The business environment, technologies, and business models have changed dramatically over the past decade. Consumer products have become more widely available.

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Technological advances have led to shorter product life cycles and a sharp rise in the number of discarded products. Consumers are increasingly emphasizing green consumption, and public expectations of environmental quality are growing. Environmental pressures have led to stringent environmental regulations, and environmental friendliness has become a key element for enterprises. In addition, information technology has promoted the development of the e-commerce model, due to which new logistics activities such as product return and remanufacturing have emerged. Green logistics is a key component for enterprises implementing the green growth model to achieve green transformation.

Green logistics has received considerable attention from academia. Some scholars define green logistics as an environmentally responsible logistics system, including both the greening of the forward logistics process from the acquisition of raw materials, production, packaging, storage, and transportation, until to end users; and the green management of the reverse logistics of waste recycling and disposal [1]. Green logistics is an environmentally friendly and effective logistics system, and its links are coordinated [2].

This book argues that green logistics is an important component in the implementation of enterprises' green growth model, which refers to an efficient, coordinated, safe, and low-carbon forward and reverse logistics system. The core of green logistics lies in resource intensification and environmental friendliness, that is, making full use of existing resources, optimizing resource allocation, reducing resource consumption, and improving resource utilization. The U.S. National Strategy for the Development of Transportation Science and Technology stipulates that the overall goal of the transportation industry structure or the progress of transportation science and technology is to establish a safe, efficient, adequate, and reliable transportation system with an international scope, comprehensive form, intelligent features, and environmentally friendly nature. Japan's "New Comprehensive Logistics Policy Outline" proposes to "build a logistics system that reduces environmental load and contributes to a recycling-oriented society." The European Union has also adopted a series of coordinated policies and measures to promote the standardization, sharing, and generalization of logistics systems to achieve the goal of resource conservation.

12.1.2 Relationship Between Green Logistics and Enterprises' Green Growth Model

The logistics industry is a significant source of carbon emissions. The report "Transport, Energy and CO_2: Towards Sustainable Development" released by the International Energy Agency shows that transportation contributes approximately 26% to global CO2 emissions. At the same time, waste recycling efficiency is low. As a result, the manufacturing and logistics cycle does not form a closed loop. A large amount of recycled resources is currently disposed of as garbage; thus, the supply and demand of solid waste treatment mismatch. Of the total hazardous waste in China, approximately 25% is treated.[1] The logistics and transportation environmental resource utilization efficiency is low in China. For example, China's current logistics empty load rate is as high as 40%,[2] resulting in serious resource wastage and environmental pollution. The greening of logistics is an inevitable requirement of the green development concept and national strategy of carbon neutrality.

The problem of high logistics costs is widespread in enterprises, especially manufacturing companies. A high proportion of logistics costs leads to high manufacturing costs. In China, logistics costs account for 15–30% of the total cost of steel products compared to 8–10% in developed countries.[3] Factors like "Ever Given" incident, the COVID-19 pandemic, logistics transportation for the "last mile", and other emergencies contribute to too much time being spent in logistics. A high percentage of logistics time leads to low manufacturing responsiveness to the market. In the entire production and sales value chain of goods, processing and manufacturing account for only 10% of the time, while logistics accounts for almost 90%. These logistics problems reflect the inefficient use of resources and have a negative impact on enterprises' green growth processes.

In addition, thanks to globalization, enterprises have built a system of global supply chains, which has enabled global circulation of resources, technologies, and products through division of labor. However, there are challenges to the smooth flow of logistics in a global supply chain in the face of serious risk events such as the "Ever Given" incident and disruptions in the supply chain caused by COVID-19 pandemic. The "Ever Given" incident led to a shortage of raw materials and components or sales shortages for many enterprises in Asia and Europe. COVID-19 has caused global manufacturing companies to face the broken value chains. The uncertainties of anti-globalization and COVID-19 have led to ineffective circulation of manufacturing and logistics, which directly affects the smooth economic operation and normal production order of enterprises and the green growth of enterprises.

Based on the new management philosophy of "Three Transmissions and One Feedback" of resources, energy, logistics, and information, we explore the green transformation of enterprises' growth models from the perspectives of resource quality transmission, energy transmission, logistics momentum transmission, and information feedback to meet the management challenges of value chain resilience, value chain quality, and value chain efficiency. Efficient, coordinated, safe, low-carbon, and green logistics is inevitable for enterprises to build a green growth model. Cainiao Logistics has built a green logistics solution for the whole chain, from order generation to parcel delivery, through the promotion of packing algorithms, intelligent path planning, environmental protection bags, and solar logistics parks. From November 1st to November 14th 2021, the Cainiao Logistics platform, enterprises, and consumers together generated 1.8 billion times green behavior, reducing carbon

[1] https://www.sohu.com/a/527231397_100012935.

[2] https://baijiahao.baidu.com/s?id=1597324356686911998&wfr=spider&for=pc.

[3] http://www.csteelnews.com/sjzx/hyyj/202104/t20210414_49107.html.

emission by 53,000 tons.[4] In rural areas, Cainiao Logistics has achieved collaborative distribution in more than 1000 counties across the country. Under the premise of improved parcel timeliness, Cainiao Logistics by sharing vehicles can reduce the fuel consumption of vehicles.[5]

12.1.3 The Implementation Paths of Green Logistics

The key to green logistics is to reduce the harm caused by logistics-related activities to the environment, while making full and reasonable use of various resources. This can be done in a few ways. First, by using clean energy as far as possible, which can be done by making carbon emission reduction the optimization goal of vehicle route planning, that is, low-carbon logistics. Second, by sharing transportation modes by using the next-generation information and communication technology to create a logistics sharing platform, optimizing transportation modes, sharing transportation resources, and maximizing the vehicle loading rate to improve the utilization rate of transportation resources, that is, collaborative logistics. Third, by paying attention to the management of transportation risks and minimizing the risk of hazardous materials, that is, the routing optimization problem for hazardous materials logistics.

Low-carbon logistics refers to the use of advanced science and technology, management methods, and transportation modes to reduce fuel consumption and exhaust emissions in the transportation process, to comprehensively improve transportation efficiency, achieve energy savings, reduce pollutant emissions, and achieve cost reduction and environmental protection and development. To reduce carbon emissions from logistics activities, all aspects of the logistics system must be optimized to promote low-carbon development of the economy, society, and the environment. Being mobile sources of carbon emissions, vehicles are important for energy saving and carbon reduction in logistics activities. However, relying solely on clean energy technologies for vehicles does not completely solve the environmental pollution problem in transportation. Therefore, using optimization methods to develop reasonable vehicle allocation and scheduling strategies is also essential to reduce environmental pollution. As a result, many scholars consider reduction in carbon emissions as the optimization goal, study the key constraints in the actual logistics process, and establish a mathematical model in line with logistics activities [3]. SF Express uses route optimization, new energy vehicles, photovoltaic equipment, energy-saving facilities, and other initiatives to reduce carbon emissions in transportation and transshipment. Simultaneously, the company has improved operational efficiency and reduced carbon emissions by promoting multimodal transportation,

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[4] https://www.dsb.cn/news-flash/84521.html.

[5] https://baijiahao.baidu.com/s?id=1709738908355396817&wfr=spider&for=pc.

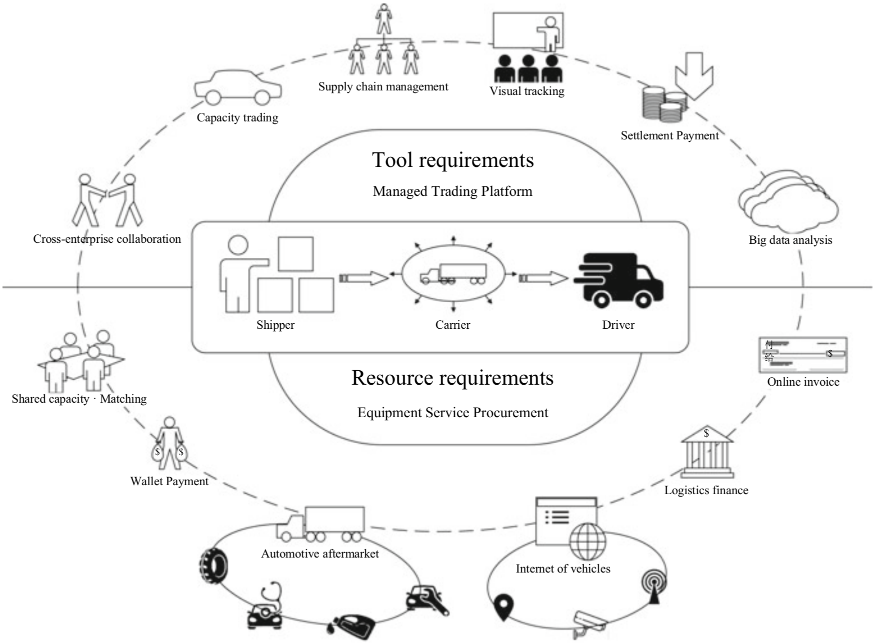

Fig. 12.1 Collaborative logistics

green packaging, intelligent enterprise management; and all green supply chain solutions to achieve an 11% reduction in carbon emissions through transportation and business model upgrades.[6]

As described in Chap. 3, through collaborative logistics, enterprises share customer order information and capacity resources, as shown in Fig. 12.1, and achieve the purpose of reducing costs and improving distribution efficiency and service level [4]. In collaborative logistics, there are two modes of information sharing: complete and incomplete. Under full information sharing, carriers in a cooperative alliance consolidate customer orders and centralize the distribution of customer orders through joint route planning tools. The economies of scale achieved by this approach can effectively reduce vehicle travel distance, empty vehicle rate, and number of shipments. When incomplete information is shared, each carrier in a cooperative alliance shares information about customer orders with other members, while identifying customer orders that can be exchanged in favor of other carriers, and finally determining the final service carrier for customer orders through an auction mechanism. Many carrier companies exchange customer orders through third-party logistics platforms to achieve cooperation, such as For-U Truck, Yunman, Nistevo, and TransPlace.

Hazardous material logistics refers to logistics activities carried out by specialized organizations and technicians to transport unconventional hazardous materials.

[6] https://www.sohu.com/a/539884296_484815.

Hazardous material logistics is an important link for transporting harmful materials to different regions, meeting the demands of enterprises and customers, and ensuring smooth operation of the industrial supply chain. In recent years, the transportation volume of hazardous materials has continued to increase. Hazardous materials include inflammables, explosives, poisons, and corrosives. If an incident occurs in logistics activities, it will cause serious consequences for the safety of life and property of personnel near the incident site. Unreasonable hazardous material logistics activities also harm the implementation of the green growth model. Even developed countries face a high risk of hazardous material logistics. According to statistics from the U.S. Department of Transportation, 6756 incidents have occurred during the transportation of hazardous materials in the United States in 2021, resulting in an economic loss of more than 46 million US dollars.[7] Therefore, decision-makers must consider how to reduce the risk of hazardous material logistics activities [5]. Increasing attention has been paid to the decision-making and optimization of hazardous material logistics. As distribution is a key activity in hazardous material logistics, many scholars have also conducted research on the multi-objective routing optimization problem for hazardous material distribution considering the minimization of risk and cost simultaneously.

12.2 Low-Carbon Logistics

12.2.1 Low Carbon Distribution

Logistics is often considered a significant source of global greenhouse gas (GHG) emissions and energy consumption. Vehicles emit significant amounts of carbon during transportation. According to a report by the International Energy Agency, transportation accounted for 26% of global CO_2 emissions in 2020. Therefore, logistics has become one of the key aspects of energy saving and emission reduction. Companies such as Procter & Gamble, Johnson & Johnson, Coca-Cola, Target, and Walmart are working with transportation companies to explore ways to reduce transportation carbon emissions.

Distribution is a core aspect of logistics. The vehicle route optimization problem with carbon emissions as the optimization objective is called the pollution routing problem. The pollution routing problem aims to reduce the carbon emissions generated by vehicles during transportation [6]. Bektas and Laporte first proposed the pollution routing problem in 2011 by considering vehicle fuel consumption, carbon emissions, and travel time [7]. Camacho-Vallejo et al. extended the pollution routing problem as a dual-objective problem by minimizing the operational cost and carbon emission cost [8]. Many scholars have studied the pollution routing problem based on

[7] https://www.phmsa.dot.gov/hazmat-program-management-data-and-statistics/data-operations/incident-statistics.

different logistics characteristics, such as demand uncertainty, time windows, fresh products, and multiple depots [9].

It is an inevitable requirement of time to introduce low-carbon technology into the logistics industry and lead it on a low-carbon path. “Low-carbon logistics” sprouted from the concept of “low-carbon,” expecting to achieve resource conservation and sustainable development. Low-carbon logistics technology is applied to all aspects of logistics activities. With low-carbon and environmental-friendly production methods, resources are saved and used efficiently; thus, enterprise logistics can achieve economic and environmental benefits by building a green growth model for enterprises.

12.2.2 Routing Optimization Problem for Low-Carbon Distribution

The low-carbon distribution routing optimization problem is usually a bi-objective optimization problem. This section generates a bi-objective splittable low-carbon distribution routing optimization problem. Given an undirected road traffic network $G\{V, E\}$, where $V = \{v_0, v_1, \ldots, v_n, \ldots, v_{n+m}, v_{n+m+1}\}$ is a set of nodes,v_0 denotes the distribution center of a transportation company, v_{n+m+1} is the replication point of the distribution center, and there are K transportation vehicles with the maximum loading capacity of Q in the distribution center. It is assumed that each vehicle route starts at the node v_0 and ends at the node v_{n+m+1}. The remaining nodes represent customers, and each customer v_i corresponds to a demand q_i and a shipping payment p_i. All customer demands can be split such that each customer point can be visited more than once. As CO_2 emissions are proportional to the amount of fuel consumed by a vehicle, this section converts the minimized carbon emissions in the objective function into minimized fuel consumption. f_{ij}^k denotes fuel consumption per unit distance that vehicle k travels on the side of $e(v_i, v_j)$, and we assume $f_{ij}^k = \rho_0 + \left(\frac{\rho^* - \rho_0}{Q}\right) l_{ij}^k$. Now, it is necessary to decide the distribution route of the transportation company to maximize the total profit and minimize the carbon emissions. Total profit is equal to total revenue minus total cost of a route. The symbolic representations involved in this problem are listed in Table 12.1.

12.2.3 Routing Optimization Model for Low-Carbon Distribution

Considering the problem objectives and constraints, the mathematical model is established as follows.

Table 12.1 Notations for the low-carbon distribution routing optimization problem

Parameters	
$G(V, E)$	Road traffic network, where V is the set of nodes, and E is the set of edges
V	Set of nodes in the network, where v_0 denotes distribution centers
d_{ij}	The distance of edge $e(v_i, v_j)$
l_{ij}^k	The load of vehicle k while driving on $e(v_i, v_j)$
ρ_0	Fuel consumption rate when the vehicle is empty
ρ^*	Fuel consumption rate when the vehicle is fully loaded
f_{ij}^k	Fuel consumption of vehicle k per unit distance on $e(v_i, v_j)$
c	Unit transportation cost
q_i	Demand of customers v_i
p_i	The shipping payment of customer v_i
Q	Maximum loading capacity of the vehicle
Decision variables	
x_{ij}^k	1 if the vehicle k passes through the side $e(v_i, v_j)$; 0 otherwise
z_i^k	The quantity of vehicles k deliveries to customers v_i

$$\max f_1 = \sum_{i=1}^{n+m} p_i - \sum_{i=0}^{n+m+1} \sum_{j=0}^{n+m+1} \sum_{k=1}^{K} c x_{ij}^k d_{ij} \tag{12.1}$$

$$\min f_2 = \delta_2 + \sum_{i=0}^{n+m+1} \sum_{j=0}^{n+m+1} \sum_{k=1}^{K} \left(\rho_0 x_{ij}^k + \left(\frac{\rho^* - \rho_0}{Q} \right) l_{ij}^k \right) d_{ij} \delta_1 \tag{12.2}$$

s.t.

$$\sum_{h=0}^{n+m+1} x_{hi}^k = \sum_{j=0}^{n+m+1} x_{ij}^k,\ i = (1, 2, \ldots, n+m+1),\ k = (1, 2, \ldots, K) \tag{12.3}$$

$$\sum_{k=1}^{K} \sum_{j=0}^{n+m+1} x_{ij}^k \geq 1,\ i = (1, 2, \ldots, n+m) \tag{12.4}$$

$$\sum_{h=0}^{n+m+1} l_{hi}^k - \sum_{j=0}^{n+m+1} l_{ij}^k = z_i^k,\ i = (1, 2, \ldots, n+m),\ k = (1, 2, \ldots, K) \tag{12.5}$$

$$z_j^k \leq l_{ij}^k \leq \left(Q - z_i^k\right),\ i = (1, 2, \ldots, n+m),\ j = (1, 2, \ldots, n+m),\ k = (1, 2, \ldots, K) \tag{12.6}$$

$$l_{ij}^k < x_{ij}^k Q, i = (1, 2, \ldots, n + m), j = (1, 2, \ldots, n + m), k = (1, 2, \ldots, K) \tag{12.7}$$

$$z_i^k \le q_i \sum_{j=0}^{n+m+1} x_{ij}^k, i = (1, 2, \ldots, n + m), k = (1, 2, \ldots, K) \tag{12.8}$$

$$\sum_{k=1}^{K} z_i^k = q_i, i = (1, 2, \ldots, n + m) \tag{12.9}$$

$$\sum_{i=1}^{n+m} z_i^k \le Q, k = (1, 2, \ldots, K) \tag{12.10}$$

$$\sum_{k=1}^{K} \sum_{i \in S} \sum_{j \in S} x_{ij}^k \le \sum_{k=1}^{K} \sum_{j=0}^{n+m+1} \sum_{i \in S} x_{ij}^k - 1,\ \ S \subset N \backslash \{0\}, |S| \ge 2 \tag{12.11}$$

$$x_{ij}^k \in \{0, 1\}, l_{ij}^k \ge 0, i = (1, 2, \ldots, n + m),$$
$$j = (1, 2, \ldots, n + m), k = (1, 2, \ldots, K) \tag{12.12}$$

$$z_i^k \ge 0, i = (1, 2, \ldots, n + m), k = (1, 2, \ldots, K) \tag{12.13}$$

The objective function (12.1) is to maximize total profit, where revenue includes transportation payments from service demand and cost is the transportation cost; and the objective function (12.2) is to minimize carbon emissions. Constraint (12.3) is the traffic conservation constraint; that is, any vehicle visiting a point must leave that point. Constraint (12.4) indicates that each customer node has been visited at least once. Constraints (12.5)–(12.7) indicate the real-time loading capacity of the vehicles. Constraint (12.8) is used to limit z_i^k to 0 before v_i receives vehicle service and to no more than that customer's demand after receiving service. Constraint (12.9) ensures that each customer's demand is met. Constraint (12.10) is the vehicle-loading constraint, constraint (12.11) is used to eliminate subloops, and constraints (12.12)–(12.13) constrain the values of decision variables.

12.2.4 ε-Constraint Hybrid Evolutionary Algorithm

The mathematical model developed in the previous section is a bi-objective mixed-integer programming model. This section proposes an ε-constraint hybrid evolutionary algorithm for solving the model. The bi-objective model is transformed into a single-objective problem using the ε-constraint method, and the greedy randomized adaptive search procedure (GRASP) and evolutionary local search (ELS) are combined to solve the transformed single-objective problem.

The ε-constraint method usually takes the objective with the highest priority as the objective function and transforms the other objective functions into constraints, thus transforming the multi-objective optimization problem into a single-objective problem for the solution. For the model proposed in this section, the profit function is taken as the objective function, and the carbon emission function is taken as the constraint to transform the multi-objective optimization problem into a single-objective problem, as follows: The Pareto solution set can be obtained by transforming the value of ε.

$$\max f_1 = \sum_{i=1}^{n+m} p_i - \sum_{i=0}^{n+m+1} \sum_{j=0}^{n+m+1} \sum_{k=1}^{K} c x_{ij}^k d_{ij} \tag{12.1}$$

s.t.
Constraints (12.3)–(12.12)

$$f_2 \le \varepsilon \tag{12.14}$$

To solve the above single-objective problem, this section designs the GRASP-ELS algorithm. A randomized nearest-neighbor heuristic algorithm is used to generate the initial travelling salesman problem (TSP) solution T, which is converted into a vehicle routing problem (VRP) solution S' by $Split$. If the number of vehicles used in the solution S' exceeds the vehicle limit, the number of vehicles is reduced to meet the limit by $Emptyroute$. The VRP solution is converted into a TSP solution T' by performing a neighborhood search on S' via LS, and then eliminating the distribution center nodes by concatenating the customer sequences of each path in S' via $Concat$.

The internally nested ELS loop performs ni iterations, with (T', S') as the starting solution. Each iteration generates nc solutions T as children of T', which are perturbed and split to obtain the VRP solution S and improved by $Emptyroute$ and LS. The solutions for the optimal children and their costs are noted as S'' and f''. If the optimal child is better than S', S' is updated. This provides a new pair of solutions to (T', S') for the next ELS iteration. At the end of each phase, the best ELS solution is used to update the global optimal solution S^*. The specific subroutine implementation is described below.

Split: For a TSP scheme called T with a sequence of n nodes, it is necessary to determine the division into paths as a solution. TSP scheme for n is alignment of client $T = \{t_1, \ldots, t_n\}$. We create an auxiliary weighted directed graph $H = \{X, A, Z\}$. X is the nodes in i range from 0 to n, where 0 is a virtual node and each non-zero node represents a customer t_i. For each customer subsequence,$(t_i, t_{i+1}, \ldots, t_j)$ in T, check if the path $(v_0, t_i, t_{i+1}, \ldots, t_j, v_0)$ is feasible, that is, its total load does not exceed the vehicle capacity Q. If the path is feasible, it is recorded as an arc $(i-1, j)$ in the arc group A and assigned a weight $Z_{(i-1,j)}$, where $Z_{(i-1,j)}$ is equal to total profit of the path. Its optimal splitting scheme corresponds to the path of maximum profit from node 0 to node n in H, and records this profit as p_n.

Empty routes: If the number of vehicles used in the current scenario exceeds the vehicle limit, empty the routes with the minimum load capacity. And insert the customers they contain into the remaining routes via $SplitReinsertion$ until the number of vehicles used in the current scenario meets the constraint. Assuming that customer v_i currently needs to be inserted into an existing path, first calculate the remaining capacity of each path r ar and if ar is greater than zero, add the path r to the list L. If the sum of the remaining capacities of all paths is insufficient for v_i, the process is aborted. Otherwise, for each path $r \in L$, compute the minimum additional cost ur of inserting a client v_i into the path r. This section uses a greedy algorithm to perform insertions in the increasing order of ur/ar until the demand of the customer v_i is fully satisfied.

LS: The current VRP solution S is improved based on the variable neighborhood search algorithm, and the neighborhood structure consists of the CVRP and SDVRP neighborhood structures. The CVRP neighborhood structure includes $swap(1, 1), swap(2, 1), swap(2, 2), shift(1, 0), shift(2, 0)$ and *cross*. The SDVRP neighborhood structure includes $swap(1, 1)^*$, $swap(2, 1)^*$, and $k - Split$.

Mutate: First, calculate the marginal profit of all customers in the current solution, then randomly select 4–6 customers with the smallest marginal profit to delete them, and finally use $SplitReinsertion$ to reinsert the deleted customers.

12.2.5 Numerical Results and Sensitivity Analysis

Five sets of randomly generated numerical cases with sizes of 10, 50, 75, 100, and 125 customer points are generated, and each set contains three cases of the same size for a total of 15 numerical cases. Distribution centers and customers are randomly generated in the interval [0,100], and the transportation distance between them is represented by the Euclidean distance. Customer's demand q_i is randomly generated in the interval [1,40], and the service price of the customer $p_i = \beta 40 q_i$, where β is the distance coefficient when the distance between the customer and the distribution center is greater than the average distance, $\beta = 1.1$; otherwise, $\beta = 1$. The loading capacity of vehicle Q is set to 40. The transportation cost per unit distance c is set to 2. A vehicle consumes 0.5 L/km when it is fully loaded and produces 2.79 kg of CO_2 per liter of diesel fuel. An empty vehicle's fuel consumption is 61% of a fully loaded vehicle's.

To prove the effectiveness of the algorithms in this section, the classical multi-objective NSGA-II algorithm is chosen to solve the model and compare the solution results of the two algorithms. Owing to the random nature of the heuristic algorithm, for each set of cases, the two algorithms are executed 11 times separately. To compare the solution effects of the two algorithms, the following two commonly used multi-objective evaluation methods are used.

(1) Hypervolume: A reference point is selected, which is generally the worst possible solution. The volume enclosing all points in the Pareto front that can dominate the reference point with the reference point is called the hypervolume. Hypervolume measures both the diversity and convergence of solutions. The larger the hypervolume, the better the set of non-dominated solutions obtained.
(2) Running time: The running time of an algorithm can measure its running efficiency.

The results of the comparison of hypervolume of the Pareto solution set obtained by the two algorithms are shown in Table 12.2. For each of the 15 cases, the supervolume obtained by the ε-constraint hybrid evolutionary algorithm outperforms that of the NSGA-II algorithm by a difference of 4.17%-23.98%. This indicates that the ε-constraint hybrid evolutionary algorithm has an advantage over the NSGA-II algorithm in terms of convergence and diversity. Table 12.1 compares the running times of the two algorithms. For each of the 15 algorithms, the running time of the ε-constraint hybrid evolution algorithm is shorter than that of the NSGA-II algorithm.

The results are shown in Fig. 12.2. When the transportation cost factor increases, total profit for the same carbon emissions case tends to decrease. In addition, when the transportation cost factor changes from 2 to 8, the average number of obtained non-dominated solutions decreases from 61.7 to 32.3, and the fluctuation range of the objective function values for both targets is reduced. This suggests that an increase in transportation costs weakens the conflict between total profit and carbon emissions. This is because as transportation costs increase, it is no longer profitable for

Table 12.2 Comparison of the hypervolume obtained by the two algorithms and the time used

Cases		Hypervolume			Calculation time (s)	
		ε-HEA	NSGA-II	Gap (%)	ε-HEA	NSGA-II
1	1	1889.17	1851.9	1.97	30.32	40.31
	2	1834.32	1802.3	1.75	29.26	39.21
	3	1913.8	1865.7	2.51	31.36	42.49
2	4	4678.92	4512.35	3.56	85.99	118.24
	5	4371.58	4218.63	3.50	81.23	116.75
	6	4459.61	4329.95	2.91	80.11	127.31
3	7	6747.92	6483.47	3.92	100.23	161.04
	8	6586.91	6271.29	4.79	101.96	150.34
	9	6483.54	6238.01	3.79	107.86	158.75
4	10	7611.1	7298.92	4.10	126.83	213.93
	11	7682.73	7337.3	4.50	128.26	208.72
	12	7531.28	7305.64	3.00	117.61	202.47
5	13	7896.71	7489.56	5.16	172.62	285.61
	14	8052.43	7587.63	5.77	187.41	274.15
	15	7973.38	7598.28	4.70	176.53	266.53

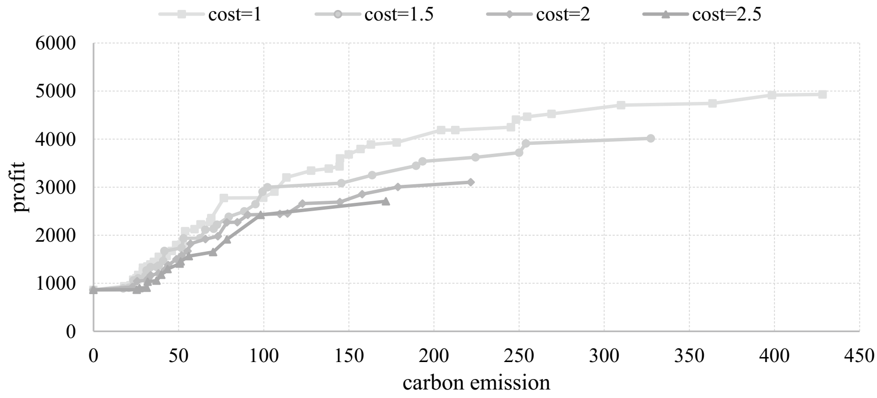

Fig. 12.2 Solution results under different transportation cost factors

a transportation company to serve some customers. Therefore, it will choose fewer customers to serve.

In this section, a demand-splittable routing optimization model with the dual objective of maximizing total profit and minimizing carbon emissions is developed for low-carbon distribution considering decentralized cooperation. An ε-constraint hybrid evolutionary algorithm combining ε-constrained and GRASP-ELS is proposed, and the advantages of the ε-constraint hybrid evolutionary algorithm over the NSGA-II algorithm are demonstrated by testing with multiple sets of cases using two evaluation methods. Then, a sensitivity analysis is performed to derive the management insight that an increase in transportation costs weakens the conflict between profit and carbon emissions.

12.3 Collaborative Logistics

12.3.1 Collaborative Distribution

Collaborative logistics is the process of providing services and coordinating all business activities using information technology to improve profits and performance by creating a collaborative environment in which companies share information and resources [10]. In collaborative logistics, multiple companies cooperate to build alliances and coordinate logistics activities to maximize the overall benefits [11]. Through cooperation, orders can be exchanged between customers to achieve more complementary transportation, reduce the phenomenon of empty trucks, and increase business efficiency, thus enhancing competitiveness [12]. Montoya-Torres et al.

discussed collaborative logistics in urban logistics and state that cooperative transportation can help achieve economies of scale and reduce transportation costs by 25.6% [13].

Facing fierce competition and shrinking profit margins in the logistics industry, enterprises seek to strengthen their cooperation with other transport enterprises and explore the use of collaborative distribution to reduce logistics costs and improve enterprise efficiency. Under complete information sharing, the participating carriers share all customer order information and solve the vehicle routing problem by centralized decision-making [14]. With increasing awareness of environmental protection and reverse logistics, resource recycling has developed rapidly. The selection of vehicle paths in the process of forward and reverse logistics has a significant impact on reducing the cost of logistics activities. In this section, the routing optimization problem of forward and reverse logistics for collaborative distribution, considering multiple types of depots, is studied under complete information sharing.

12.3.2 Routing Optimization Problem for Collaborative Distribution

This section considers the cooperation of carriers in forward and reverse logistics. A forward logistics carrier M_1 and a reverse logistics carrier M_2 form a cooperative alliance $M = M_1 \cup M_2$ to combine pickup and delivery customer orders and jointly plan vehicle routes. Let NC_m denote the set of customers of the carrier $m \in M$, $NC = \bigcup_{m \in M} NC_m$ denote the set of customers of the cooperative alliance, and s_i and t_i denote the product depot and recycle depot of the customer $i \in NC$, respectively. The forward logistics carrier $m \in M_1$ picks up new products of d_i weight from the product depot and distributes them to the customer $i \in NC_m$. The reverse logistics carrier $m \in M_2$ collects the used product weight p_i from its customer $i \in NC_m$ and returns it to the recycle depot t_i. This section presents a new class of collaborative vehicle routing problem that satisfies the customer needs of all carriers by rationalizing the route of vehicles with the goal of minimizing the overall transportation cost of the cooperative alliance. In this collaborative vehicle routing problem, each customer is visited once, each product depot and recycle depot can be visited by vehicles multiple times, different customers with the same distribution product demand are supplied by the same product depot, and the same used products recovered from different customers are transported to the same recycle depot. Consider a collaborative distribution network of multiple types of depots as shown in Fig. 12.3.

The following assumptions are made regarding this issue.

(1) No transfer between vehicles is allowed, and each customer must be served by only one vehicle.
(2) As multiple carriers may share the same product depot and recycle depot, the demand for new products from the product depot or the return of used products from the recycle depot may exceed the vehicle capacity limit. Therefore, this

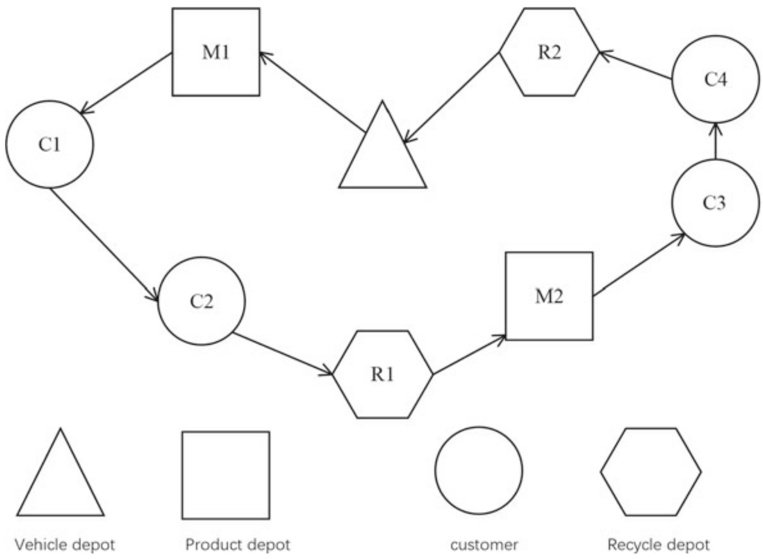

Fig. 12.3 Collaborative distribution network

issue allows each product depot and recycle depot to be visited multiple times by a fleet but at most once per vehicle.

(3) Each distribution order has only one specific product depot, and each recycling order has only one designated product recycling depot.

(4) Each vehicle must return to the vehicle depot after departing from the depot and completing the transportation task.

The parameters involved in the mathematical model are shown in Table 12.3.

12.3.3 Routing Optimization Model for Collaborative Distribution

Based on the above analysis, the forward and reverse logistics collaborative distribution vehicle routing optimization model considering multiple types of depots is expressed as follows:

$$\min \sum_{v \in NV} \sum_{i \in N} \sum_{j \in N, j \neq i} c_{ij} x_{ij}^v \tag{12.15}$$

s.t.

$$\sum_{j \in N, j \neq i} x_{ij}^v \leq 1, \quad \forall i \in O, v \in NV \tag{12.16}$$

Table 12.3 Notations for the collaborative distribution routing optimization problem

Parameters	
M	The set of carriers, $m \in M$
O	The set of vehicle depots
NC	The set of customers, $NC = \underset{m \in M}{\cup} NC_m$
NP	The set of product depots, $NP = \underset{m \in M_1}{\cup} \underset{i \in NC_m}{\cup} \{s_i\}$
NR	The set of recycle depots, $NR = \underset{m \in M_2}{\cup} \underset{i \in NC_m}{\cup} \{t_i\}$
N	The set of all nodes in the distribution network, $N = O \cup NC \cup NP \cup NR$
c_{ij}	Distance traveled by the vehicle from the node $i \in N$ to $j \in N$, $j \neq i$
NV	The set of vehicles in carrier alliances
Q	The capacity of vehicle
α_{ij}	1 if $i = j, i, j \in NP \cup NR$; 0 otherwise
β_{jk}	1 if $k = s_j$ or $k = t_j$, $j \in NC, k \in NP \cup NR$; 0 otherwise
Decision variables	
x_{ij}^v	1 if vehicle $v \in NV$ is going from node $i \in N$ to node $j \in N$, $j \neq i$; 0 otherwise
lp_{ki}^v	Product load of each vehicle $v(v \in NV)$ at each node i,$i \in N$, $k \in NP$
lr_{ki}^v	Recycle load of each vehicle $v(v \in NV)$ at each node i,$i \in N$, $k \in NR$
q_i^v	Virtual load of vehicle $v(v \in NV)$ after visiting node i,,$i \in N$

$$\sum_{v \in NV} \sum_{j \in N, j \neq i} x_{ij}^v = 1, \ \forall i \in NC \tag{12.17}$$

$$\sum_{j \in N, j \neq i} x_{ij}^v = \sum_{j \in N, j \neq i} x_{ji}^v, \forall i \in N, v \in NV \tag{12.18}$$

$$\sum_{j \in N, j \neq i} x_{ij}^v \leq \sum_{j \in N, j \neq s_i} x_{s_i,j}^v, \forall i \in NC, v \in NV \tag{12.19}$$

$$\sum_{j \in N, j \neq i} x_{ij}^v \leq \sum_{j \in N, j \neq t_i} x_{j,t_i}^v, \forall i \in NC, v \in NV \tag{12.20}$$

$$lp_{kj}^v \geq lp_{ki}^v + \sum_{h \in NC, s_h = j} \sum_{i \in N} x_{ih}^v \cdot d_h \cdot \alpha_{jk} - Q \cdot (1 - x_{ij}^v),$$
$$\forall i \in N, j, k \in NP, i \neq j, v \in NV \tag{12.21}$$

$$lp_{kj}^v \geq lp_{ki}^v - d_j \cdot \beta_{jk} - Q \cdot (1 - x_{ij}^v), \forall i \in N, j \in NC, k \in NP, i \neq j, v \in NV \tag{12.22}$$

$$lr_{kj}^v \geq lr_{ki}^v - \sum_{h \in NC, t_h = j} \sum_{i \in N} x_{ih}^v \cdot p_h \cdot \alpha_{jk} - Q \cdot (1 - x_{ij}^v),$$

$$\forall i \in N, j, k \in NR, i \neq j, v \in NV \tag{12.23}$$

$$lr_{kj}^{v} \geq lr_{ki}^{v} + p_j \cdot \beta_{jk} - Q \cdot (1 - x_{ij}^{v}), \forall i \in N, j \in NC, k \in NR, i \neq j, v \in NV \tag{12.24}$$

$$lp_{ji}^{v} + lr_{ki}^{v} = 0, \forall i \in O, j \in NP, k \in NR, v \in NV \tag{12.25}$$

$$0 \leq \sum_{k \in NP} lp_{ki}^{v} + \sum_{k \in NR} lr_{ki}^{v} \leq Q, \forall i \in N \backslash O, v \in NV \tag{12.26}$$

$$q_j^v \geq q_i^v + 1 - N(1 - x_{ij}^{v}), \forall i \in N, j \in N, j \neq i, v \in NV \tag{12.27}$$

$$x_{ij}^{v} \in \{0, 1\}, \forall i, j \in N, v \in NV \tag{12.28}$$

$$0 \leq lp_{ki}^{v} \leq Q, \forall i \in N, k \in NP, v \in NV \tag{12.29}$$

$$0 \leq lr_{ki}^{v} \leq Q, \forall i \in N, k \in NR, v \in NV \tag{12.30}$$

$$1 \leq q_i^v \leq N, \forall i \in N, v \in NV \tag{12.31}$$

The objective function (12.15) is to minimize the overall transportation cost of the carrier alliance. The constraint (12.16) indicates that each vehicle must depart from the vehicle depot at most once. Constraint (12.17) indicates that each customer must and can only be visited once. Constraint (12.18) indicates that vehicle access is balanced. Constraints (12.19) and (12.20) indicate that a vehicle must visit the corresponding product depot before visiting a customer, and the corresponding recycle depot after visiting a customer. Constraints (12.21)–(12.24) indicate that the load flow of vehicles is balanced at each point. Constraint (12.25) indicates that a vehicle leaves the vehicle depot empty and returns to the vehicle depot empty. Constraint (12.26) indicates that a vehicle load cannot exceed the vehicle capacity limit. Constraint (12.27) indicates the subloop elimination constraint, which is used to eliminate the subloops in this problem. Constraints (12.28)–(12.31) denote the properties of all variables and their upper and lower bounds, respectively.

12.3.4 GRASP-ILS

As the problem presented in this section is NP-hard, this section proposes a hybrid algorithm (GRASP-ILS) that combines a greedy randomized adaptive search procedure (GRASP) and an iterative local search algorithm (ILS). The GRASP algorithm is a multistart iterative process, where each iteration consists of two phases: construction and local search. The ILS algorithm is a simple and efficient method for solving various combinatorial optimization problems. A local search is performed starting from an initial solution, and the processes of perturbation, local search, and acceptance of new solutions are then performed iteratively. To avoid getting trapped in a local optimum, the ILS algorithm perturbs the current locally optimal solution with the help of a perturbation mechanism to generate a new solution and then performs a local search on the new solution. Algorithm 12.1 shows the main flow of the GRASP-ILS algorithm.

Algorithm 12.1

Step 1. Given the initial parameters, including the maximum number of iterations *np in the* GRASP phase and the maximum number of iterations *ni in the* ILS phase, make $f^* = +\infty, i, j = 0$.
Step 2. Generate the initial solution via *GenerationInitialSolution()* S^0.
Step 3. Make initial improvements to S^0 via *LocalSearch().*
Step 4. Make the current solution $S = S^0$.
Step 5. Apply perturbations to S, $S{:} = Perturbation(S)$.
Step 6. Start the local search process from S, $S := LocalSearch(S)$.
Step 7. If $f(S) < f(S^0)$, then $S^0 = S$.
Step 8. Make $j = j + 1$.
Step 9. If $j < ni$, proceed to Step 4; otherwise, proceed to Step 10.
Step 10. If $f(S^0) < f^*$, then $f^* = f(S^0)$, $S^* = S^0$.
Step 11. Make $i = i + 1$. If $i < np$, go to Step 2; otherwise, output the current optimal solution, S^*.

The initial solution construction phase is a cyclic iterative process that generates feasible solutions for the problem. Each iteration forms a restricted candidate list (RCL) based on greedy function values and randomly selects elements from it to form a feasible solution. Before each iteration, the number of vehicle paths $l = 0$ and customer set CL are initialized. Each iteration selects some elements from the CL to form the RCL according to certain evaluation rules, randomly selects an element from the RCL to form a feasible solution, and finally updates the CL while re-evaluating each element.

During the iterative process, the RCL construct is used to select the elements based on the value of the greedy function. For each element i in CL, the greedy evaluation function $c(r^l, i, j)$ is applied to evaluate the minimum insertion cost of inserting client i into path r^1 after element j. If an element cannot be inserted into the current path, its insertion cost is set to a very large positive number. The minimum and maximum insertion costs are denoted as $c^{\min}$ and $c^{\max}$, respectively, based on the insertion cost of all elements in the current path r^1. Elements with insertion costs in the range of $\left[c^{\min}, \lambda \cdot (c^{\max} - c^{\min})\right]$ are selected and added to the RCL, where the threshold parameter is $\lambda \in [0, 1]$. A customer point is randomly selected from the RCL and inserted into the current path. If the customer cannot be inserted into any position in the current path because it does not satisfy the vehicle capacity constraint or cannot satisfy the sequential service order constraint, a new path is constructed. If a minimum cost insertion position is found in the current path, the element is removed from the CL. In addition, we judge whether the CL set is empty if $CL = \phi$, then terminate the initial solution generation algorithm and output the feasible initial solution; otherwise, continue to execute the algorithm.

The local search parts of GRASP and the ILS play an important role in improving the quality of the final solution. Usually, the local search process explores all or some of the neighbors of the current solution and then moves to the best or first improved solution. The order in which different neighborhood structures are searched is important for jumping out of the local optimum and saving computation time. To improve search efficiency, this section adopts a random search of neighborhood structures in the local search phase of GRASP-ILS.

12.3.5 Numerical Results and Sensitivity Analysis

As the problem studied in this chapter is new, there are no standard numerical examples in the literature that can be directly used to evaluate the effectiveness of GRASP-ILS and to determine the benefits of collaborative logistics. Therefore, this section generates randomly generated cases of different sizes and distribution areas. The GRASP-ILS algorithm proposed in this chapter is tested, and the impact of the geographic distribution areas of customers and the number of customer orders on cooperative transportation benefits are analyzed.

In this problem, three carriers are considered for cooperative transportation, such that $|O| = 1, |NP| = 2, |NR| = 1$. The generated cases included Set A, Set O, and Set I, depending on the distribution of customers in three categories: connected, overlapping, and coincident. The total number of cases in each group is 40, including 10 cases with a size of 20 customer orders, 10 cases with a size of 40 customer orders, 10 cases with a size of 60 customer orders, and 10 cases with a size of 100 orders, where the number of customer orders is the number of customers each carrier has. To test the effectiveness of the GRASP-ILS algorithm, the results are compared with GRASP and ILS calculations. Table 12.4 shows the notations and descriptions of the indicators used to evaluate the effectiveness of the algorithm.

To fairly compare the effectiveness of the three algorithms, the computation time of the three algorithms is made equal. Table 12.5 shows the average comparison results of the three algorithms. For the case of 20 customer orders, GRASP-ILS is more effective than GRASP and ILS, with average improvements of 5.34% and 2.57%, respectively, in terms of computation results. When the number of customer orders increases to 40, GRASP-ILS provides better solutions than GRASP and ILS, with an average percentage improvement of 4.57% and 3.52%, respectively. For the case of 60 customer orders, GRASP-ILS calculations can achieve the largest percentage improvement value of 5.95% compared to the GRASP results and can provide a better solution than ILS with an average percentage improvement of 2.67%. When the number of customer orders increases to 100, GRASP-ILS can obtain better

Table 12.4 Algorithm evaluation index notations

Notations	Description
Zmin	The best feasible solution for each metaheuristic run 10 times
$Imp_{\text{GRASP- ILS,GRASP}}$	$Z_{\min,GRASP-ILS}$ improvements to $Z_{\min,GRASP}$.$(Z_{\min,GRASP} - Z_{\min,GRASP-ILS})/Z_{\min,GRASP-ILS} * 100\%$
$Imp_{\text{GRASP- ILS,ILS}}$	$Z_{\min,GRASP-ILS}$ improvements to $Z_{\min,ILS}$. $(Z_{\min,ILS} - Z_{\min,GRASP-ILS})/Z_{\min,GRASP-ILS} * 100\%$
N_v	Average total number of vehicles
ϕ	Percentage of total cost savings for carrier collaborative,$\phi = (\text{Cos}\, t_N - \text{Cos}\, t_C)/\text{Cos}\, t_N * 100\%$

Table 12.5 Average calculation results of GRASP, ILS, and GRASP-ILS

Set of cases	$Imp_{\text{GRASP-ILS, GRASP}}$	$Imp_{\text{GRASP-ILS, ILS}}$
I20	6.51	3.17
O20	1.87	0.86
A20	7.65	3.68
Average value	5.34	2.57
I40	3.95	3.71
O40	3.00	3.23
A40	6.75	3.62
Average value	4.57	3.52
I60	4.09	2.65
O60	7.42	0.73
A60	6.35	4.64
Average value	5.95	2.67
I100	7.20	4.19
O100	6.59	3.78
A100	5.00	4.06
Average value	6.26	4.01

solutions than GRASP and ILS, with an average percentage improvement of 6.26% and 4.01%, respectively. Therefore, GRASP-ILS is significantly more effective than GRASP and ILS for all cases tested with the same computation time.

This subsection analyzes the impact of the geographic distribution of customers and the number of customer orders on the collaborative transportation benefits. The evaluation metrics Nv and ϕ indicate the number of vehicles used in each scenario and the percentage of cost savings achieved through cooperation between the carriers. Tables 12.4 and 12.5 indicate the impact of the customer distribution area and number of customer orders on collaborative transportation benefits, respectively.

In Table 12.6, the mean values of ϕ are 22.57%, 17.90%, and 10.76% for the numerical set I, O, and A with 20 customer orders, respectively, while the mean

Table 12.6 Impact of customer geographical distribution area on synergistic transportation benefits

Geographical distribution of customers	Before cooperation	After cooperation	ϕ
	Nv	*Nv*	
I20	4.3	2.3	22.57
O20	4.1	2	17.90
A20	4.2	2.1	10.76
I40	8	6	31.02
O40	7.3	3.5	24.19
A40	7.5	3.9	16.35
I60	11	6.3	33.31
O60	10.1	4.9	28.22
A60	10.1	5.2	24.42
I100	17.8	9.8	41.37
O100	14.1	8.4	33.79
A100	13.8	8.7	30.96

values of ϕ have the same trend for the numerical set I, O, and A with 40 customer orders, 60 customer orders, and 100 customer orders. From the statistical results, it is found that the numerical cases with closer customer distribution area distances always produce higher synergy gains than the cases with farther customer area distances, and the synergy benefit continues to decrease from the set of cases I to O and from the set of numerical cases O to A. This is because the higher the overlap of customer distribution areas, the closer the physical distance of customer orders, and similar customer orders are completed by one vehicle of the same carrier as far as possible, which can reduce the overlapping transportation routes of different carriers, reduce the phenomenon of duplicated vehicle transportation, and thus reduce the overall transportation cost.

In Table 12.7, the percentage increase in cost savings is observed by comparing the 20-customer order case with the 40-customer order case. The same observation can be used to compare the 40-customer order case, 60-customer order case, and 100-customer order case. For example, for the same type of customer geographic distribution, the average percentage of cost savings achieved by inter-carrier collaboration are 22.57%, 31.02%, 33.31%, and 41.37%, respectively. This indicates that the higher the number of customer orders involved in the collaborative transportation of carriers, the higher the benefits of their collaboration, which is due to the fact that the larger the number of customer orders, the larger the size of the transportation network and the greater the economies of scope generated. The more aggregated a carrier's customers, the higher their percentage of cost savings.

Tables 12.6 and 12.7 show that through cooperation, the average number of vehicles used by all carriers is reduced to almost half of the total number of vehicles used by carriers otherwise. Thus, collaborative transportation planning in forward

Table 12.7 Impact of the number of customer orders on synergistic transport benefits

Number of customer orders	Before cooperation	After cooperation	ϕ
	Nv	Nv	
I20	4.3	2.3	22.57
I40	8.0	6	31.02
I60	11	6.3	33.31
I100	17.8	9.8	41.37
O20	4.1	2	17.90
O40	7.3	3.5	24.19
O60	10.1	4.9	28.22
O100	14.1	8.4	33.79
A20	4.2	2.1	10.76
A40	7.5	3.9	16.35
A60	10.1	5.2	24.42
A100	13.8	8.7	30.96

and reverse logistics can significantly improve vehicle utilization and reduce logistics costs. When multiple forward and reverse logistics carriers have the same or overlapping customer distribution areas, it makes sense to serve a large number of customer orders and have larger transportation networks. This is because the higher the potential for synergistic transportation between carriers, the greater the synergistic transportation benefits achieved by cooperating with each other.

In this section, we focus on the actual situation of the distribution network, considering multiple types of depots in the cooperative transportation of forward and reverse logistics. To minimize the overall transportation cost of the cooperative alliance, a single-level cooperative routing optimization model considering multiple types of depots is established, and the GRASP-ILS algorithm is designed to solve the problem. Finally, the effectiveness of the GRASP-ILS algorithm proposed in this section is verified by comparing the best solution obtained by GRASP-ILS with the GRASP and ILS algorithms through extensive numerical experiments. Through sensitivity calculation experiments, the impact of the carrier's customer distribution area and the number of customer orders handled by the carrier due to the benefits of cooperative transportation are analyzed to provide the following management insights. First, the higher the overlap in various carriers' customer distribution areas, that is, the closer the physical distance, the more benefits can be realized through cooperative transportation. Second, the greater the number of customer orders served by a carrier and the larger the scale of the transportation network, the greater the complementarity between customer orders under full information sharing and the greater the synergistic benefits achieved by adopting the synergistic transportation model.

12.4 Hazardous Materials Logistics

12.4.1 Hazardous Materials Distribution

Distribution is a key activity in hazardous material logistics. Owing to their characteristics, risk is one of the most important factors to consider in the decision-making of hazardous materials distribution. Erkut et al. sorted out the measurements of risk; the most commonly used measurement is to define risk as the product of an incident's possibility and its likely consequence [15]. Whether the routing plan is reasonable is significant for hazardous materials distribution. If the routing plan is not reasonable, it increases the risks and causes extreme adverse effects. Therefore, the routing optimization problem for hazardous materials distribution is usually defined as a bi-objective vehicle routing optimization problem, in which one objective is to minimize the transportation cost and the other objective is to minimize the risk [16].

In recent years, increasing attention has been paid to the routing optimization problem for hazardous materials distribution, and scholars have also conducted a series of research works. For example, Wang et al. considered avoiding the situation of a particularly high risk of a certain vehicle, developed a bi-objective routing optimization model for hazardous materials distribution by minimizing the maximum risk of each vehicle, and developed a two-stage solution method [17]. Bula et al. developed a bi-objective routing optimization model for hazardous materials distribution with time windows, simultaneously minimizing the transportation cost and risk. They proposed two solution methods: the multi-objective neighborhood search method and the heuristic approach based on the ε-constraint method [18]. Zhang et al. defined risk based on the actual load and studied the vehicle routing problem for hazardous materials distribution combined with this measurement of risk [5]. Ghaderi et al. optimized the routes of hazardous materials distribution in a bimodal transportation network. They developed a two-stage stochastic routing optimization model and compared it with the maximum likelihood sampling, sample average approximation, and hybrid algorithm [19]. Zhang et al. studied vehicle routing optimization for hazardous materials distribution considering failed edges after incidents. They constructed a two-stage decision-making framework, proposed two different strategies to deal with failed edges, and developed bi-objective routing optimization models and corresponding algorithms for both strategies [20].

12.4.2 Routing Optimization Problem for Hazardous Materials Distribution

The routing optimization problem for hazardous materials distribution is usually defined as a bi-objective routing optimization problem that considers minimizing risk and cost simultaneously. This section proposes a routing optimization problem for hazardous materials distribution based on the principles of fatal incident avoidance. The problem is described as follows.

Provide a transportation network that includes a distribution center and customers. The distances between any two vertices are known. Each customer demands hazardous materials, and the distribution center has a certain number of vehicles. The vehicles start from the distribution center to distribute hazardous materials to each customer, and finally return to the distribution center. The problem is defined as: How to decide the route of each vehicle with the objective of minimizing transportation cost and risk simultaneously. The assumptions for this problem are explained below.

(1) The number of vehicles in the distribution center is sufficient to meet the needs of the distribution.
(2) Each customer can be visited only once, and the demands of all the customers must be met.
(3) Based on the principles of fatal incident avoidance, the risk is defined as the maximum incident consequence during the distribution.
(4) The incident consequences are related to the actual loads of the vehicles.

The notations for this problem are shown in Table 12.8.

Table 12.8 Notations for the routing optimization problem for hazardous materials distribution

Parameters	
$G(V, E)$	Transportation network, where V is the set of vertices, E is the set of edges
$V = \{v_0, v_1, \ldots, v_n\}$	Set of vertices, where v_0 is the distribution center, $v_1, v_2, \ldots, v_n$ are the customers
r_{ij}	Risk of $e(v_i, v_j)$
D_{ij}	Incident consequence of $e(v_i, v_j)$
l_{ij}	Distance of $e(v_i, v_j)$
c	Unit transportation cost
q_i	Demand of customer v_i
Q	Capacity of vehicles
Pop_{ij}	Population exposure of $e(v_i, v_j)$
s^{λ}	Consequence caused by each unit amount of hazardous material λ
K	Number of vehicles
M	A large enough positive number
Decision variables	
x_{ijk}	0–1 variable, if vehicle k passes through $e(v_i, v_j)$, it equals to 1
y_{ij}	The actual load of the vehicle on $e(v_i, v_j)$
u_{ik}	The actual load of vehicle k when leaving v_i

12.4.3 Routing Optimization Model for Hazardous Materials Distribution

(1) Risk Assessment

Risk is one of the most important factors in the decision-making of hazardous materials distribution. The most common way to understand risk is to see it as the product of an incident's possibility and its likely consequence. However, it is contrary to the principles of fatal incident avoidance to interpret risk in this manner. The low expected value of risk is likely to come from the low incident possibility. However, the low incident possibility does not mean that incidents are completely impossible. Once an incident occurs in a place with significant consequences, it can cause serious damages. Therefore, in the routing optimization problem for hazardous materials distribution based on the principles of fatal incident avoidance, the risk is defined by an incident's consequences. Thus, the risk should be $r_{ij} = D_{ij} = Pop_{ij}s^{\lambda}y_{ij}$, and the objective to minimize the risk should be $\min \max_{i,j} r_{ij} = \min \max_{i,j} Pop_{ij}s^{\lambda}y_{ij}$.

(2) Mathematical Model

Integrating the above analysis with the objectives and constraints of the problem, the routing optimization model for hazardous materials distribution is developed as follows:

$$f_1 = \min \max_{i,j} r_{ij} \tag{12.32}$$

$$f_2 = \min \sum_{i=0}^{n} \sum_{j=0}^{n} \sum_{k=1}^{K} cl_{ij} x_{ijk} \tag{12.33}$$

s.t.

$$\sum_{h=0}^{n} x_{hik} = \sum_{j=0}^{n} x_{ijk} \quad (i = 0, 1, \ldots, n; k = 1, 2, \ldots, K) \tag{12.34}$$

$$\sum_{h=0}^{n} \sum_{k=1}^{K} x_{hik} = 1 \quad (i = 1, 2, \ldots, n) \tag{12.35}$$

$$u_{ik} \le Q \quad (i = 0, 1, \ldots, n; k = 1, 2, \ldots, K) \tag{12.36}$$

$$u_{jk} + q_j - u_{ik} \le (1 - x_{ijk})M \quad (i = 0, 1, \ldots, n;\ j = 1, 2, \ldots, n; k = 1, 2, \ldots, K) \tag{12.37}$$

$$u_{jk} + q_j - y_{ij} \le (1 - x_{ijk})M \quad (i = 0, 1, \ldots, n;\ j = 1, 2, \ldots, n; k = 1, 2, \ldots, K) \tag{12.38}$$

$$r_{ij} = Pop_{ij} s^{\lambda} y_{ij} \quad (i = 0, 1, \ldots, n;\ j = 1, 2, \ldots, n) \tag{12.39}$$

$$x_{ijk} \in \{0, 1\};\ u_{ik}, y_{ij} \geq 0 \quad (i = 0, 1, \ldots, n;\ j = 0, 1, \ldots, n;\ k = 1, 2, \ldots, K) \tag{12.40}$$

Objective function (12.32) minimizes the risk. Objective function (12.33) minimizes the transportation cost. Constraint (12.34) indicates that each vehicle must leave after visiting each customer and finally return to the distribution center. Constraint (12.35) ensures that each customer is visited only once. Constraint (12.36) indicates the capacity of vehicles. Constraints (12.37) and (12.38) represent the actual loads of vehicles. Constraint (12.39) expresses the risk. Constraint (12.40) is the value range of the decision variables.

12.4.4 Improved ε-Constraint Method

The routing optimization model for hazardous materials distribution in the previous subsection is a bi-objective optimization model. The solution process is more complex than that of a single-objective optimization model. The most commonly used method in related studies is the weighting method, which combines various objectives into a single objective by weighting. However, it is extremely difficult to generate all Pareto optimal solutions using the weighting method [17]. The ε-constraint method is an efficient method for solving multi-objective optimization problems and can theoretically obtain the complete Pareto front. Therefore, based on the basic concept of the ε-constraint method, this section develops an improved ε-constraint method with several improvements to solve the routing optimization problem for hazardous materials distribution.

(1) Classical ε-Constraint Method

The ε-constraint method transforms the original problem into a single objective subproblem P0 with ε-constraints, as shown below.

Problem P0:

$$f_2 = \min \sum_{i=0}^{n} \sum_{j=0}^{n} \sum_{k=1}^{K} cl_{ij} x_{ijk} \tag{12.33}$$

s.t.
Constraints (12.34)–(12.40)

$$\max_{i,j} r_{ij} \leq \varepsilon \quad (i = 0, 1, \ldots, n;\ j = 1, 2, \ldots, n) \tag{12.41}$$

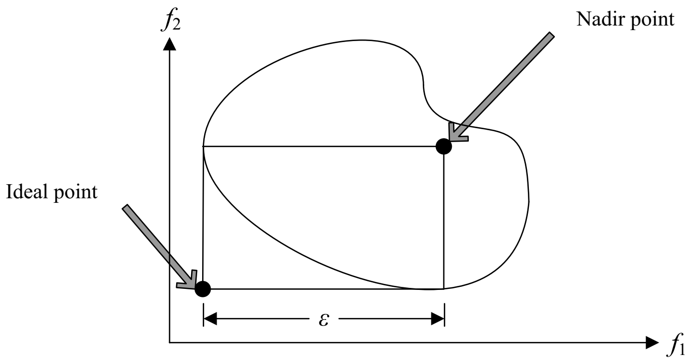

Fig. 12.4 Ideal point and nadir point

Then, the ideal point (f_1^I, f_2^I) and nadir point (f_1^N, f_2^N) as shown in Fig. 12.4 need to be determined, and the range of ε is determined accordingly. Problem P0 is solved several times by changing the value of ε. Finally, the Pareto front can be obtained by deleting the dominated solutions. The detailed steps are as follows.

Step 1: Compute (f_1^I, f_2^I) and (f_1^N, f_2^N).
Step 2: Let $Y' = \{(f_1^N, f_2^I)\}$, $\varepsilon = f_1^N - \delta$, where δ is a small enough positive number.
Step 3: Solve Problem P0 and obtain the solution x^*. Add $(f_1(x^*), f_2(x^*))$ to Y'.
Step 4: Let $\varepsilon = f_1(x^*) - \delta$. If $\varepsilon < f_1^I$, go to the next step. Else, go to Step 3.
Step 5: Delete the dominated solutions from Y' and obtain the Pareto front Y.

(2) Fast method for Determining the Range of ε

Let us use ε_L and ε_U to represent the lower and upper bounds of ε. The classic ε-constraint method needs to solve the subproblems of the original problem with f_1 and f_2, respectively, to obtain the range of ε_L and ε_U. However, this method requires a long computation time. Here, a fast method for obtaining the lower and upper bounds of ε for the routing optimization model for hazardous materials distribution is proposed.

First, let us discuss the lower bound of ε. $Pop_{ij}s^{\lambda}$ is a unit incident consequence of $e(v_i, v_j)$. srp_{0i} is used to represent the route from the distribution center to the customer, minimizing the maximum unit incident consequence. The following property is obtained.

Property 12.1 The lower bound of the maximum incident consequence is $\max_i w(srp_{0i})q_i$, where $w(srp_{0i})$ is the maximum unit incident consequence of srp_{0i}.

Proof The incident consequence is related to the unit incident consequence of the incident edge and actual load of the incident vehicle. First, as all customers' demands must be met, and the actual load of the vehicle to serve customer v_i is at least q_i. Second, as srp_{0i} is the route that minimizes the maximum unit incident consequence, the minimum incident consequence of the vehicle serving customer v_i is at least $w(srp_{0i})q_i$. In summary, the lower bound of the maximum incident consequence during the distribution is $\max_i w(srp_{0i})q_i$.

According to Property 1, the lower bound of ε is $\max_i w(srp_{0i})q_i$. The only unknown parameter in $\max_i w(srp_{0i})q_i$ is $w(srp_{0i})$. srp_{0i} must be computed to obtain $w(srp_{0i})$. srp_{0i} belongs to the route that minimizes the maximum weight, which must be located on the minimum spanning tree of the network. The minimum spanning tree can be obtained easily using Kruskal's algorithm, and the time complexity is $O(n \log n)$. Therefore, the lower bound of ε can be obtained using the polynomial computation time.

Next, let us discuss the upper bound of ε. The upper bound corresponds to the solution of the subproblem of the original problem with the single objective of minimizing the transportation cost. As the optimal transportation cost of TSP is the lower bound of the optimal cost of the vehicle routing problem, the upper bound of ε can be obtained from the optimal TSP route. Although TSP is an NP-hard problem, the computation time required to find the optimal solution of TSP is much lesser than time required to find the optimal solution of the vehicle routing problem.

(3) Overall Algorithm

Step 1: Compute f_1^I by Property 1 and Kruskal's algorithm.
Step 2: Compute the optimal TSP route. Let $\varepsilon = r(TSP)$, where $r(TSP)$ denotes the risk of the optimal TSP route.
Step 3: Solve Problem P0 and obtain the solution x^*. Add $(f_1(x^*), f_2(x^*))$ to Y'.
Step 4: Let $\varepsilon = f_1(x^*) - \delta$. If $\varepsilon < f_1^I$, go to the next step. Else, go to Step 3.
Step 5: Delete the dominated solutions from Y' and obtain the Pareto front Y.

12.4.5 Numerical Results and Sensitivity Analysis

The distribution center and customers are randomly generated on a plane, and the distances between them are expressed by Euclidean distances. As it takes a lot of time to solve large-scale problems, to ensure that the results can be obtained in a reasonable time, eight instances are randomly generated, of which the first to fourth instances contain ten customers, and the fifth to eighth instances contain 15 customers. The parameters Pop_{ij} and s^λ are randomly generated. Without losing generality, the unit transportation cost can be set to 1. The customers' demands are randomly generated in the interval [1,30], and the capacity of the vehicles is set to 30.

Based on the generated instances, the improved ε-constraint method and classic ε-constraint method are tested and compared. The programs are coded using visual studio C++ 2017 and CPLEX (version 12.6). All tests are conducted on a PC with 3.3-GHz CPU, 8.0-GB RAM, and a Windows 10 system. The results in Table 12.9 show that the computation time of the improved ε-constraint method to obtain the Pareto

Table 12.9 Comparison between the computation times of improved ε-constraint method and classic ε-constraint method

Instance	Improved ε-constraint method	Classic ε-constraint method	Ratio of the computation times (%)
#1	372	535	69.53
#2	378	636	59.43
#3	344	711	48.38
#4	390	790	49.37
#5	679	1405	48.33
#6	843	1625	51.88
#7	821	1565	52.46
#8	740	1265	58.50
Average			54.74

front is less than that of the classic ε-constraint method. The average computation time of the improved ε-constraint method is only 54.74% of that of the classic ε-constraint method, and the best result is only 48.33%. This shows that the proposed improved ε-constraint method is faster than the classic ε-constraint method and can effectively shorten the computation time.

The weighting method is further used to solve the above instances and is compared with the proposed improved ε-constraint method. The results are shown in Table 12.10. It can be seen that the complete Pareto front cannot be obtained by using the weighting method in Instance #6, which also confirms the defects of the weighting method compared with the ε-constraint method.

In reality, decision makers often have a variety of vehicles to choose from; that is, there can be vehicles with different capacities. Here, let us test whether the capacity of the vehicles affects the results. The capacity of the vehicles is set to Q, $Q + 10$, $Q + 20$, respectively, and the results are shown in Fig. 12.5.

Table 12.10 Comparison between the weighting method and improved ε-constraint method

Instance	Number of solutions obtained by weighting method	Number of solutions obtained by improved ε-constraint method
#1	2	2
#2	2	2
#3	2	2
#4	3	3
#5	3	3
#6	2	3
#7	3	3
#8	3	3

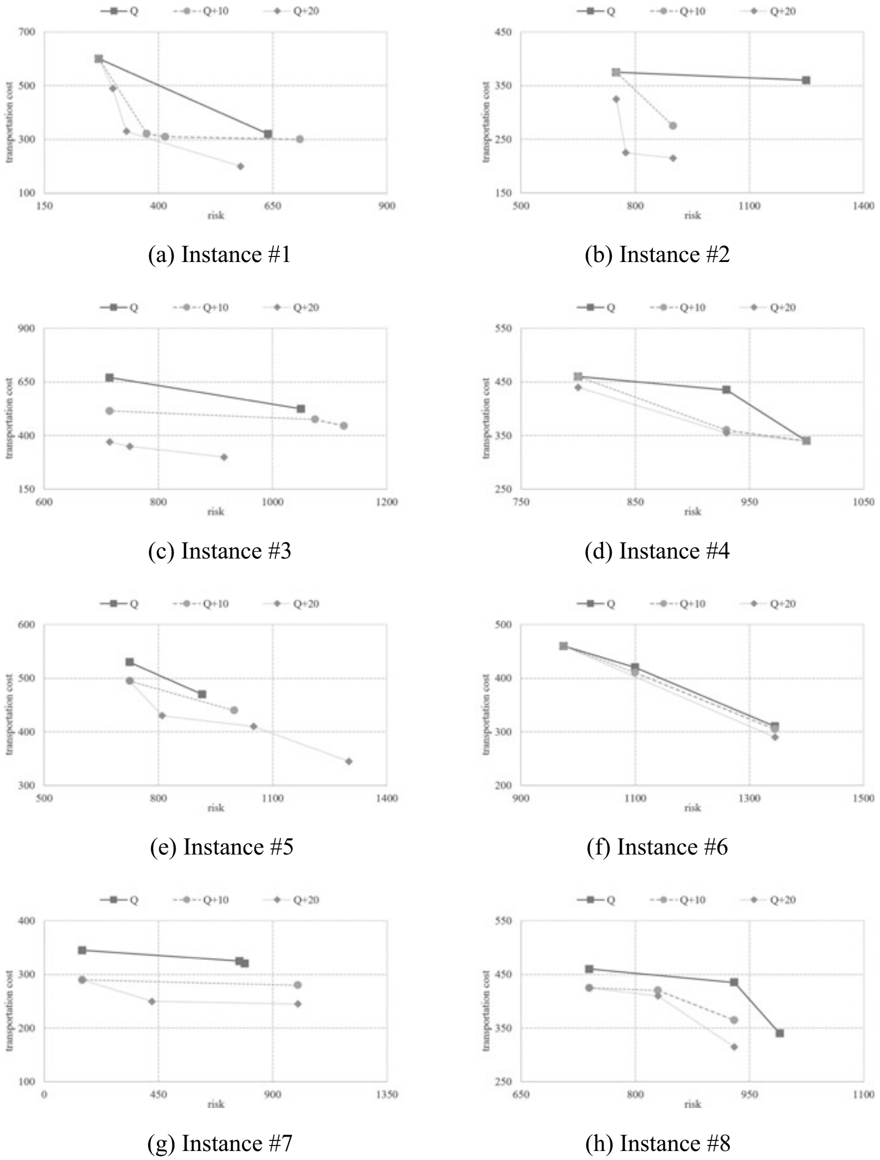

Fig. 12.5 Results of different capacities

As can be observed from Fig. 12.5, with an increase in the capacity of vehicles, the overall transportation cost shows a downward trend. This is because when the capacity of vehicles increases, it gets easier to deal with constraints, as more distribution routes become feasible. In addition, many overlapping points can still be observed in Fig. 12.5. This is because the routes are also constrained by risks.

In many situations, even if there are lesser costly distribution routes, they cannot be adopted because the risks of these routes exceed the limit. It is better to choose vehicles with a larger capacity for distribution than those with a smaller capacity. However, this cannot be generalized because vehicles with larger capacities often incur higher unit transportation costs. Therefore, decision makers need to incorporate the capacity and unit transportation cost of optional vehicles into the model, weigh the results, and choose the appropriate vehicles.

12.5 Summary

In this chapter, from the perspective of green logistics, after introducing the basic connotation and implementation path of green logistics, three specific green logistics approaches are proposed to help enterprises implement the green growth model. First, we propose low-carbon distribution. The routing optimization model for low-carbon distribution is based on the principles of low-carbon and energy-saving, with profit maximization and carbon emission minimization as the optimization objectives. An ε-constraint hybrid evolutionary algorithm combining ε-constraint and GRASP-ELS is designed, leading to the management insight that an increase in transportation cost weakens the conflict between profit and carbon emission. Second, we propose collaborative distribution. The routing optimization model for collaborative distribution is based on the principle of improving vehicle utilization. We propose a collaborative routing optimization model that considers multi-type depots in forward and reverse logistics. For this purpose, we designed a GRASP-ILS algorithm. The key managerial insights from the chapter are as follows. First, the higher the regional overlap, the greater the benefits that can be achieved through collaborative distribution. Second, the larger the scale of the transportation network, the greater the benefits that can be achieved by adopting collaborative distribution. The third insight concerns hazardous materials distribution. The routing optimization model for hazardous materials distribution based on the principles of fatal incident avoidance is developed from the perspective of the security of distribution, simultaneously minimizing transportation cost and risk. An improved ε-constraint method is proposed. The managerial insight is that it is generally better to choose vehicles with a larger capacity for distribution than vehicles with smaller capacities.

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Chapter 13
Resource Recycling

Shuyi Sun, Nengmin Wang, Qi Jiang, and Bin Jiang

Abstract Resource recycling is an important part of enterprises' green growth model, and is necessary for the upgrade and reconstruction of enterprise value chains. Based on the new forms of industry, new business models, and next generation information and communication technologies, we examine the new problem of resource recycling of manufacturing enterprises on the Internet platform. This chapter studies the efficiency and benefits for manufacturers and third-party platforms in recycling used products. Different platform recycling models are modeled and analyzed. We find that recycling prices, agency fees, and consumers' willingness to use different recycling models affected consumers' recycling choices. Consumer willingness results in different third-party recycling platforms occupying different market shares. Our research demonstrates the impact of consumers' willingness to recycle on recycling efficiency. We provide management implications for recycling enterprises when reconstructing the value chain.

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13.1 Resource Recycling and Enterprises' Green Growth Model

13.1.1 Resource Recycling: An Element of Enterprises' Green Growth Model

Currently, the operating environment of enterprises has undergone revolutionary changes. Given the changes in the international competitive environment and the deepening of the concept of green consumption, resource and environmental constraints have tightened. The increase in the disposable income of consumers has changed their demand from emphasizing cost-effective mass consumption to the pursuit of green, personalized services, product performance, and so on [1]. Enterprises that carry out green development and transformation have become an inevitable trend.

Resource recycling is an important part of the transformation of enterprises into a green growth model. It is also important to value chain reconstruction. A resource circular economy is an economic development model characterized by resource conservation and recycling. It is harmonious with the environment, and is characterized by low mining, high utilization, and low emissions [2]. At the micro level of the enterprise, resource recycling requires the enterprise to organize internal economic activities into a feedback process of "resource-product-renewable resource". All materials and energy can be rationally and sustainably used in this ongoing economic cycle to reduce the impact of economic activities on the natural environment as much as possible. The reverse value chain of resource recycling connects the end consumer with the manufacturing enterprise in a positive value chain [3]. It is also a key activity for enterprises to achieve green growth.

Cainiao Logistics is a representative enterprise of logistics value chain reconstruction in China. In 2016, Cainiao Logistics and several major Chinese express-delivery companies, such as ZTO Express, YTO Express, and STO Express, jointly launched Cainiao Green Action to promote the upgrade of the logistics industry to a green industry. In China, the Cainiao Green Action is the largest environmental protection action in the logistics joint industry. Since the "Double 11" in 2017, Cainiao Logistics has set up approximately 5,000 recycling stations in 200 cities across the country. Consumers can find the nearest recycling station, using the AutoNavi map, to donate cartons. Cainiao Logistics provides recycled cartons offline directly to consumers of Cainiao Station for free, pioneering the local recycling of express cartons. According to Cainiao Logistics's "Double 11 Green Logistics Carbon Reduction Report" in 2021, Double 11, Cainiao Logistics joined with T-mall Supermarket to promote original, used, and recycled box deliveries. More than 70% of their parcel shipments no longer use new cartons. The proportion of single-warehouse recycled cartons was 30%–40%. A total of 75,000 packages were issued using recycled cartons. The T-mall warehouse in Shanghai Jiading reduced the number of carton and plastic packaging materials by nearly 300,000 daily. A total of 4.8 million people participated in and shared Cainiao Logistics's express packaging recycling activities online and offline. By 2021, Cainiao Green Logistics had more than 1.8 billion green behaviors. Cainiao Logistics' merchants and consumers jointly reduced carbon emissions by 53,000 tons for the entire society.[1]

13.1.2 Resource Recycling: An Element of Value Chain Reconstruction

In the traditional growth model, products abandoned by consumers due to damage, waste, and other factors are not returned to the value chain through recycling. They are eventually landfilled as garbage, which has a significant impact on the environment. However, the backlog of the large number of used products that remain idle with consumers due to product upgrade or other reasons is also a huge waste of resources. For enterprises, used and waste products are recycled into the production line through some channels. The recycled waste products are decomposed, reused, and remanufactured. After dismantling modules or product refurbishment, they enter new sales channels to reduce the resource investment in new product manufacturing and realize resource recycling [4]. The realization of resource recycling requires enterprises to reconstruct some activities and modules in the value chain, reduce the cost of recycling, and improve the efficiency of resource recycling through technological upgrade and industrial transformation. Consumer electronics is a prime example.

Taking Huawei as an example, in the traditional consumer electronics industry, Huawei as the upstream product manufacturer, sells products through regional distributors. The recycling business of used mobile phones is often concentrated in the hands of small recycling vendors and secondary dealers in local regions. The distance between manufacturers and consumers is quite large, making a high cost of recycling old electronics from customers. And it is also very expensive to disassemble recyclable electronic components for remanufacturing before mobile phones achieve uniform production standards and modularization. With the upgrade of mobile phone manufacturing and recycling technology, and the popularization of Internet platforms and big data technologies, Huawei began to recycle used mobile phones to improve the efficiency of resource recycling. Consumers can find the nearest recycling outlet on Huawei's official website and visit the outlet to recycle their mobile phones. In 2015, Huawei launched the "Green Action 2.0" for mobile phone recycling. Consumers can value and recover idle mobile phones on the Huawei Mall trade-in platform, receiving mobile phone vouchers to purchase Huawei's new devices. Huawei assesses the recycled used mobile phones and divides them into two types: "mobile phones that can continue to use", and "mobile phones that cannot continue

[1] https://www.cainiao.com/green.html.

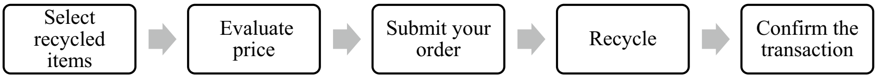

Fig. 13.1 Huawei's official trade-in process for consumers

to use" [2]. Mobile phones that can continue to be used will be handed over to third-party recyclers who have undergone rigorous qualification review. After the third-party recycler cleans the data on the mobile phone and performs related processing measures, it is sold through regularly used mobile phone retail channels. If mobile phones can no longer be used, the recycler will disassemble the modular accessories that can continue to be used through 23 processes, including disfiguring and scanning codes, returning them to the mobile phone manufacturers for the manufacture of new products, and carrying out thorough environmental protection and pollution-free treatment of accessory materials that cannot be used.[2] Huawei's trade-in process for consumers on its official website is as shown in Fig. 13.1.

13.2 Drivers of Resource Recycling

13.2.1 To Conform to Consumers' Environmental Protection Concepts

As the concept of environmental protection gradually becomes popular, consumer demand for green products increases daily, and the importance of green products is emphasized more [5]. Consumers' preference for environmentally friendly products is considered an important driving force for enterprises to implement green environmental protection and resource recycling. It is also a key factor for consumers to assume social responsibility [6]. Simultaneously, resource recycling by enterprises changes consumers' consumption concepts and market demand. If more enterprises in a certain industry begin to carry out recycling activities and promote a resource circular economy to society, consumer prejudice against recycled products will gradually be eliminated. Through the continuous implementation of these appropriate incentives, consumers will pay more attention to the overall image of the enterprise when choosing goods and will be more willing to choose products produced by enterprises that consider environmental protection. Therefore, through recycling, trading in, and other methods, enterprises can better meet consumers' preferences for green consumption, thereby enhancing their competitiveness.

Alibaba's Freshhema is an example. As a new retail format, Freshhema has been exploring models to innovate and optimize its services. In 2019, Freshhema announced the launch of the "Green Box Plan", which involved optimizing the supply chain and processes from the source to the table, to reduce the use of plastic products.

[2] https://www.vmall.com/help/faq-7923.html.

The annual target is to reduce plastic use by 3.8 million kilograms. To encourage consumers to spend in environmentally conscious ways in stores, Freshhema and Alibaba's Alipay Ant Forest declared that consumers who did not buy plastic bags when checking out with the Freshhema APP would obtain 21g of green energy in the ant forest once a day. Simultaneously, Freshhema and Octopus Recycling placed smart machines that sort and recycle plastics in stores in Hangzhou, Beijing, and Shanghai. Consumers would only need to open their mobile phones to scan items to be recycled. They can participate in plastic recycling delivery and exchange them for environmentally friendly gifts. This novel, full self-service recycling method has attracted the participation of many Freshhema users. In less than two months, the first two stores participating in the pilot recycled more than 1700 plastic bottles and more than 1400 kg of plastic.[3]

13.2.2 To Respond to Government Environmental Regulations

Governments' environmental protection laws and regulations are important influencing factors and driving forces for enterprises to implement resource recycling. To promote resource recycling and strengthen environmental protection and industrial green development, local governments issue requirements for environmental protection capabilities and relevant environmental protection laws and regulations for local enterprises. They also provide corresponding incentives or constraints on the production behavior of domestic enterprises [7]. Governments' environmental rules causes companies to consider transitioning to the green growth model to avoid larger policy fines or even business closure penalties. Governments have put forward corresponding protection laws and regulations for environmental protection and the green development of enterprises and have formulated a series of environmental management systems. Furthermore, a series of international regulations have been introduced to strengthen resource recycling. For example, in 2002, the European Union issued the WEEE, ROHS, and EUP Directives. Through these, the government promotes the recovery of recyclable products by setting the appropriate target recovery rates.

In this context, society began to pay attention to green development, and the irrational factors of enterprises began to reflect the awareness of corporate social responsibility. Although companies' responses to environmental regulatory policies may be passive, they reduce environmental risks and enhance the company's corporate social responsibility image. However, mandatory environmental laws and regulations have a significantly positive impact on enterprises' green innovation practices [8]. For example, China began implementing the "Circular Economy Promotion Law of the People's Republic of China" in 2009. Since then, China introduced a policy for the "trading-in of used appliances for new ones" to promote urban consumption. This

[3] https://www.163.com/dy/article/E820OCF30512DU6N.html.

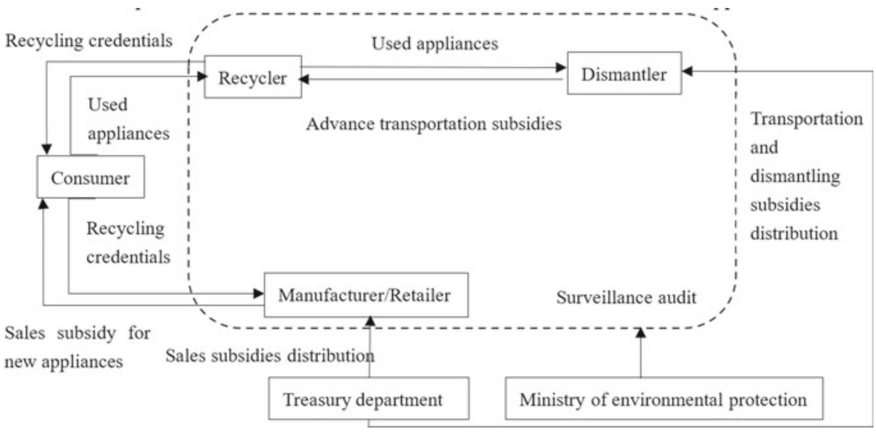

Fig. 13.2 Implementation process for "trading-in used appliances for new ones" [9]

was first piloted in nine provinces and cities, including Beijing, Tianjin, Shanghai, Jiangsu, Zhejiang, Shandong, Guangdong, Fuzhou, and Changsha. Since June 1, 2010, the scope of implementation has gradually expanded to the entire country. The Ministry of Commerce, Ministry of Finance, and Ministry of Environmental Protection issued the Work Plan for the Replacement of Household Appliances. The implementation process is showed in Fig. 13.2, [9]. Initially, the policy was led by the state and was subject to financial subsidies. Since then, more home appliance manufacturers, recycling platforms, and other entities have participated, and the "old-for-new" appliances have gradually evolved into market-oriented measures, such as "Suning Tesco" and "JD". Other large e-commerce platforms have launched "old-for-new" subsidies for household appliances as well.

In 2021, the number of trade-in orders on JD's appliance platform increased by more than 300% year-on-year. The air conditioner alone saved nearly 300 million yuan for users.[4] The Suning Tesco platform has achieved exchanges between home appliance categories as well. For example, computers are exchanged for mobile phones. Refrigerators are exchanged for air conditioners. The platform has 350 stores ordering and renewing services. Suning Tesco's appliance recycling process is showed in Fig. 13.3. In 2021, Suning Tesco launched an appliance replacement and upgrade scheme to increase the subsidy for replacement. The newly upgraded trade-in service is simpler, more convenient, and more comprehensive, realizing one-click valuation and price-difference payments. In addition, it is a one-stop service for new machines and old tractors, which greatly saves consumers' waiting time.[5] The relevant person in charge of JD appliances pointed out that the "old-for-new" appliances can guide users to update them promptly. It is also one way to activate a huge stock market. Simultaneously,

[4] http://news.cheaa.com/2022/0124/602208.shtml.

[5] https://new.qq.com/omn/20210416/20210416A0B0I900.html.

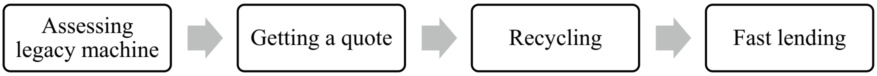

Fig. 13.3 Suning Tesco's appliance recycling process[6]

for enterprises, a strong after-sales system is the guarantee for upgrading the "old-for-new" policy. Enterprises need to sort and professionally crush recovered electronic products to ensure the rational use of idle resources and protect the privacy rights and interests of consumers. Therefore, in addition to stimulating consumer demand, the "old-for-new" policy has also positively driven the sustainable development of the waste electronic product recycling industry.[7]

13.2.3 To Promote the Reconstruction and Upgrade of Value Chains

The traditional high-input, high-consumption growth model has long led to different degrees of environmental pollution and large resource consumption problems worldwide, especially in developing countries. The enterprises' traditional growth model focuses mainly on resource and labor consumption and pollution-end control. Regarding low-cost resource and labor and loose environmental constraints, the growth of the traditional model may have obvious performance. The implementation of a green performing resource cycle is not obvious, or may even be negative. The cost of resource recycling has gradually decreased, which can better meet consumers' demand for green environmental protection and reduce potential policy risks. The main reasons for cost reduction are the requirements of policies, innovation of environmental protection technologies and means, and continuous development of consumer concepts. Changes in the resource environment restrict enterprises from choosing a green growth model. Recycling resources can reduce the resource consumption of enterprises. Following this, a closed loop of the value network can be built. The realization of resource circulation must be supported by new technologies and enterprise models. Enterprises need to use more advanced technology and replace material inputs with knowledge input, as much as possible, to achieve the recycling of the resource life cycle.

The resource life cycle of enterprises needs to comply with the "3R1D" principle of "reducing, reusing, recycling and degradable" [10]. "Reducing" belongs to the input side. It is required to input less raw materials and energy to achieve the intended production or consumption purposes, and then pay attention to saving resources and reducing pollution from the source of economic activity. "Reusing" belongs to the

[6] https://hx.suning.com/.

[7] https://huishou.jd.com/home.html.

process aimed at prolonging the length of use of products and services. “Recycling” belongs to the output side; it aims to reduce the amount of disposal. “Degradable” means the product should be easy to degrade at the end of its life cycle. Resource recycling requires enterprises to evolve to a stage with a more advanced form, complex division of labor, and reasonable structure. Enterprises should implement the green growth model during the entire life cycle of the product and reengineering and reconstruction of the value chain. In the resource development stage, enterprises should consider rational development and the multilevel reuse of resources. In the product and production design stage, enterprises should consider the basic functional attributes of the product, while considering its negative impact on the environment, from the non-polluting and non-toxic selection of raw materials and processes to manufacturing. In other words, the design of all aspects, from use to recycling after disposal, must implement the concept of green design, consider the multilevel utilization of resources, and integrate a standardized design of the production process. In the production, product transportation, and sales stages, enterprises should consider process integration and waste reuse. In the circulation and consumption stage, enterprises should consider extending the service life of products and realizing multiple uses of resources. At the end of the lifecycle, enterprises should consider the reuse of resources and waste recycling.

Taking the new energy vehicle battery industry as an example, recycling is the last link in the value chain and has drawn a completely closed loop for the power battery industry.[8] Upstream of the power battery industry are positive and negative electrode materials, electrolytes, diaphragms, and other materials. The intermediate link is the preparation of these materials. The downstream industry is the new energy automobile industry. By recycling the power battery, most materials other than the separator and negative electrode can be retained. Thus, resource recycling can be achieved. The front and back end of the value chain are the link that forms an important closed loop for power battery recycling. The new battery passes through the battery enterprises, vehicle enterprises, car dealers, and finally, the consumers. Consumers will replace the scrapped battery through after-sales service outlets, and battery rental enterprises will replace the new battery. After-sales outlets and battery rental enterprises collect waste batteries and transfer them to recycling service outlets and waste battery comprehensive utilization enterprises, to generate reusable products. The batteries return to the comprehensive utilization enterprises for the renewable resource to be utilized after scrapping. These renewable resources flow into battery production enterprises to create new batteries. Then, they flow to vehicle enterprises, forming a closed loop.

As one of the leading enterprises in the field of new energy vehicles in China, “XPENG” recycles the waste power batteries contained in the models it sells. Waste power batteries include those that cannot be repaired after scrapping or damage, and XPENG has the right to dispose of them. XPENG will recycle them through the after-sales service center and the recycling network established in cooperation with battery recycling enterprises to avoid environmental pollution and waste of resources.

[8] https://www.zhidx.com/p/135289.html.

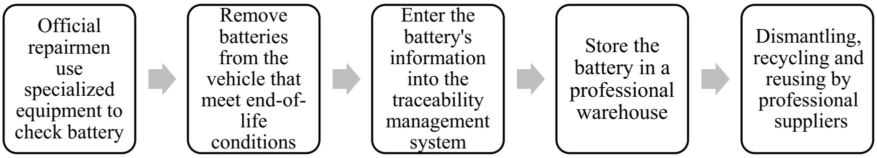

Fig. 13.4 XPENG's waste power battery recycling management process

XPENG's waste power battery recycling management process is as Fig. 13.4 shown. In terms of wastewater, waste gas, and waste recycling, XPENG uses a deep treatment system to produce reclaimed water from the sewage treatment station, treating qualified wastewater for factory greening, toilet flushing, car washing, and cooling towers in its Zhaoqing production base. This saves 110,000 tons of freshwater per year. Additionally, the welding workshop adopts an efficient filter dust collector to adsorb soot. The dust removal efficiency is 99%. The painting workshop uses environmentally friendly water-soluble coatings as well, to reduce the amount and emission of organic pollutants from the source. To improve the efficiency of solid waste recycling, XPENG further built a waste warehouse in June 2021 to improve the storage conditions and transfer methods of recyclable materials. As of May 2021, XPENG has achieved a 100% recyclable solid waste utilization rate.

XPENG strives to complete the green ecological layout of its entire industry chain from manufacturing and use, to recycling. Under the Chinese government's "double carbon" goal, the transformation of "zero emissions" in the entire life cycle of pure electric vehicles will be realized. In the production and manufacturing process, XPENG promotes clean energy research, development, and application projects, and adopts a large number of intelligent equipment and concepts. It realizes lean production methods that consider quality, environmental protection, flexibility, and efficiency. In terms of production technology, the Zhaoqing production and application base achieves emission reduction with a high automation rate and advanced technology. For example, their painting workshop adopts advanced treatment film technology, which reduces the slag production from waste paint by 94% and reduces energy consumption by more than 25%. It further adopts circulating air in the painting room, which saves energy and reduces exhaust emissions by 30%. On October 14, 2021, XPENG released its first Environmental, Social, and Governance (ESG) report, which was also the first ESG report released by China's new car-making enterprise with reference to national standards. For two consecutive years, XPENG received an ESG rating of AA, which is the highest rating for global car companies. This indicates that the leading ESG achievements of XPENG have been recognized by the industry.[9]

[9] https://3g.163.com/dy/article/GS7AL40O0527CR28.html.

13.3 Design of Transaction Model of the Online Used Product Recycling Platforms

13.3.1 Resource Recycling with the Next Generation Information and Communication Technology

The integration of next generation information and communication technology and environmental protection technology provides an important means for enterprises to implement the green growth model [11]. The next generation information and communication technology is profoundly changing the strategic decision-making, organizational form, business model, and operation model of enterprises. New models and formats of recycling and resource recycling have spawned from the establishment of various used goods trading platforms and product recycling platforms based on Internet technology. The most typical examples include the following:

(1) The emergence of the Internet platform has formed a recycling and trading system that combines online and offline channels. For example, the "easy to sell" business of the Idle Fish APP integrates the online recycling, warehouse management, and distribution transaction service sharing platform of various brands of mobile phones. The Idle Fish receives consumers' requests online, detects and recycles the used goods offline, and evaluates price by big data valuation.[10] This integration improves the recovery rate of renewable resources and completely changes the traditional offline recycling method. Similarly used product trading recycling platforms are "Aihuishou," which recycles waste electronic products; Baidu recycling stations; and other young recycling platforms.[11] The core of this innovation lies in the fact that the next generation internet technology instantly and accurately matches the supply and demand of recycling. Moreover, a collection and transaction system that combines online and offline channels have been established.

(2) The internet, combined with the real economy, develops into an ecosystem with integrated processes. For example, China Baowu has built a micro platform for collecting hazardous waste, specifically for enterprises with small industrial waste production. The Baowu platform helps enterprises choose appropriate channels for disposal, either by the enterprise itself, or entrusted to qualified hazardous waste disposal units.[12] China Lanzhou Renewable Resources Company chose the chain operation business model of self-operation and franchise, to build a recycling station base, professional sorting center, and processing enterprises as the core of a "Trinity" recycling system.[13] The core

[10] https://goofish.com/.

[11] https://www.aihuishou.com/.

[12] https://www.thepaper.cn/newsDetail_forward_15115265.

[13] http://lz.wenming.cn/wmcj1/wmcj/202010/t20201022_6773364.shtml

of the above-mentioned enterprise model innovation is the use of the next generation internet technology, while achieving an instant and accurate matching of recycling supply and demand. This further extends the recycling behavior to remanufacturing, resale, and recycling. These behaviors do not include all the activities undertaken by the enterprise itself, but follows the labor advantages of core competitiveness in the platform and ecosystem to find the most suitable partner. The core of this model is to solve the information-matching problem of scattered supply and demand and build an ecosystem of value added and shared profits.

The rapid development of Information and communication technology provides important technical support for promoting green consumption. With the development of e-commerce, more merchants conduct business on Internet trading platforms. In the secondary market, recyclers can use the convenience and timeliness of Internet platform transactions to cover more consumers, expand the scope of recycling, and improve recycling efficiency. However, one challenge is the competition between various used product recycling platforms online.

13.3.2 Transaction Model of Used Product Recycling Platforms

At present, most mainstream product recycling platforms in the market are large-scale, third-party, recycler-led product trading platforms that provide manufacturers and consumers with a market for used product recycling transactions. There are three main trading models on platforms: the conventional third-party recycling platform model, the agency third-party recycling platform model, and the emerging guaranteed selling duration (GSD) recycling model.

Conventional third-party recycling platform models, including online recycling platforms for used electronic products such as Aihuishou and Idle Fish, acquire used products from consumers and resell them to manufacturers for recycling. Third-party platforms conduct quality checks on the used products, assess product conditions, set wholesale prices, and purchase used products from consumers. The platforms determine the resale prices to manufacturers based on various factors. The agency third-party recycling platform model is one in which the manufacturer relies on a bilateral market to directly conduct recycling business for consumers on the used product recycling trading platform. The platform acts as an agent for buyers and sellers, providing manufacturers and consumers with trading channels. The platform provides a channel for consumers to sell used products that are evaluated, priced, and recycled by manufacturers. The manufacturer or consumer must only pay an agency fee to the platform. The platform itself is not involved in the buying process.

A key difference between the conventional and agency recycling models is the ownership of used products. In the agency recycling model, the manufacturer is the direct recycler of the used product, which means that the platform does not bear the risk of transaction failure. In the conventional recycling model, the platform owns the product; therefore, it must bear the risk of transaction failure and product backlog. However, while the agency recycling model eliminates the risk of trade failure for manufacturers, they lose a portion of their recycling pricing rights for used products when faced with third-party platforms with independent recycling capabilities. Only two models have managed to strike a balance between profit and risk in an increasingly complex platform economy. Therefore, the platform needs to expand its trading model to be more responsive to the market.

Combined with the market environment and real cases, we propose a hybrid retail model that sets the GSD. If the used product is successfully recycled during the GSD, the platform adopts the agency recycling method and only charges a certain fee to the buyer and seller. Otherwise, the platform reclaims ownership of the used product from the seller at a discounted price and then resells it to the manufacturer, essentially switching to a conventional recycling model. At present, some platforms have begun to try this emerging trading model, such as the “Easy to sell” business launched by China’s secondary trading platform, Idle Fish, and the 30-day guarantee sale business of the Guazi used cars platform.

In this section, we consider a used product recycling platform that can be selected from different recycling models. We believe that used product recycling platforms need to choose their recycling models from the above three models. Our main objective is to develop the best recycling strategy and pricing policy for the platform. We focus on the following issues:

(1) What is the best pricing policy for the platform among the three models?
(2) How does the recycling model affect platforms, manufacturers’ decisions, and consumer behavior?
(3) Which of the three recycling models is best for a new trading platform?

To answer these three questions, we built a value chain involving manufacturers, consumers, and a used product recycling platform that can choose its own business model from the three recycling models. To build effective solutions, we break down multi-user competition into multiple single-match and single-product issues.

We characterize this research question based on research models for two-sided markets, such as Rochet and Tirole [12] and Parker and Van Alstyne [13]. This study builds on existing literature on the secondary durable goods market, consumer behavior in recycling channel competition, and two-sided markets. Previous studies on recycling model selection have concluded that users’ evaluations of products are influenced by recycling patterns, which are defined as consumer preferences for channels. Chiang et al. [14] first introduced the concept of consumer acceptance in their study of channel competition. They studied the channel competition between direct and retail channels and found that direct sales channels can increase suppliers’ profits. Our research also refers to their approach to portraying consumer preferences. Other studies have focused on the portrayal of buyers’ willingness to, rather than on sellers’ portrayal of, channel preferences and product quality in two-sided markets. In this study, we adopt Armstrong’s assumption that sellers’ and buyers’ utilities directly affect the platform’s requested price for either party and total trading volume [15].

Based on the above literature, our study compares the conventional, agency, and GSD recycling models. With this comparison, we attempted to determine the optimal pricing strategy for the third-party platform in each of the three models. Our findings provide reference and management implications for companies adopting an online market model.

13.3.3 Assumptions and Models

First, we discuss the trading models of the three recycling models in monopolistic markets, as benchmarks. We start by building a value chain involving manufacturers, consumers, and a third-party used product recycling platform that is strong enough to determine the transaction prices for both customers. The platform offers three recycling models: conventional, agency, and GSD recycling. We assume that this is a single-period transaction, in which a consumer is willing to sell no more than one used product per recycle, and that both the buyer and seller are rational individuals seeking to maximize utility. The success of a transaction depends on the consumer's decision to sell $u_s \geq 0$ and the manufacturer's decision to recycle $u_b \geq 0$. Thus, the expected profit of the platform can be estimated as the possible revenue minus the various costs incurred. The structures of these three models are illustrated in Fig. 13.5.

Both consumers and manufacturers will have certain expectations for the residual value of the used products. They will have different value preferences for the same used product due to various factors. For a used product of value v, the consumer will only choose to recycle the product if the consumer's expectation from recycling the used product is higher than the expected value of the product they retain. This expectation can also be called the consumer's "willingness to recycle". We use $\alpha_i, i = 1, 2, 3$ to express the consumer's "willingness to recycle" in different recycling patterns. Similarly, a rational manufacturer will only decide to recycle the product if the expected value of the recycled product is greater than the cost

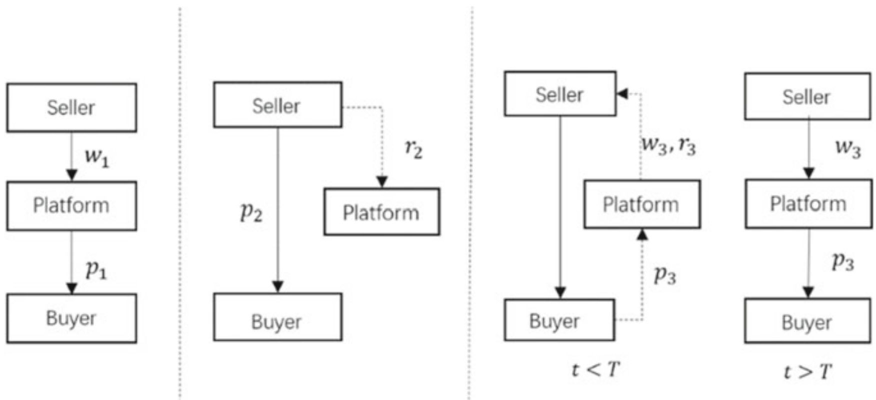

Fig. 13.5 Three recycling models

of recycling. It can also be called the manufacturer's "willingness to pay". We use the parameter $\beta_i, i = 1, 2, 3$ to indicate the manufacturer's "willingness to pay". $i = 1, 2, 3$ represents conventional, agency, and GSD recycling, respectively. We define u_{si} and u_{bi} as the utility that consumers and manufacturers, respectively, can derive from transactions on the three platforms. When utility is not positive, neither the seller nor the buyer will complete the transaction. According to research by Meredith and Akinc [16], we assume that both buyers and sellers are price-sensitive when evaluating used products. The number of bilateral users is normalized to 1. Without losing universality, we assume that the buyer and seller's preferences for the expected value of the product are independent, evenly distributed between 0 and 1, and follow the distribution density function $f(v) = 1$. All parameters involved in the model are normalized to between 0 and 1. Recycling platforms need to ensure that both buyers and sellers get positive utility before setting the transaction price.

(1) Conventional Recycling Model on Third-party Platforms

In the third-party platform conventional recycling model, the platform first needs to assess the value of the used product, then provide the consumer with a recycled price w_1. If the consumer agrees to sell the used product, ownership of the product passes to the platform. Finally, the manufacturer recycles the used product from the platform at the price of p_1.

The utility of the manufacturer-side user can be expressed as:

$$u_{b1} = \beta_1 v - p_1$$

Similarly, the utility of the seller can be expressed as:

$$u_{s1} = w_1 - \alpha_1 v$$

If the product cannot be sold, the platform will bear the loss w_1. A successful transaction depends on the seller's decision to sell ($u_{s1} \geq 0$) and the buyer's decision to buy ($u_{b1} \geq 0$). Thus, the profit of the platform can be estimated as possible sales revenue minus possible losses:

$$\begin{aligned}\pi_1 &= P(u_{s1} \geq 0) \cdot (P(u_{b1} \geq 0) \cdot (p_1 - w_1) - P(u_{b1} < 0) \cdot w_1) \\ &= \int_0^{\frac{w_1}{\alpha_1}} f(v)\mathrm{d}v\left(\left(\int_{\frac{p_1}{\beta_1}}^1 f(v)\mathrm{d}v \cdot (p_1 - w_1)\right) - \int_0^{\frac{p_1}{\beta_1}} f(v)\mathrm{d}v \cdot w_1\right)\end{aligned}$$

$$\max_{p_1, w_1} \pi_1 = \frac{w_1}{\alpha_1}\left[\left(1 - \frac{p_1}{\beta_1}\right)p_1 - w_1\right]$$

(2) Agency Recycling Model on Third-Party Platforms

In the third-party platform agency recycling model, the platform first evaluates the recycling price of the used product, according to its quality and recycling value.

Consumers post information about used products at recycling prices p_2 on the platform. Manufacturers recycle these products from consumers. Then, the platform charges consumers a share r_2 of the recovered price as an agency fee. In this case, the platform does not own used products, and only provides a place for buyers and sellers to trade.

The utility of the manufacturer-side user can be expressed as:

$$u_{b2} = \beta_2 v - p_2$$

The utility of the seller can be expressed as:

$$u_{s2} = p_2 - r_2 p_2 - \alpha_2 v$$

The profit function that can be obtained by the recycling platform can be expressed as:

$$\begin{aligned}\pi_2 &= P(u_{s2} \geq 0) \cdot (P(u_{b2} \geq 0) \cdot r_2 p_2 - P(u_{b2} < 0) \cdot 0) \\ &= \int_0^{\frac{(1-r_2)p_2}{\alpha_2}} f(v)\mathrm{d}v \left(\int_{\frac{p_2}{\beta_2}}^{1} f(v)\mathrm{d}v \cdot r_2 p_2 \right) \\ \max_{p_2} \pi_2 &= \frac{(1-r_2)p_2}{\alpha_2} \left(1 - \frac{p_2}{\beta_2} \right) r_2 p_2\end{aligned}$$

(3) GSD Recycling Model on Third-party Platforms

In the GSD recycling model, if the product is sold during the GSD, T, the platform will act as an agency recycler, and only the agency fee r_3 is charged. If the product fails to sell within this period, the platform will purchase it from the seller at wholesale price w_3, become a conventional recycler, and continue to sell the product to the manufacturer at sales price p_3. w_3 and p_3 are set and announced to consumers before the GSD begins. This setting is derived from Gan's [17] probability of a commodity being sold, which increases with the time it is on the market. To simplify the model, we set the probability that the product will be sold during the GSD to be proportional to the length of time. When T is normalized, the probability of the product being sold during the GSD is defined as $P(t \leq T) = T$, and the probability of selling after the GSD is $P(t > T) = 1 - T$.

In this case, the manufacturer-side user gets the desired utility for:

$$u_{b3} = \beta_3 v - p_3$$

The utility obtained by the seller is:

$$\begin{aligned}u_{s3} &= P(t \leq T)(p_3 - r_3 p_3 - \alpha_3 v) + P(t > T)(w_3 - \alpha_3 v) \\ &= T(p_3 - r_3 p_3) + (1 - T)w_3 - \alpha_3 v\end{aligned}$$

Table 13.1 Recycling strategies for third-party recycling platforms

Optimal recycling strategy	Conventional recycling	Agency recycling	GSD recycling
w	$\frac{\beta_1}{8}$	–	$\frac{\beta_3-4\beta_3T+4\beta_3Tr_3}{8(Tr_3-2T-T^2r_3+T^2+1)}$
p	$\frac{\beta_1}{2}$	$\frac{2\beta_2}{3}$	$\frac{\beta_3}{2(Tr_3-T+1)}$
π	$\frac{\beta_1^2}{64\alpha_1}$	$\frac{4\beta_2^2(r_2-r_2^2)}{27\alpha_2}$	$\frac{\beta_3^2}{64\alpha_3^2(Tr_3-T+1)^2}$
u_s	$\frac{\beta_1}{8}-\alpha_1 v$	$(1-r_2)\frac{2\beta_2}{3}-\alpha_2 v$	$\frac{\beta_3}{8(Tr_3-T+1)}-\alpha_3 v$
u_b	$\beta_1 v-\frac{\beta_1}{2}$	$\beta_2 v-\frac{2\beta_2}{3}$	$\beta_3 v-\frac{\beta_3}{2(Tr_3-T+1)}$

The profit function that can be obtained by the recycling platform can be expressed as:

$$\begin{aligned}\pi_3 = P(u_{s3} \geq 0)\cdot((P(u_{b3} \geq 0)\cdot(P(t \leq T)\cdot r_2 p_2 \\ + P(t > T)(p_3 - w_3))) - P(u_{b3} < 0)P(t > T)w_3)\end{aligned}$$

$$\max_{p_3, w_3} \pi_3 = \frac{T(1-r_3)p_3 + (1-T)w_3}{\alpha_3}\left\{T\left(1-\frac{p_3}{\beta_3}\right)r_3 p_3 + (1-T)\left[\left(1-\frac{p_3}{\beta_3}\right)p_3 - w_3\right]\right\}$$

(4) Comparison of the Three Recycling Models

In this section, we compare the profits, selling prices, and utility of the platforms using the different recycling models. The advantages and disadvantages of the three models are also discussed.

The profits of the specific recycling strategy and platform under the different structures are listed in Table 13.1. The best recycling strategy for a platform depends on a comparison of the agency rates, GSD, and bilateral user recycling preferences.

(5) Channel Selection of Consumers in Competitive Markets

In a highly competitive secondary market, we assume that three platforms offer three recycling models. Consumers are free to choose the channel through which to sell their used products. Each channel initially has a corresponding recycling manufacturer. The market structure is shown in Fig. 13.6.

In a competitive market, for a seller who chooses conventional recycling, the utility benefits he receives from recycling must meet three conditions simultaneously: $u_{s1} > 0 \cap u_{s1} > u_{s2} \cap u_{s1} > u_{s3}$. Similarly, the utility of a seller who chooses to sell on an agency recycling channel must meet three conditions simultaneously: $u_{s2} > 0 \cap u_{s2} > u_{s1} \cap u_{s2} > u_{s3}$. The utility of a seller that chooses to sell on a GSD channel must meet three conditions: $u_{s3} > 0 \cap u_{s3} > u_{s1} \cap u_{s3} > u_{s2}$. By calculation, we use $v_{12} = v(u_{s2} = u_{s1})$, $v_{13} = v(u_{s3} = u_{s1})$, $v_{23} = v(u_{s2} = u_{s3})$ to

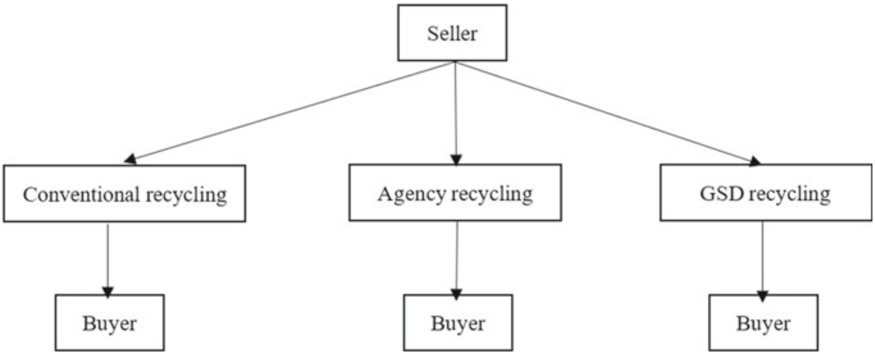

Fig. 13.6 Competitive secondary recycling market structure

represent the value of the three channels when consumer utility is equal. According to the following calculations and comparisons, there are six possible structures in this market after the introduction of competition.

Scenario 1: When $v_{23} > v_{13}$, $U_{s3} = (0, v_3) \cap (0, v_{13}) \cap (v_{23}, 1) = \emptyset$, this represents a loss of market competitiveness in the GSD model.

When $r_2 > 1 - \frac{3\beta_1\alpha_2}{16\beta_2\alpha_1}$, the conventional and agency recycling platforms form a dual-channel competitive market (Fig. 13.7).

When $r_2 < 1 - \frac{3\beta_1\alpha_2}{16\beta_2\alpha_1}$ occurs, agency recycling platforms monopolize all potential seller consumers, and the other two third-party platforms lose their market competitiveness (Fig. 13.8).

Scenario 2: when $v_{23} < v_{12} < v_{13}$.

When $r_3T - T + 1 > \frac{\alpha_1\beta_3}{\alpha_3\beta_1}$, all three recycling platforms exist in the market, but the market share varies according to the size of user preferences. When $v_2 > v_{23}$, the agency recycling platform can engage all inefficient sellers that the other two

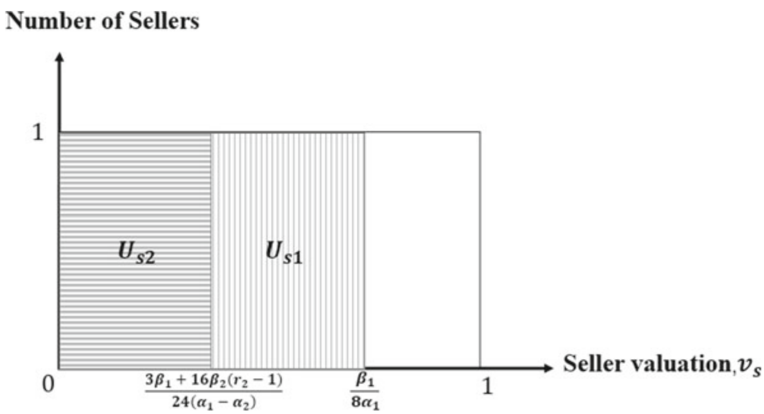

Fig. 13.7 Dual-channel competition between conventional and agency recycling platforms

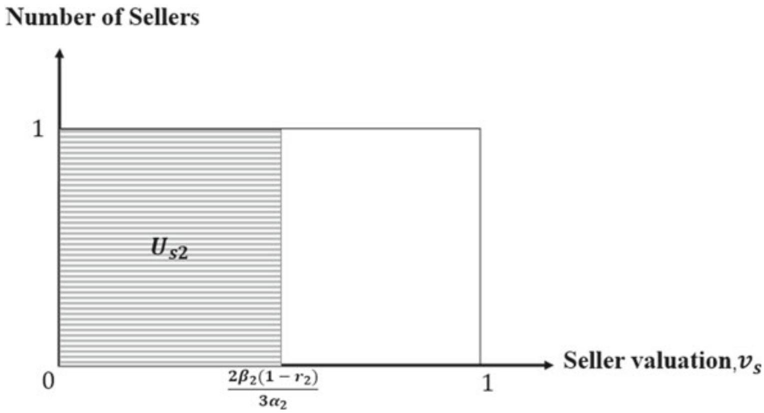

Fig. 13.8 Agency recycling platform monopoly

recycling platforms cannot attract. In contrast, when $v_2 < v_{23}$, the agency recycling platform cannot engage all low-end sellers; therefore, the market may form two competitive models (Figs. 13.9 and 13.10).

When $r_3T - T + 1 < \frac{\alpha_1\beta_3}{\alpha_3\beta_1}$, the conventional recycling platform loses its market competitiveness. The agency and GSD recycling platforms will form a dual-channel competitive market. Simultaneously, when $v_2 > v_{23}$, the agency recycling platform can engage all inefficient sellers that the GSD recycling platforms cannot attract. In contrast, when $v_2 < v_{23}$, the agency recycling platform provider cannot engage all low-end sellers; therefore, the market may form two competitive models (Figs. 13.11 and 13.12):

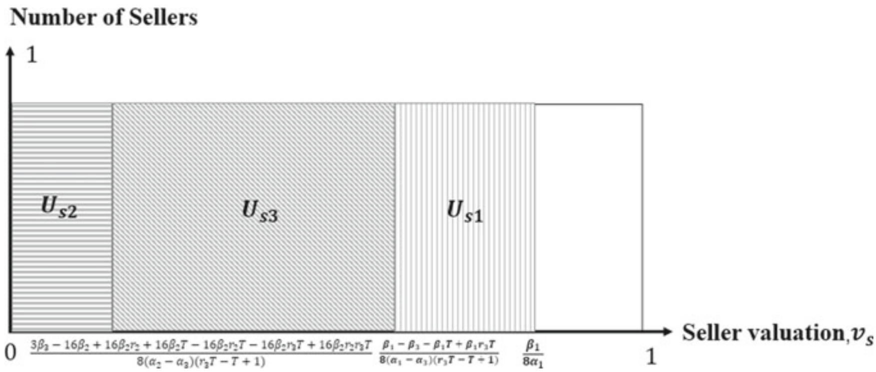

Fig. 13.9 The first situation of the multi-channel competition where three platforms coexist

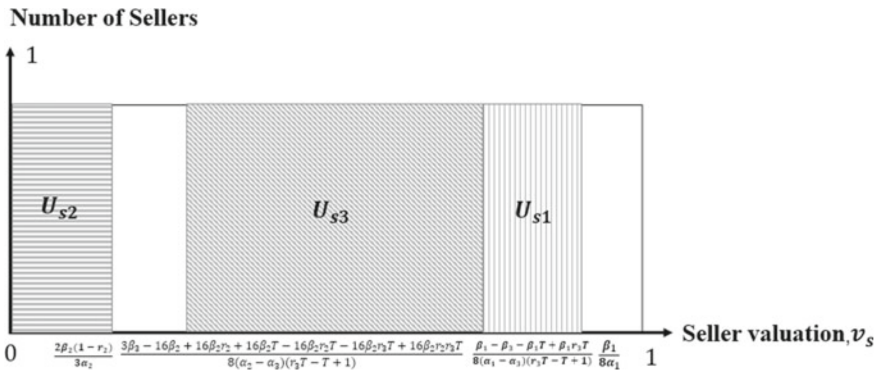

Fig. 13.10 The second situation of the multi-channel competition where three platforms coexist

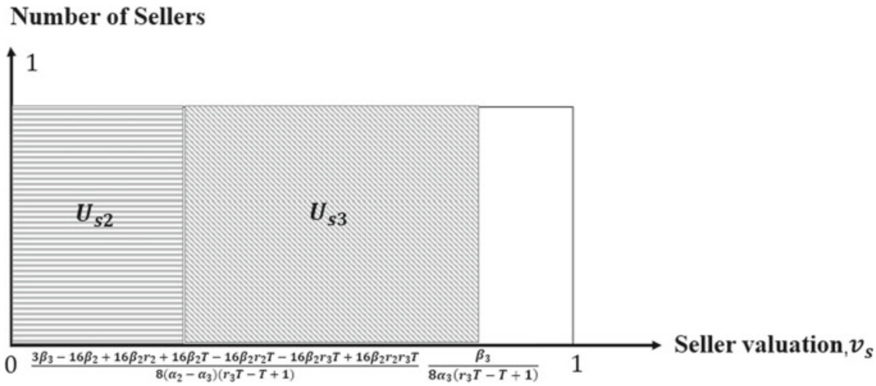

Fig. 13.11 The first situation of the dual-channel competition between the GSD and agency recycling platforms

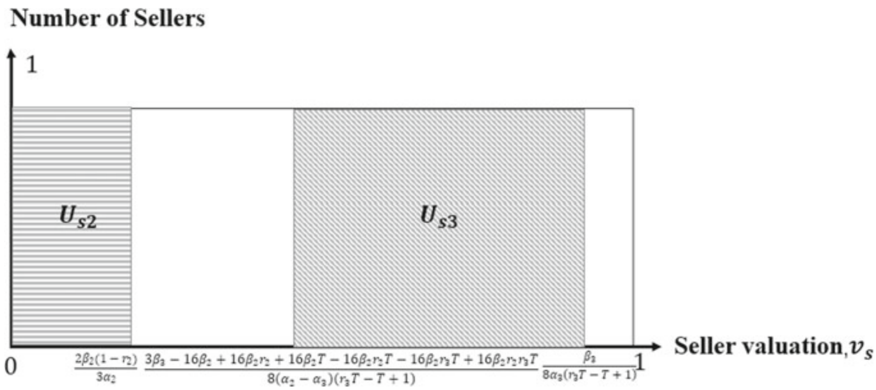

Fig. 13.12 The second situation of the dual-channel competition between the GSD and agency recycling platforms

13.3.4 Analysis and Conclusions

This study first introduces different recycling models, such as the third-party platform conventional, agency, and GSD recycling, into the decision-making of the platform. It studies the pricing behavior adopted by the three models based on their advantages and disadvantages in the online recycling platform of used products. For example, third-party platform conventional recycling reduces the manufacturer's transaction risk, while third-party platform agency recycling increases the probability of high-priced recycling for consumers. Furthermore, this study considers a competitive market environment to explore competition among the three platform recycling models. It differs from previous research on the platform economy in that it uses the concept of two-sided markets to compare the three types of competition. By comparing the three recycling models, we obtain the best decisions for the platform. We also find that these three channels have different competitive advantages in attracting consumers with different preferences or from different market segments.

The main conclusions are as follows:

(1) Third-party platforms that use agency recycling should not attempt to set extremely high agency rates, even if they occupy a near-monopoly position in the market. Doing so could hurt consumers' and manufacturers' willingness to recycle on the platform. However, the agency rate should not be reduced too much; doing so will hurt the profit margin of the platform. The platform should set a modest agency rate to maintain its optimal profits and market share. It should provide more services to help buyers and sellers identify the value of used products more accurately and increase consumer acceptance.

(2) Regardless of which recycling model the third-party platform chooses, the recycling price and the profit of the platform increases with an increase in the manufacturer's willingness to recycle and decreases with a decrease in the consumer's willingness to recycle. This result illustrates the importance of enhancing the bilateral users' willingness to recycle. For example, the platform could develop a more robust quality assessment and pricing system that enables sellers to estimate the quality of their used products more accurately. The platform should also provide buyers with as much product information as possible, to enhance their trust in the information provided. These methods can help the platform increase its price and profit margins.

(3) The implementation of the GSD recycling model is determined by the relationship between the GSD and the agency rate. Within a certain threshold determined by the agency rate, extending the GSD increases the profitability and recovery rate of the recycling platform. For sellers, the GSD model eliminates the risk of failed recycling of used products, and low fees increase the recovery profits. Therefore, the GSD model can be a platform that absorbs more consumers in a competitive market, seizes market share, and further promotes the restructuring of the product recycling value chain.

(4) In a competitive market, the platform can choose more targeted recycling channels based on consumers' willingness to recycle. As previously mentioned,

these three models have different market segments for bilateral users. The new GSD model mainly captures the market share of the conventional and agency recycling models. The conventional recycling model may even be excluded from the used product recycling market. This reflects the competitive advantage of the emerging platform economy in used market recycling and proposes the direction of the value chain reconstruction of Internet recycling enterprises.

Our research has practical implications for recycling platforms that determine their trading model. As discussed in the context of this study, platforms can establish a direct connection between manufacturers and consumers, as consumers increasingly choose to trade their used products on online marketplaces. However, when dealing with consumers with different levels of market acceptance, the same recycling model may not be profitable for third-party platforms. Therefore, a platform's choice of recycling mode requires further research.

13.4 Summary

This chapter mainly studies resource recycling, which is circular in the enterprises' green growth model. Resource recycling is an important element for enterprises to achieve green transformation and growth and an important link in the upgrade and reconstruction of enterprise value chains. The driving forces that promote the implementation of resource recycling and circular economy by enterprises include consumers' environmental protection concepts, government environmental protection rules, Non-Governmental Organizations' environmental protection calls, and the reconstruction and upgrade of the value chain. Combined with the historical context, this chapter builds an online market model. We study the recycling competition of a used product recycling trading platform using a new business, technology, and model of "Internet + green recycling." We propose management insights and suggestions for enterprises to achieve green transformation and value chain reconstruction.

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Chapter 14
Supply Disruptions and Value Chain Reconstruction

Qi Jiang, Bin Wei, Nengmin Wang, and Zhengwen He

Abstract Supply disruptions hinder the smooth circulation of resources, technology, and services within the value chain, seriously affecting enterprises' green growth. Effectively dealing with supply disruptions and minimizing their impact are vital to ensure the circulation of the value chain and achieve green growth. This chapter discusses the relationship between supply disruptions and enterprises' green growth and summarizes the ex-ante defense strategies, in-process control strategies, and ex-post coordination strategies of enterprises in response to supply disruptions. Then, in a scenario of cross-border supply disruptions, a procurement game model involving two manufacturing enterprises is established, and the procurement and production strategies of enterprises and their applicable conditions are analyzed. The research shows that the supply risk can increase the output of enterprises to some extent; enterprises with first-mover advantages often have higher profits; when the enterprise conducts emergency procurement, the strategy of ordering ahead of the competitor can achieve the optimal profit in all cases.

14.1 Supply Disruptions and Enterprises' Green Growth

14.1.1 Supply Disruptions

Globalization has constructed a global value chain system. By integrating the division of labor and cooperation of the global value chain, enterprises can utilize and circulate

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resources, technology, and products on a global scale. In the process of continuous development of the global value chain, the complex, dynamic, and highly uncertain environment poses a threat to enterprises' value chains, leading to their disruptions. The destruction of the value chain indicates that the interconnection of entities in the value chain is broken and the enterprises fail to materialize value creation and gain competitive advantage, which is mainly reflected in the form of supply chain disruptions.

In recent decades, various uncertain events, such as the rise and implementation of deglobalization and the outbreak of COVID-19, have resulted in supply chain disruptions. According to Resilinc, a California supply chain monitoring company, reports of supply chain disruptions in 2020 have increased by 67%, compared to that in 2019.[1] Supply chain disruptions are unplanned and unexpected events that interrupt the normal flow of goods and materials within the supply chain, therefore, enterprises encounter operational and financial risks [1]. Supply chain disruption risks can be divided into three categories according to the source of the risks: disruption risks internal to the firm, including the process disruptions and control disruptions; disruption risks external to the firm but internal to the supply chain, including supply disruptions and demand disruptions; and the disruption external to the supply chain, that is, environmental disruption [2]. Supply disruptions usually occur in the upstream of the supply chain, which is related to the situation in which suppliers are unable to provide products or the products cannot be delivered to customers [3]. Parast and Subramanian found that supply disruptions have the greatest impact on supply chain performance [4]. Therefore, it is crucial for enterprises to reduce supply chain disruptions to ensure the growth of their value chain.

14.1.2 Causes for Supply Disruptions

Typically, the external environment, internal operations and management strategies of enterprises account for supply disruptions.

In terms of the external environment, there have been profound changes in the international political and economic situation. For one thing, the increase of geopolitical risks has blocked the free flow of production factors. For example, the political turmoil in Guinea in September 2021 hindered aluminum ore exports, which resulted in a short-term surge of more than 30% in global aluminum prices and had a far-reaching impact on the manufacturing industry, raising concerns about the supply disruption.[2] For another thing, the regulations of trade affect the effective utilization of resources. Phadnis and Joglekar argued that changes in regulations would lead to supply chain disruptions [5]. For instance, due to the trade disputes between

[1] https://www.resilinc.com/learning-center/white-papers-reports/resilinc-annual-report-2020-carpe-diem/

[2] https://www.republicworld.com/world-news/africa/military-coup-in-guinea-aluminum-prices-hit-decade-high-amid-concerns-over-bauxite-export.html.

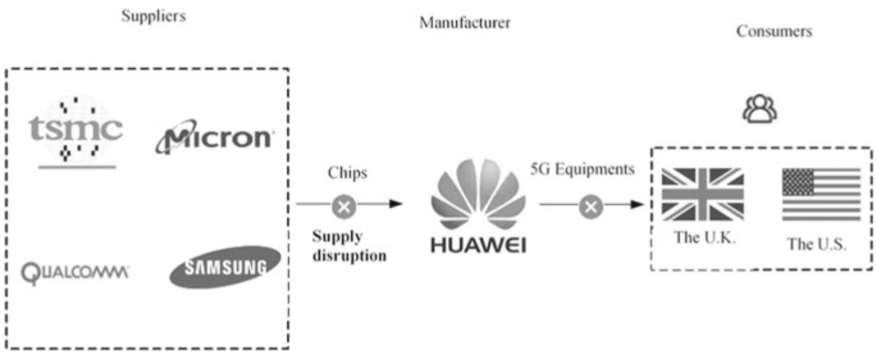

Fig. 14.1 The deconstructed value chain of Huawei

China and the United States, the U.S. government included Chinese technology giant Huawei in its export control entity list, prohibiting the sale of items manufactured with controlled U.S. technology or software to Huawei.[3] The production of Huawei 5G mobile phones was confronted with a great crisis because of the unavailable mobile phone chips, components, and technology. Meanwhile, Western countries, such as the United States, Britain, and Sweden, banned Huawei 5G equipment from their networks. Consequently, enterprises in these countries have also encountered supply disruptions. Hence, the value chain of Huawei has been broken, as shown in Fig. 14.1.

Natural disasters and accidents can also lead to supply disruptions. For instance, the global pandemic of COVID-19 is seen as a supply chain disruptor. Wuhan, which was hit hardest in the initial stage of the epidemic, had to lock down the city and close factories to contain the spread of the virus.[4] Hubei Province, whose capital is Wuhan, clustered many automobile vehicle manufacturers and component manufacturers. The blockage in Wuhan ravaged automobile production bases, not only interrupting automobile production in China but also creating a massive supply disruption of automobile components in the global supply chain. In addition, supply disruption can be attributed to unanticipated events. In March 2021, the containership Ever Given ran aground in the Suez Canal, lodging herself against both banks of the waterway and halting the traffic. The accident caused port congestion and led to suppliers' inability to deliver raw materials to manufacturers in time.[5] Owing to supply shortages, some manufacturers had to stop production.

As for operations and management strategies of enterprises, the operational situation of the supplier could lead to supply disruptions. De Oliveira and Handfield mentioned that during the global economic recession in 2008, longer payment terms imposed on suppliers by some buyers cause suppliers to suffer from a shortage of

[3] https://economictimes.indiatimes.com/news/international/business/us-includes-huawei-india-in-its-export-control-entity-list/articleshow/75844494.cms.

[4] https://abcnews.go.com/Health/timeline-coronavirus-started/story?id=69435165.

[5] https://edition.cnn.com/2021/07/07/business/ever-given-suez-canal/index.html.

funds and potential disruptions [6]. Moreover, the operational strategies adopted by suppliers could result in supply disruptions. Ambulkar et al. proposed that enterprises implementing more product innovation may increase their dependence on suppliers and product diversity, thereby increasing the risk of supply disruption [7]. Insufficient production yield intensifies the supply uncertainty as well. Finally, the quality of products provided by suppliers is an important contributor to supply disruption. Speier et al. pointed out that low-quality products may lead to product recalls, which is a costly reverse supply chain activity [8].

14.1.3 Impact of Supply Disruptions on Enterprises' Green Growth

Supply disruptions have brought serious consequences to enterprises. First, the shortage of resources, technology, and key components leads to the suspension of production by manufacturers; thus, enterprises are unable to operate normally and achieve growth. Chakraborty et al. analyzed the impact of COVID-19 on the supply chain of textile, apparel, and fashion manufacturing, and concluded that the outbreak of the pandemic increases production costs and reduces apparel consumption [9]. Hendricks et al. studied the impact of the 2011 Great East Japan Earthquake on corporate financial performance, and found out that companies experiencing supply chain disruptions due to the earthquake lose an average of 3.73% of shareholder value in the following month [10].

Second, once supply disruptions occur, there is a supply and demand mismatch. Supply disruptions often lead to the rise of product prices in the end market. In 2021, as the semiconductor production decreased, the production capacity of automobile chips became significantly inadequate. As a result, global semiconductor companies such as Renesas in Japan, NXP semiconductors in the Netherlands, and Toshiba in Japan have raised the price of semiconductor products for automobiles.[6] Although the rise in chip prices increases chip manufacturers' profits, it undermines the profits of vehicle manufacturers, thereby affecting the growth of enterprises. Furthermore, supply disruptions engender a waste of resources, which means that enterprises cannot effectively implement green practices. As mentioned, some Western countries prohibit the sale of Huawei's 5G equipment. This prohibition makes Huawei lose customers and hold excess inventory on a global scale, which proves to be a waste of resources worldwide.

Finally, the disruption risks have a ripple effect, that is, the disruption in the supply chain transmits and influences the overall performance of the supply chain. The disruption in the upstream of the supply chain may be transmitted to the downstream of the supply chain, and vice versa [11]. Swierczek found that disruptions in the supply chain intensify during the transmission process [12]. According to a report

[6] https://www.allchips.ai/news/automotive-chips-shortage-renesas-nxp-st-increase-their-prices-by-10-20.

by His Markit in 2021, the global shortage of semiconductors has led to a reduction of 7.1 million vehicles in global automobile production this year.[7] Supply disruptions have forced automobile manufacturers to reduce or even halt production. Holweg and Helo indicated that value is created by a group of different firms in order in the value chain [13]. Ensuring that the linear flow of information and materials is disrupted as little as possible is an effective way to increase value. It is clear that supply disruptions not only prevent the effective utilization and circulation of resources and products, but also cause a waste of resources. The inability to create value in the entire supply chain makes it necessary to reconstruct the value chain.

14.2 Solutions to Supply Disruptions

To avoid frequent supply disruptions, enterprises must take risk-prevention measures to achieve green growth. In general, enterprises adopt ex-ante defense strategies before supply disruption, in-process control strategies when supply disruption occurs, and ex-post coordination strategies after supply disruption.

14.2.1 Ex-ante Defense Strategies

The ex-ante defense strategy of supply disruption is mainly to prevent supply disruptions by taking corresponding measures before the disruption to reduce the losses of enterprises after the disruption. The ex-ante defense strategy of supply disruption is indispensable for improving supply chain resilience and reducing operational risk. Ex-ante defense strategies for supply disruptions include establishing an early risk warning system, safety stocks, multi-sourcing strategy, and contract mechanism.

(1) Establishing an Early Risk Warning System

Establishing an effective early risk warning system can help enterprises respond to emergencies in advance, adjust their operation modes, thus reducing the impact of risks on profits. However, in the normal operation of enterprises, they seldom take the initiative to incur extra costs to build an early warning system, and they only realize the importance of an early warning after the disruption. Special attention should be paid to the following two aspects when building an early risk warning system in the value chain. First, from the perspective of the value chain level, when establishing an early risk warning system, all members of the whole value chain should be considered, including upstream suppliers, enterprises, and customers, because this risk can be transmissible. The impact of risk can be reduced to the greatest extent by coordinating the interests of all members of the value chain. Second, from the

[7] https://ihsmarkit.com/research-analysis/major-revision-for-global-light-vehicle-production-forecast.html.

perspective of the enterprise, enterprises' businesses such as market forecasts, logistics, and their relevant information flow and capital flow, should be considered. The early risk warning system can respond to market demand in time and avoid logistics disruptions, capital fractures, and other information deviations, thus improving the flexibility of the value chain. For example, using the traceability of blockchain technology, both upstream and downstream enterprises in the value chain can use blockchain technology to share resources and information to better coordinate the value chain. Another example is the kiwifruit supply chain from New Zealand to China; information on fruits can be obtained by scanning the code, ranging from the place of origin to the temperature in the process of picking, transportation, and sales.[8] Therefore, product quality could be better monitored to prevent sudden supply disruptions. In addition, the use of blockchain technology can significantly reduce intermediaries and simplify contract procedures. This technology has fundamentally changed the structure or power relationship of the supply chain, better reconstructed the value chain, and is better adapted to the green growth needs of enterprises [14].

(2) Safety Stocks

Setting safety stocks is one of the common strategies to deal with supply disruptions. By reserving a certain amount of raw materials or inventories, enterprises can maintain production activities or directly meet customer needs through inventory products after supply disruptions. However, this strategy will require company funds and generate costs that cannot be ignored. For small companies with low profit margins, a tradeoff between cost control and supply risk is required. Gao studied a dynamic risk management problem with collaborative forecasting, contract coordination and inventory hedging by developing a high fidelity Markov model. And he found that the model is superior to traditional inventory hedging and lean management by reducing premature inventory holdings at a good time and increasing safety stock in time before the looming disruptions [15].

(3) Multi-Sourcing Strategy

In a multi-sourcing strategy, companies do not rely only on a single supplier to provide products when purchasing. Relying on a single supplier exposes the enterprise to the risk of greater disruption, and the company is likely to lose its pricing power because of the dominance of one supplier. Therefore, a multi-sourcing strategy requires enterprises to comprehensively consider two or more suppliers and distribute them across different regions when selecting suppliers. This strategy can alleviate the passive dependence of a single supplier and thus improve the resilience of the value chain. Moreover, due to competition among upstream suppliers, enterprises can obtain a certain advantageous position in terms of procurement quantity, quality, and speed; they can obtain higher-quality products at a lower price. For example, in 2015, Samsung and GlobalFoundries both won the A9 processor supply contract for the iPhone 6S, with Samsung being the main supplier and GlobalFoundries the

[8] https://www.gs1.org/standards/fresh-fruit-and-vegetable-traceability-guideline/current-standard.

standby supplier.[9] Akella et al. addressed the operational issue of quantity allocation between two uncertain suppliers and their effects on buyers' inventory policies. They proposed dealing with supply uncertainty first and considering the procurement quantity allocation strategy under dual source procurement to mitigate risk [16]. However, a multi-sourcing strategy will undoubtedly increase the complexity of the value chain and the operational costs of enterprises. Jafar and Namdar et al. compared the performance of single source procurement and dual source procurement in dealing with supply disruption risks and operational risks, and found that different risk types affect the choice of procurement strategy; multi-sourcing is not always dominant under a certain supply risk level [17].

(4) Contract Mechanism

Once a supply disruption event occurs, the downstream manufacturers are often the risk-bearers. For example, as the world's largest semiconductor chip manufacturer, Intel will bear losses if production is disrupted owing to suppliers' equipment failure. Therefore, Intel requires the installation, maintenance and service of semiconductor equipment suppliers to meet their own standards.[10] How does Intel ensure that suppliers deliver on their commitment to restore their devices quickly? Therefore, the design of the contract mechanism is particularly important. A contract is a legally enforceable agreement between two or more people to create contractual obligations between them. The contract mechanism can bring a balance between the rights and obligations of both parties and is conducive to the unity of efficiency and fairness. Cohen et al. designed a performance-based contract mechanism stipulating that suppliers receive the corresponding compensation according to the normal operation time of the system. They demonstrated that if the disruption is caused by exogenous factors such as natural disasters, the performance contract based on the average disruption time of the sample is better. However, if the disruption is caused internally by the supplier, a performance contract based on the cumulative disruption time is preferred [18].

14.2.2 In-process Control Strategies

When a supply disruption occurs, the manufacturer needs to respond in time to resume production as soon as possible, maintain the normal operation of the value chain, and minimize the losses caused by the disruption. In the disruption process, alternative procurement strategies, dynamic emergency procurement strategies, and responsive pricing strategies are usually adopted.

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[9] http://www.informationweek.com/mobile/mobile-devices/samsung-supplying-apples-a9-processor-for-next-iphone/a/d-id/1319766.

[10] https://www.intel.com/content/dam/www/public/us/en/documents/supplier/supplier-ehs-performance-requirements.pdf.

(1) Alternative Procurement Strategy

An alternative procurement strategy requires enterprises to be able to produce alternative parts or raw materials when production is limited because of supply disruptions caused by emergencies. This strategy can provide sufficient time for the supply chain to repair and reduce losses. Because of trade disputes between China and the United States, some American enterprises are restricted from providing parts needed for Huawei's equipment production, which leads to the obstruction of production. Therefore, Huawei continues to invest in key parts enterprises and strives to improve the supply ability of domestic suppliers. Some parts have been fully produced domestically, laying the foundation for the normal operation of the company in the future. In addition, most global multinational manufacturing companies such as Intel, have built many semiconductor manufacturing plants around the world through the "precision replication" model, adopting identical production processes and standards. If one of the supply bases encounters natural disasters such as earthquakes or tsunamis, the production of the company can be quickly supplemented by other bases, thus not having a significant impact on corporate profits.

(2) Dynamic Emergency Procurement Strategy

Dynamic emergency procurement is a common measure for dealing with supply disruption and has been widely used in actual operations. As the market is dynamic, enterprises must comprehensively consider customer preferences, market demand, and other factors. In the face of sudden supply disruptions, manufacturers can obtain replenishment from secondary suppliers, that is, spot markets or standby suppliers, at a higher price. If the manufacturer turns to the secondary supplier immediately after the shortage and continues to purchase until the main supplier returns to normal, the supply of raw materials after the supply disruption of the primary supplier may remain stable without loss of production capacity. If the primary supplier can recover quickly, the manufacturer can obtain replenishment at the normal price to avoid greater losses. However, if the disruption lasts for a long time, there will be a loss of some part of the market demand, which will cause direct short-term economic losses or even long-term losses to the manufacturer, such as deterioration of reputation and reduction of market share [19]. Yong He et al. demonstrated that dynamic demand and dynamic inventory after supply disruptions can be predicted by considering customer behaviors. By building a sequential model that incorporates various relevant factors, companies can determine the optimal time to purchase, thereby minimizing the impact of disruptions [20].

(3) Responsive Pricing Strategy

Another strategy to alleviate supply uncertainty is responsive pricing; that is, after a supply uncertainty occurs, retailers adjust product prices to a certain extent to better match supply and demand. Such retailers are called responsive pricing retailers [21]. Shan et al. proposed a model in which a retailer purchases at a new retail price from a competitor's supplier at the time of delivery. They concluded that improvements in supplier reliability may be harmful to suppliers because there is competition among suppliers of responsive pricing retailers. A high probability of disruption may favor cost-advantaged suppliers, coupled with supplier competition effects, and the total order volume may increase with an increase in disruption risk [22].

14.2.3 Ex-post Coordination Strategies

Supply disruptions are generally short-term events. With the recovery of productivity and coordination between the upstream and downstream of the supply chain, there is a high probability that a company can return to the status before the disruption. Accumulation of experience provides unique insights into business operations; therefore, after supply disruptions, enterprises should formulate further strategic planning to prevent similar events from reoccurring. This is the only way to ensure the green growth of the supply chain. The following section introduces two aspects: industrial transfer and government coordination.

(1) Industrial Transfer

In the past 20 years, due to the development of economic globalization, an increasing number of enterprises have outsourced manufacturing activities offshore and chosen a lower-cost area for production. However, in the past decade, some enterprises have begun to gradually move manufacturing activities back to their home countries, which is called manufacturing reshoring. The horizontal division of labor structure of the global industrial chain formed in the past three decades has led to too many links in the industrial chain, long transportation distances, and high logistics costs, which increases the risk of global industrial chain disruption. Furthermore, frequent international economic and trade frictions have increased the geopolitical risks faced by multinational corporations, severely damaging the original open global trade system, and unprecedentedly hindering the cross-border flow of production factors. This has resulted in the complete disruption of production of some enterprises because of a shortage of key parts and components. Therefore, multinational enterprises prioritize areas close to the headquarters for production or procurement. Wu et al. demonstrated a procurement game model in which competitive enterprises can choose between low-cost procurement such as overseas procurement, and rapid-response procurement such as home-country procurement. They found that, in the case of more unstable demand, shrinking market size, and rising global commodity prices, the reshoring strategy is better [23].

(2) Government Coordination

The macroeconomy and the international situation have left enterprises in a weak position in decision-making. The government should provide a sound security system with mutual benefits for domestic enterprises or enterprises from other countries. Free Trade Agreements (FTAs) are legally binding contracts between two or more countries, whose purpose is to promote economic integration. One of its objectives is to eliminate trade barriers, allowing the free flow of products and services among countries. This is a beneficial tool for reducing the possibility of supply disruptions. At the same time, the Chinese government has accelerated the establishment of "dual circulation" development patterns, in which the domestic economic cycle plays a leading role while the international economic cycle remains its extension and supplements it, aiming to encourage the large-scale market and domestic demand. This policy helps enterprises to reduce the uncertainty of long-distance operations. Overall, enterprises need to improve their independent innovation ability, whereas the government needs to actively guide the cultivation of local market demand.

14.3 Analysis of Enterprise Emergency Sourcing Strategy Under the Risk of Cross-Border Supply Disruption

14.3.1 Introduction to Cross-Border Supply Disruption

Emergency sourcing has become a key strategic decision for mitigating the risk of supply disruptions. Enterprises mainly consider the following three factors when choosing procurement sources: the first is low operational costs, which are obtained through access to low-cost raw materials and industrial cluster efficiency; the second is market advantage, which is acquired by being close to the sales market and using local infrastructure and suppliers; the third is the future development ability cultivated through access to the necessary knowledge or technical resources from advanced suppliers or research institutions [24]. Considering the above factors, manufacturers must weigh the cost and disruption risk when selecting suppliers. In general, sourcing from non-native developing countries can provide cost advantages, but there is a risk of supply disruption due to product quality, delivery times, strikes, and so on. For example, owing to strict environmental regulations and rising labor costs in China, some manufacturing industries, such as clothing and household products, have been transferred to India and Southeast Asian countries.[11] However, inadequate infrastructure in these areas, strikes, and the COVID-19 pandemic may cause disruptions in production.

Based on the real situation, we study the following three questions:

(1) When there is a risk of supply disruption, how does a manufacturer decide where to source from?
(2) How does the emergency sourcing strategy affect the manufacturer's profit?
(3) How does the decision-making time for the manufacturer's emergency procurement affect its profits?

To answer these three questions, we established a model comprising two manufacturers and two suppliers. Two manufacturers produce the same product at the

[11] https://www.unreservedmedia.com/clothing-factories-grow-in-southeast-asia/

same time and engage in Cournot competition. In most cases, companies compete for market sources from different suppliers. If there are only two suppliers in the market, after a disruption event in one supplier, the other supplier is likely to increase wholesale prices. In turn, downstream firms that have been interrupted can purchase from other suppliers at higher prices to compensate for losses.

14.3.2 Mathematical Modeling

Consider a single-period duopoly, in which two manufacturing firms compete in the same market by selling substitutable products. One manufacturer M mainly procures parts from a low-cost foreign supplier F with a probability of supply disruption at a unit procurement price of c_1. Manufacturer C is a competitive manufacturer, acting as a competitor. For comparison, the competitor only procures from a high-cost but reliable domestic supplier D at a unit procurement price of c_2. The probability of foreign supplier disruption is q. When a disruption event occurs, the foreign supplier does not provide anything, that is, the "all-or-nothing" supply mode. Here, we use the binary random variable $X \in \{0, 1\}$ to represent the production delivery of foreign suppliers. In particular, when supply disruptions occur, $X = 0$. Therefore, when a disruption occurs, the manufacturer M can choose to make emergency procurements

Table 14.1 Notations of parameters

Parameter	Definition
Q_j^i	Orders placed by firm j in different strategies i
	$i = B$ represents the benchmark model
	$i = 1, 2, 3, 4, 5$ represents 5 different situations
	$j = M$ represents the manufacturer
	$j = C$ represents the competitor
	$j = E$ represents emergency sourcing
a	Potential market size
X	$X \in \{0, 1\}$, the supply state of foreign supplier
c_1	Manufacturer's unit cost of procurement from foreign supplier
c_2	Competitor's unit cost of procurement from domestic supplier
c_3	Manufacturer's unit cost of procurement from domestic supplier
q	Probability of supply disruption,$0 \leq q \leq 1$
π_j^i	Expected profit of firm j under different strategy i
S^i	Total product quantity under different strategy i

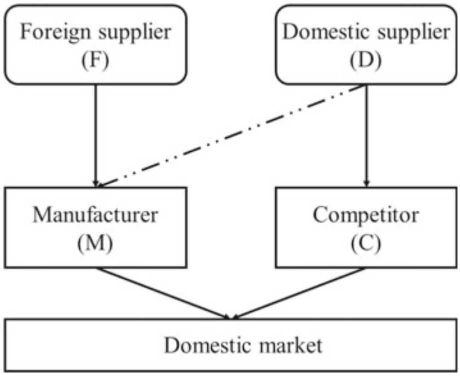

Fig. 14.2 Pictorial representation of the model

from the domestic supplier D. However, due to a lack of long-term cooperation, the domestic supplier charges a higher wholesale price c_3; hence, we have $c_1 < c_2 < c_3$. Please refer to Table 14.1 for all the notations and variables used in the analytical models.

It is assumed that both manufacturers are risk-neutral and that there is no information asymmetry. Both manufacturers know the cost of purchasing from different suppliers and the supply status of the foreign suppliers. For ease of exposition, we consider the manufacturer's procurement decision rather than the outsourcing decision, and simplify the production processing cost to 0. Because both enterprises are produced in the same country, the production cost should be close. Since the production cost and procurement cost have a linear relationship, setting the cost to 0 does not affect our main conclusion. Additionally, we assume that the manufacturer's sourcing cost from suppliers refers to the sum of the direct costs per unit incurred by the manufacturer when purchasing products, including procurement, logistics, handling, and labor costs. Finally, we assume that the domestic supplier has no risk of supply disruption and that they can flexibly increase the supply of their own products to meet the market demand in a very short delivery time without capacity constraints. The model is depicted in Fig. 14.2.

14.3.3 Model Analysis Under Different Sourcing Strategies and Decision Sequences

We model the manufacturer and the competitor to engage in quantity competition by selling substitutable products. The Cournot model is appropriate in our situation, because we focus on firms' procurement quantity decisions under supply uncertainty. Specifically, given the firms' procurement quantities Q^i_j, the market clearing price p is determined by a linear inverse demand function $p = a - S$, where S is the total product quantity and a is the total market size. We assume that a is sufficiently large to guarantee positive profits for all players. According to the manufacturer's and competitor's decision-making and emergency procurement time orders, we divide the situation into benchmark models and five other special cases. Notably, we assume that the manufacturer decide to buy from foreign suppliers no later than the competitor because cross-border procurement involves long-distance transport and demand fluctuations, and companies must order in advance.

(1) Benchmark model: Both manufacturer and competitor source from domestic suppliers

The demand function faced by the manufacturer and the competitor in the end consumer market is

$$p = a - Q_M^B - Q_C^B.$$

The profit functions of the manufacturer and the competitor are

$$\pi_M^B = (p - c_3)Q_M^B, \pi_C^B = (p - c_2)Q_C^B.$$

(a) Both the manufacturer and the competitor make decisions at the same time, and the optimal order quantities are

$$Q_M^B = \frac{1}{3}(a + c_2 - 2c_3),\ Q_C^B = \frac{1}{3}(a - 2c_2 + c_3).$$

The maximum profits of the manufacturer and competitor are

$$\pi_M^B = \frac{1}{9}(a + c_2 - 2c_3)^2, \pi_C^B = \frac{1}{9}(a - 2c_2 + c_3)^2.$$

(b) When the competitor is a Stackelberg leader, the competitor makes quantity decisions before the manufacturer. We can easily obtain

$$Q_M^B = \frac{1}{4}(a - 3c_2 + 2c_3),\ Q_C^B = \frac{1}{2}(a + c_2 - 2c_3).$$

The maximum profits of the manufacturer and competitor are

$$\pi_M^B = \frac{1}{16}(a - 3c_3 + 2c_2)^2, \pi_C^B = \frac{1}{8}(a + c_3 - 2c_2)^2.$$

(c) When the manufacturer is a Stackelberg leader, the manufacturer makes quantity decisions before the competitor. Note that the result is symmetric to case (b); therefore,

$$Q_M^B = \frac{1}{2}(a + c_2 - 2c_3),\ Q_C^B = \frac{1}{4}(a - 3c_2 + 2c_3).$$

and

$$\pi_M^B = \frac{1}{8}(a + c_2 - 2c_3)^2, \pi_C^B = \frac{1}{16}(a - 3c_2 + 2c_3)^2.$$

From the equilibrium results, we can find that under three different decision sequences, when manufacturer and competitor source from domestic suppliers, the optimal profits are $\frac{1}{8}(a+c_2-2c_3)^2$ and $\frac{1}{8}(a+c_3-2c_2)^2$, respectively. From $c_2 < c_3$, we can see that the optimal profits are $\pi_M^B < \pi_C^B$.

This result shows that among the three different market power structures, the leader of the Stackelberg game can make more profits than in the case of simultaneous decision-making. In addition, the largest profit of the competitor is greater than that of the manufacturer, which indicates that a firm with an adequate cost advantage has a first-mover advantage in a duopoly. Therefore, the manufacturer has an incentive to purchase overseas, even if there is a risk of supply disruption. There are several cases of manufacturer procurement from foreign suppliers.

(2) Case 1

In this case, the manufacturer can purchase from both domestic and foreign suppliers. If and only when the foreign supplier defaults, will the manufacturer choose a domestic supplier at a high cost.

The sequence of events is as follows. In the first stage, the manufacturer and competitor simultaneously place orders with foreign and domestic suppliers at the same time. In the second stage, after the supply risk situation is observed, the manufacturer receives XQ_M^1 from a foreign supplier, and the competitor receives Q_C^1 from a domestic supplier. If the foreign supplier defaults, the manufacturer will conduct an emergency procurement Q_E^1 from another expensive domestic supplier. Finally, the market clears.

Using backward induction, we can easily obtain the firms' optimal decisions and their corresponding profits. First, we discuss it in two cases according to whether the disruption occurs or not. If no supply disruption event occurs, i.e. $X = 1$, then clearly, $Q_E^1 = 0$. However, when $X = 0$, it means that the manufacturer cannot get any orders, so they will maximize their profit by emergency sourcing Q_E^1 from domestic suppliers, i.e., $\max_{Q_E}\left[\left(a - Q_E^1 - Q_C^1 - c_3\right)Q_E^1\right]$. So $Q_E^1 = \frac{a-Q_C^1-c_3}{2}$, when $X = 0$.

After obtaining the number of emergency orders, we obtain the Nash equilibrium of the manufacturer and competitor. The maximum profits of the manufacturer and competitor are:

$$\max_{Q_M^1}\left[(1-q)\left(a - Q_M^1 - Q_C^1 - c_1\right)Q_M^1 + q\left(\frac{a - Q_C^1 - c_3}{2}\right)^2\right],$$

$$\max_{Q_C^1}\left[(1-q)\left(a - Q_M^1 - Q_C^1 - c_2\right)Q_C^1 + q\left(a - \frac{a - Q_C^1 - c_3}{2} - Q_C^1 - c_2\right)Q_C^1\right].$$

Solving First Order Conditions, we can get

$$Q_M^{1^*} = \frac{(2-q)(a-2c_1)+2c_2-qc_3}{2(3-q)};\ Q_C^{1^*} = \frac{a+(1-q)c_1-2c_2+qc_3}{3-q}.$$

Next, substitute $Q_M^{1^*}$ and $Q_C^{1^*}$ into Q_E^1's function, we can get,

$$Q_E^{1^*} = \begin{cases} 0, X=1 \\ \frac{(2-q)a+(q-1)c_1+2c_2-3c_3}{2(3-q)}, X=0 \end{cases}.$$

Finally, we find the respective expected profits of the manufacturer and the competitor,

$$E\left(\pi_M^1\right) = \frac{q[(2-q)a+(q-1)c_1+2c_2-3c_3]^2 + (1-q)[(q-2)(a-2c_1)-2c_2+qc_3]^2}{4(3-q)^2}$$

$$E\left(\pi_C^1\right) = \frac{(2-q)[a+(1-q)c_1-2c_2+qc_3]^2}{2(3-q)^2}.$$

The expected total output of the market is

$$\begin{aligned} E\left(S^1\right) &= (1-q)\left(Q_M^{1^*}+Q_C^{1^*}\right)+q\left(Q_E^{1^*}+Q_C^{1^*}\right) \\ &= \frac{(4-q)a-\left(2-3q+q^2\right)c_1-2c_2+(q^2-2q)c_3}{2(3-q)} \end{aligned}$$

From the result of Case 1, we can deduce that $Q_M^{1^*}$ increases in c_2 and decreases in q, c_1 and c_3; $Q_C^{1^*}$ is an increasing function of q,c_1 and c_3, and $Q_C^{1^*}$ is a decreasing function of c_2; $Q_E^{1^*}$ decreases in q, c_1, c_2 and c_3.

These conclusions indicate that when c_2 increases, the foreign supplier has a higher cost advantage than the domestic supplier; thus, the manufacturer will increase orders from foreign suppliers. The increased disruption risk q of the foreign supplier implies that the cost advantage of the manufacturer's overseas procurement decreases. As a result, the manufacturer buy less from foreign suppliers, and the competitor buy more from domestic suppliers.

It is worth noting that in the equilibrium in Case 1, the expected total market output decreases in c_1, c_2, and c_3. The expected total market output increases in q only if $-\left(7-6q+q^2\right)c_1+2c_2+\left(6-6q+q^2\right)c_3 < a$, and does not increase otherwise. This conclusion shows that the increase in firms' procurement cost represents the decline in total market output. In a specific risk area, the greater the risk, the higher the output. Combined with the actual situation, when the manufacturing industry is aware of the risk, it may order more quantities to compensate for the loss of disruption.

(3) Case 2

In this case, the sequence of events is as follows. In the first stage, M places orders from F before C places them from D. In the second stage, the supply state realizes that M receives XQ_M^2 from F, and C receives Q_C^2 from D. Therefore, C leads with its order Q_C^2 and M follows by its emergency order Q_E^2. Finally, the market clears, and both M and C earn profits.

In this case, two Stackelberg game processes exist. The manufacturer orders first as the leader and the competitor orders later as the follower. In the second stage, the competitor leads the manufacturer to order emergency orders. Similar to Case 1, we use the backward induction method to solve the equilibrium solution.

The objective function of C is

$$\max_{Q_C^2}\left[(1-q)\left(a-Q_M^2-Q_C^2-c_2\right)Q_C^2+q\left(\frac{a-Q_C^2+c_3-2c_2}{2}\right)Q_C^2\right].$$

According to the first-order condition,

$$Q^2_{C(Q_M^2)}=\frac{(2-q)a-2c_2+qc_3-2(1-q)Q_M^2}{2(2-q)}.$$

According to the above conditions, the manufacturer's objective function is

$$\max_{Q_M^2}\left[(1-q)\left(a-Q_M^2-Q^2_{C(Q_M^2)}-c_1\right)Q_M^2+q\left(\frac{a-Q^2_{C(Q_M^2)}-c_3}{2}\right)^2\right].$$

In summary, we obtain the equilibrium solution of Case 2:

$$Q_M^{2^*}=\frac{\left(8-6q+q^2\right)a-4(2-q)^2c_1+2(4-q)c_2+\left(3q^2-8q\right)c_3}{2\left(8-5q+q^2\right)},$$

$$Q_C^{2^*}=\frac{2\left[a+\left(2-3q+q^2\right)c_1+(q-3)c_2+\left(2q-q^2\right)c_3\right]}{8-5q+q^2}.$$

Similarly, we get the optimal emergency order $Q_E^{2^*}$:

$$Q_E^{1^*}=\begin{cases}0,\ X=1\\ \frac{\left(6-4q+q^2\right)a-2\left(2-3q+q^2\right)c_1+2(3-q)c_2+\left(q-8+q^2\right)c_3}{2\left(8-5q+q^2\right)},\ X=0\end{cases}.$$

Substituting into the objective profit function, we obtain the optimal profits:

$$E\left(\pi_M^2\right)=\frac{1}{4\left(8-5q+q^2\right)}$$

$$\begin{Bmatrix} 4(2-q)^2(1-q)c_1^2 + (2a-qa+2c_2)^2 + 2q(4-q)(aq-2a-2c_2)c_3 \\ +q\left(8+3q-2q^2\right)c_3^2 + 2(q-1)[(q-4)(aq-2a-2c_2) + q(-8+3q)c_3]c_1 \end{Bmatrix}$$

$$E\left(\pi_C^2\right) = \frac{2(2-q)\left[a + \left(2-3q+q^2\right)c_1 + (q-3)c_2 + \left(2q-q^2\right)c_3\right]^2}{\left(8-5q+q^2\right)^2}.$$

The expected total market output is

$$\begin{aligned} E\left(S^2\right) &= (1-q)\left(Q_M^{2^*} + Q_C^{2^*}\right) + q\left(Q_E^{2^*} + Q_C^{2^*}\right) \\ &= \frac{\left(6-4q+q^2\right)a + (2-q)^2(q-1)c_1 - 2c_2 + \left(4q^2-4q-q^3\right)c_3}{8-5q+q^2}. \end{aligned}$$

The conclusion of Case 2 is very similar to that of Case 1, so we compare and analyze the results at the end.

(4) Case 3

In this case, C makes decisions after M completes overseas and emergency procurement. The game sequence is listed as follows. In the first stage, M places orders on F. In the second stage, the supply state realizes that M receives XQ_M^3 from F, and M makes its emergency order Q_E^3. Next, C orders from D. Finally, the market clears, and both M and C earn profits.

We use the backward induction method to solve the equilibrium solution. First, we consider C's profit maximization problem:

$$\max_{Q_C^3}\left[\left(a - Q_M^3 X - Q^3_{E(Q_M^3,X)} - Q_C^3 - c_2\right)Q_C^3\right].$$

From this function, we can get the best procurement quantity of C. That is

$$Q_C^{3^*} = \frac{a - Q_M^3 X - Q^3_{E(Q_M^3,X)} - c_2}{2}.$$

We need to find the optimal order under supply disruption, so M's expected profit maximization problem is

$$\begin{aligned} \max_{Q_M^3,Q_E^3}\Bigg[&(1-q)\left(a - Q_M^3 - \frac{a - Q_M^3 - c_2}{2} - c_1\right)Q_M^3 \\ &+q\left(a - Q_E^3 - \frac{a - Q_E^3 - c_2}{2} - c_3\right)Q_E^3\Bigg]. \end{aligned}$$

We can get the optimal order quantity by solving the above formula; therefore,

$$Q_M^{3^*} = \frac{a + c_2 - 2c_1}{2},$$

$$Q_E^{3^*} = \begin{cases} 0, X = 1 \\ \frac{a+c_2-2c_3}{2}, X = 0 \end{cases},$$

$$Q_C^{3^*} = \begin{cases} \frac{a-3c_2+2c_1}{4}, X = 1 \\ \frac{a-3c_2+2c_3}{4}, X = 0 \end{cases}.$$

The optimal expected profit of both M and C are

$$E\left(\pi_M^3\right) = \frac{(1-q)(a+c_2-2c_1)^2}{8} + \frac{q(a+c_2-2c_3)^2}{8},$$

$$E\left(\pi_C^3\right) = \frac{(1-q)(a-3c_2+2c_1)^2}{16} + \frac{q(a-3c_2+2c_3)^2}{16}.$$

The expected total market output is

$$E\left(S^3\right) = (1-q)\left(Q_M^{3^*} + Q_C^{3^*}\right) + q\left(Q_E^{3^*} + Q_C^{3^*}\right) = \frac{3a - 2(1-q)c_1 - c_2 - 2qc_3}{4}.$$

It can be seen that when $c_2 = c_3$, $E\left(\pi_M^3\right) > E\left(\pi_C^3\right)$; when the value of c_3 and q is large enough, $E\left(\pi_M^3\right) < E\left(\pi_C^3\right)$. The result shows that if the manufacturer and the competitor have the same cost of domestic procurement, the one who decides first will get the greater benefit, which is the same as the benchmark model. When the cost gap is too large, manufacturers are less profitable than domestic competitors, even with a first-mover advantage and the benefit of a low-risk supply. Furthermore, in the equilibrium state of Case 3, the expected output $E\left(S^3\right)$ is a decreasing function of c_1, c_2, c_3 and q. In this order of decisions, supply risk increases but market output decreases, indicating that manufacturers and competitors tend to buy more to compensate for the impact of supply risk, which is more conducive to consumer surplus. Moreover, the increase in procurement costs leads to a decrease in procurement volume.

(5) Case 4

In this case, M first places orders from F. Next, when C observes M's foreign order delivery, M and C simultaneously determine the emergency procurement of M's and C's orders from domestic suppliers.

The solving process is the same as in the previous cases; therefore, we only list the results here.

M's and C's optimal order quantites are

$$Q_M^{4^*} = \frac{a + c_2 - 2c_1}{2},$$

$$Q_C^{4^*} = \begin{cases} \frac{a-3c_2+2c_1}{4}, X = 1 \\ \frac{a-2c_2+c_3}{3}, X = 0 \end{cases},$$

$$Q_E^{4^*} = \begin{cases} 0, X = 1 \\ \frac{a+c_2-2c_3}{3}, X = 0 \end{cases}.$$

The optimal expected profits of M and C are

$$E\left(\pi_M^4\right) = \frac{(1-q)(a+c_2-2c_1)^2}{8} + \frac{q(a+c_2-2c_3)^2}{9},$$
$$E\left(\pi_C^4\right) = \frac{(1-q)(a-3c_2+2c_1)^2}{16} + \frac{q(a-2c_2+c_3)^2}{9}.$$

The total market output is

$$E\left(S^4\right) = \frac{(1-q)(3a-c_2-2c_1)}{4} + \frac{q(2a-c_2-c_3)}{3}.$$

(6) Case 5

In this case, M first places orders with F, and then both M and C recognize the state of supply. Subsequently, C orders from D. If supply disruptions occur, M makes an emergency procurement. Finally, the market clears.

We can easily get the optimal order quantity:

$$Q_M^{5*} = \frac{a+c_2-2c_1}{2},$$
$$Q_C^{5*} = \begin{cases} \frac{a-3c_2+2c_1}{4}, X=1 \\ \frac{a-c_2}{2}, X=0 \end{cases},$$
$$Q_E^{5*} = \begin{cases} 0, X=1 \\ \frac{a+c_2-2c_3}{4}, X=0 \end{cases}.$$

The optimal expected profits of M and C are

$$E\left(\pi_M^5\right) = \frac{(1-q)(a+c_2-2c_1)^2}{8} + \frac{q(a+c_2-2c_3)^2}{16},$$
$$E\left(\pi_C^5\right) = \frac{(1-q)(a-3c_2+2c_1)^2}{16} + \frac{q(a-c_2)^2}{8}.$$

The total market output is

$$E\left(S^5\right) = \frac{3a-2(1-q)c_1-c_2-2qc_3}{4}.$$

According to the benchmark model and five different cases, we derive the mathematical expression of the equilibrium expected profit for the manufacturer and competitor in all cases. Here, we compare the expected and benchmark profits of the manufacturers and competitors in all cases.

From the perspective of the manufacturer, we can obtain that $E\left(\pi_M^2\right) > E\left(\pi_M^1\right)$, $E\left(\pi_M^5\right) > E\left(\pi_M^1\right)$, $E\left(\pi_M^3\right) > E\left(\pi_M^4\right) > E\left(\pi_M^5\right)$.

From the perspective of the competitor, we can obtain that $E(\pi_C^2) < E(\pi_C^1)$, $E(\pi_C^3) < E(\pi_C^4) < E(\pi_C^5)$, $E(\pi_C^4) < E(\pi_C^1)$.

For the manufacturer, except in Case 3, the expected profit is less than the benchmark model profit. In Case 3,$E(\pi_M^3) > E(\pi_M^B) = \frac{1}{8}(a + c_2 - 2c_3)^2$; for the competitor, all equilibrium profits are less than in the benchmark model.

From Case 3 to 5, the manufacturer executes emergency orders at different times. The earlier they make decisions, known as the Stackelberg leader in the game, the more favorable it is for themselves. Therefore, manufacturers' profits increase, while competitors' profits decrease. By comparing the manufacturer's expected and benchmark profits, we conclude that only in Case 3, the manufacturer's profit is higher than its benchmark profit. The intuitive explanation is that when purchasing from an unreliable supplier, we not only need to have the first-mover advantage but also realize that after the supply state is detected, the manufacturer must deliver the order before the competitor orders. In this way, the manufacturer can achieve excess expected profits. Simultaneously, in all cases, the equilibrium expected profit of competitors is lower than the benchmark profit. Therefore, in Case 3, the profits of the manufacturers are always greater than those of competitors. This opinion provides guidance for multinational enterprises to purchase from risky suppliers.

In summary, through the establishment and analysis of a single procurement strategy for emergency procurement under competition and supply disruption, we find that the supply status of unreliable suppliers and the time when competitors place orders are critical to the profit of buyers operating under supply disruption. As supply disruption cannot be controlled, we suggest that manufacturers make emergency strategies in advance and place orders before competitors to effectively alleviate the negative impact of supply disruption on their profits. In addition, for any strategy, companies that make decisions before competitors can achieve optimal profits. In equilibrium, companies with different procurement costs must choose different strategies according to the suppliers' reliability level. When the reliability of unreliable suppliers is high and the cost is sufficiently low, companies should choose a dual-source emergency procurement strategy. However, this model is relatively simple and has several restrictions. In a realistic situation, suppliers often have capacity constraints, and enterprises may not be able to purchase the required products within a specific time range, which can have a significant impact on the equilibrium.

14.4 Summary

Under the trend of value chain globalization, transnational procurement and global production are common. Supply disruptions are common and affect the green growth of enterprises. Starting from the concept of supply disruption, this chapter analyzes various reasons for supply disruption, including external environment factors, such as natural disasters and international political factors, and enterprises' internal operations and management strategies. Then, it analyzes ex-ante defense strategies, in-process control strategies, and ex-post coordination strategies to cope with supply disruption. Finally, this chapter constructs a game model in which the manufacturer can purchase from unreliable foreign suppliers at low cost as well as domestic stable suppliers for emergency procurement. In contrast, the competitor can only purchase from the domestic market. It is concluded that the dispuption probability of unreliable suppliers and order time of competitors are crucial to buyers' profit under supply disruption. Although supply disruption cannot be predicted and controlled, operators can evaluate the possibility of supply disruptions through the macro environment and professional institutions, combine their own technical competence, and gain an initial advantage to improve their own profit at an optimal level. Future research may consider issues such as supplier capacity constraints, tariffs involved in cross-border procurement, and trade disputes among multilateral governments to better approach reality and provide more accurate suggestions for preventing supply disruption risks and green growth of enterprises.

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Chapter 15
Organization of Value Chain Reconstruction

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Abstract Value chain reconstruction, designed according to green and growth coordination requirements, is a critical path for an enterprise to implement the green growth model and realize green transformation. During value chain reconstruction, the enterprise systematically evaluates each activity's agent and element in the value network and establishes the value chain based on the mission or problem orientation. The reconstruction implementation involves the reselection and matching of cooperation agents, such as the choice of suppliers, and the devotion and adjustment of activity elements, such as the adoption of environmental management technology, is often carried out in the form of a project. Due to the influence of uncertain factors on the value chain reconstruction, the enterprise faces the disturbance of complex and dynamic environments. Hence, it should effectively manage the activities before and during the reconstruction. For the aforementioned facts, the proactive and reactive project scheduling theories can provide important support for the enterprise to reconstruct its value chain. Additionally, because value chain reconstruction involves the coordination of green and growth, its implementation must simultaneously consider time, cost, and schedule robustness. As a result, multi-objective project scheduling theory can also be employed to help the organization of value chain reconstruction. Based on the above discussion, this chapter presents the relationship between value chain reconstruction and project management first. Then, we introduce the model and algorithm for proactive and reactive project scheduling to maximize the net present value (NPV). Finally, we describe the time-cost-robustness trade-off project-scheduling method in an uncertain environment.

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15.1 Value Chain Reconstruction and Project Scheduling

Value chain reconstruction refers to maximizing strategic activities and the main value-added process and minimizing other activities by redefining the basic and auxiliary activities of the enterprise, which improves its core competitiveness and business performance [1]. Thus, taking the green transformation as orientation, value chain reconstruction innovates the organizational fashion of the agent and element for each activity in the value network, according to green and growth coordination requirements. Through the redefinition of basic and auxiliary activities, the enterprise maximizes strategic activities in the main value flow and minimizes other activities, thus improving its green core competitiveness and economic performance. There is an interactive relationship between the green growth model and value chain reconstruction described below. The enterprise green growth model presents a green standard for production elements. This green standard requires the enterprise to innovate the composite mode of the activities' agent and element in its value network and reestablish its value chain considering the coordination between green and growth. According to the environmental friendliness and economic performance requirements, value chain reconstruction innovates the combination of elements in the value network, which is the path for the enterprise to achieve green growth and transformation. Through value chain reconstruction, enterprises can enhance resource efficiency, reduce production costs, and decrease operational risk. As a result, enterprises realize the coordinated development of green and growth and the global optimization of economic, social, and environmental benefits under consideration of cost, environment, and safety.

Due to the impact of the increasingly strict environmental regulations, anti-globalization, and the COVID-19 pandemic, enterprises' circumstances have become more complex, dynamic, and highly uncertain [2]. Meanwhile, upgrading technology, constantly updating demand, and intense market competition require the enterprise to reconstruct its value chain frequently during green growth implementation. In other words, the enterprise must find and adopt new value elements, such as environmental protection technology, and select new cooperation agents in the value chain to realize the whole process environmental management and value creation and sharing in its value network. Value chain reconstruction is generally carried out in the fashion of a project, which needs to consider the uncertainties that occur before and during its course to ensure smooth implementation and comprehensive optimization of the whole process. On the one hand, before the reconstruction, the enterprise should intensively investigate and analyze the uncertain disruptions that may appear in the reconstruction. Based on this, they should employ proactive scheduling to accurately add time and resource buffers to project the baseline schedule so that it can own the ability to resist uncertain interference. On the other hand, when the project baseline schedule has to be modified during the reconstruction owing to the limitation of managers' predictions, reactive scheduling is utilized to generate an optimal adjustment scheme based on the variation in reality to reduce the influence on project execution. From the discussion above, it can be concluded that proactive and reactive scheduling may provide theoretical support for an enterprise to organize its value chain reconstruction.

The basic idea of proactive and reactive project scheduling is the manager generating a robust baseline schedule by adding time and/or resource buffers before starting a project. Then, the schedule is adjusted optimally using proper reactive rules when unexpected disruptions occur. During value chain reconstruction, the enterprise must consider green and growth concurrently and aim to realize proper coordination between these two objectives. In the face of a complex and changeable external environment, the enterprise must realize the smooth implementation of the project through reasonable scheduling, thereby achieving coordination among multiple objectives regarding resource efficiency, production cost, and delivery time. This idea can be illustrated by the practical case described below. "Jiufeng Waste Incineration Power Generation Project" was initially a failed project, which was terminated during its construction due to strong opposition from surrounding residents [3]. On August 18, 2014, China's Everbright Environment took over this stopped project and resuscitated it using proactive and reactive project scheduling theory. Before the start of the project, the company investigated the demands of the government, investors, surrounding residents, and some non-governmental organizations. As a result, they worked out a comprehensive and robust schedule for the project by taking these demands into account. Additionally, when unexpected events occurred during the scheduled execution, the company took swift reactive action to avoid or reduce the influence of these events on the project. In this way, the company reconstructed its value chain, including various agents in this project, and realized the coordination of green and growth, which were reflected by project quality, cost, and time. On September 22, 2017, this project was successfully put into operation, with a capacity to process and incinerate 3000 tons of household waste per day.[1]

Based on the discussion above, in the organization of value chain reconstruction and green-oriented productions and operations, the proactive and reactive project scheduling theories can provide indispensable support tools and methods. Using these theories, the enterprise can systematically analyze environmental variations and generate an optimal schedule for the value reconstruction project through the reasonable addition of time and resource buffers. In this way, the organization, management, and operation of green production in the enterprise can achieve the best trade-off among resource efficiency, production cost, and delivery time. As a result, the organization can optimally integrate the enterprise's efficiency and benefits and significantly enhance its core competitiveness.

[1] https://xueqiu.com/3093244593/146175482.

15.2 Proactive and Reactive Scheduling to Maximize the Net Present Value of Projects

Based on the above discussion, value chain reconstruction is often conducted in the form of a project. While in a complex and dynamic environment, proactive and reactive scheduling can deal with the disruptions of uncertain factors to ensure smooth implementation and realize NPV maximization. Therefore, this section presents the model of the project and algorithm of proactive and reactive project scheduling to maximize its NPV.

15.2.1 Optimization Model

We assume that a value chain reconstruction project is represented as an activity-on-node (AoN) network $G = (N, A)$, in which the set of nodes, $N = \{1, 2, \ldots, n\}$, represents the value chain reconstruction activities and the set of arcs, A, is the finish-start zero-lag precedence. Start activity 1 and end activity n are dummy activities. Activity duration d_i follows a given stochastic distribution with a known mean value $E(d_i)$, and standard variance $\sigma(d_i)$. There are K types of renewable resources, and their availabilities are R_k ($k = 1, 2, \ldots, K$). The execution of activity i demands r_{ik} amount of renewable resources, k. The earned value of activity i is v_i and the project's contract price is EU ($EU = \sum_{i=1}^{n} v_i$). The number of payments is H ($H \leq n$) and these payments are attached to certain activities i_h ($h = 1, 2, \ldots, H$), as defined by the client. The amount of the h-th payment, p_h, equals the product of the accumulated earned value by the payment time and the payment proportion θ ($0 \leq \theta \leq 1$). Note that the last payment must be arranged at activity n, and when the project is finished, the total amount of the client's payments must equal EU. The project deadline is D.

Corresponding to the expected duration of activity i, $E(d_i)$, we assume that the basic cost of activity i is c_i. Therefore, to enhance the robustness of the baseline schedule in proactive scheduling, we add time buffer B_i to activity i using the resource flow-dependent float factor (RFDFF) [4] or virtual activity duration extension (VADE) methods [5]. As the insertion of B_i may extend the period of activity i occupying renewable resources, this causes an additional cost called the time buffer cost in our research. Assuming the cost caused by adding per unit time buffer is β_i, then the cost of time buffer B_i is c_{i1}, $c_{i1} = \beta_i \cdot B_i$. Therefore, in proactive scheduling, the total cost of activity i is c_i^*, $c_i^* = c_i + c_{i1}$. Using c_{i1}, we can also compute the total time buffer cost of the baseline schedule, denoted as rc, $rc = \sum_{i=1}^{n} c_{i1}$.

We suppose that in proactive scheduling, the start time of activity i is arranged as s_i^B after the insertion of time buffers. However, owing to the randomness of the activities' duration, s_i^B may be postponed to s_i^T in reactive scheduling, although the baseline schedule has some robustness. We assume that the adjustment cost of s_i^T deviating from s_i^B by one unit time is γ_i, then the cost of this postponement will be c_{i2}, $c_{i2} = \gamma_i \cdot (s_i^T - s_i^B)$. Therefore, when the project is finished, the total cost of activity i will be $c_i^\wedge$ and $c_i^\wedge = c_i^* + c_{i2} = c_i + c_{i1} + c_{i2}$.

We denote the relative instability weight of activity i as ω_i, and thus, the robustness of a schedule can be represented as rb and $rb = \sum_{i=1}^{n} (\omega_i \cdot B_i)$. Based on the above discussion, it is evident that if more time buffers are added to its baseline schedule for a given project, both rb and rc will increase. However, with an increase in rb, the total adjustment costs during schedule execution, which equals the sum of c_{i2}, will decrease. This implies an important trade-off between the time buffer cost and adjustment cost, and the robustness of the schedule should be set at a reasonable level from the perspective of cost control.

Let $S = (s_1, s_2, \ldots, s_n)$, where s_i represents the start time of activity i, which is a non-robust feasible schedule constructed based on $E(d_i)$. Applying the RFDFF (VADE) method to S, we build a robust schedule S^B, $S^B = (s_1^B, s_2^B, \ldots, s_n^B)$, and represent this course as $S^B = \text{RFDFF}(S)$ ($S^B = \text{VADE}(S)$). Assuming that cash inflows and outflows occur upon activity completion, we formulate a proactive optimization model as follows:

$$\text{Max } NPV^{expe} = \sum_{h=1}^{H} \{p_h \cdot \exp[-\alpha \cdot (s_{i_h}^B + d_{i_h})]\} - \sum_{i=1}^{n} \{c_i^* \cdot \exp[-\alpha \cdot (s_i^B + d_i)]\} \tag{15.1}$$

$$\text{s.t. } S^B = \text{RFDFF}(S)\big(S^B = \text{VADE}(S)\big) \tag{15.2}$$

$$s_n^B \le D \tag{15.3}$$

$$p_h = \theta \cdot \left(\sum_{i \in V^h} v_i - \sum_{i \in V^{h-1}} v_i\right) \quad h = 1, 2, \ldots, H-1 \tag{15.4}$$

$$p_H = EU - \sum_{h=1}^{H-1} p_h \tag{15.5}$$

$$s_i^B \text{ are nonnegative integers } i = 1, 2, \ldots, n \tag{15.6}$$

where NPV^{expe} is the expected project NPV; V^h ($h = 1, 2, \ldots, H$) is the set of activities that should be paid at payment h, and S is determined by the following constraints:

$$s_i + d_i \le s_j \quad \forall (i, j) \in A \tag{15.7}$$

$$\sum_{i \in P^t} r_{ik} \le R_k \quad k = 1, 2, \ldots, K; t = 1, 2, \ldots, D \tag{15.8}$$

$$s_n \le D \tag{15.9}$$

$$s_i \text{ are nonnegative integers } i = 1, 2, \ldots, n \tag{15.10}$$

where P^t is the set of activities in progress at time t. In the model, the objective Eq. (15.1) maximizes the expected project NPV. Constraint (15.2) expresses the course for generating S^B using the RFDFF (VADE) method. Constraint (15.3) ensures that S^B meets the project deadline constraint. Constraint (15.4) determines the amount of the h-th payment, whereas constraint (15.5) makes the total payment equal to the contract price. Constraint (15.6) stipulates that the decision variables are integers. Constraints (15.7), (15.8), (15.9), and (15.10), imposed on S, are the precedence feasibility constraints, renewable resource availability, project deadline, and the value range of s_i, respectively.

Now, suppose that at time T during the execution of S^B, the schedule has to be adjusted because of the influence of the randomness of activity duration. At this time, the sets of the completed activities, the activities that are in progress, and those that have not yet been started are denoted as F^T, P^T, and U^T, respectively. The duration of the activities is represented as d_i^T. For the activities in F^T and P^T, because they have been completed or in progress, their d_i^T becomes the real value, whereas for those in U^T, their d_i^T are still set as $E(d_i)$. Based on the definitions above, by minimizing the total adjustment cost as an objective, we construct a reactive scheduling model as follows:

$$\text{Min}\ Loss^T = \sum_{i=1}^{n} [\gamma_i \cdot (s_i^T - s_i^B)] \tag{15.11}$$

$$\text{s.t.}\ \ s_i^T = s_i^B \ \ i \in F^T \cup P^T \tag{15.12}$$

$$s_i^T + d_i^T \le s_j^T \ \ \forall(i, j) \in A \tag{15.13}$$

$$\sum_{i \in P^t} r_{ik} \le R_k \ \ k = 1, 2, \ldots, K; t = T, T+1, \tag{15.14}$$

$$s_i^T \text{ are nonnegative integers } i = 1, 2, \ldots, n \tag{15.15}$$

The objective Eq. (15.11) minimizes the sum of all activities' adjustment costs in the model. Constraint (15.12) makes the start times of the activities in $F^T \cup P^T$ equal to their original values, as defined by S^B. Constraint (15.13) is a precedence relationship whereas constraint (15.14) is a renewable resource constraint. Finally, constraint (15.15) stipulates that the decision variables are nonnegative integers.

Note that reactive scheduling models may be invoked several times during project execution. After each model operation, we update S^B because the generated S^T and new S^B will be used as the baseline schedule in the next operation of the models. Additionally, when the project is completed, we name the obtained project NPV the realized NPV, NPV^{real}, and the sum of the adjustment costs the realized loss, $Loss^{real}$.

15.2.2 Heuristic Algorithms

The studied problem can be regarded as an uncertain extension of the resource-constrained max-NPV project scheduling problem, for which researchers proved to be NP-hard [6]. The RFDFF or VADE methods are used to add time buffers to the unbuffered schedules during the generation of a robust schedule. However, it is easy to understand from the aforementioned facts that finding the optimal solution is very difficult, even for small problems. Therefore, to solve this problem, we developed three heuristic algorithms: tabu search (TS) [7], variable neighborhood search (VNS) [8], and a mixed version of TS and VNS. Note that the algorithms are designed for a proactive scheduling model and can be conveniently adjusted to solve the reactive scheduling model by changing the searching objective function and some constraint judgments.

We represent the solution to the problem with an activity order list L, which must meet precedence constraints. For a given L, the robust schedule S^B can be generated by the decoding procedure RFDFF(L) (VADE(L)), described as follows:

Step 1. Input the order list L.
Step 2. Transform L to a non-robust schedule, S, using the serial schedule generation scheme (SSGS).
Step 3. Judge whether S meets the project deadline constraint. If the answer is true, go to Step 4; otherwise, output the result that L is an infeasible solution regarding the project deadline.
Step 4. Based on S, generate a robust schedule, S^B, using the RFDFF (VADE) method.
Step 5. Judge whether S^B meets the project deadline constraint or not. If the answer is true, go to Step 6; otherwise, output the result that L is an infeasible solution to the project deadline.
Step 6. Output the obtained robust schedule, S^B.

An initial solution for the problem, L_{init}, can be generated by RFDFF(L) (VADE(L)) according to the following steps:

Step 1. Without any violations of the precedence constraints, construct L randomly.
Step 2. Check whether the project deadline constraint is met or not by using RFDFF(L) (VADE(L)). If the answer is false, go to Step 1; otherwise, go to Step 3.
Step 3. Output L as the initial solution obtained, namely L_{init}.

Tabu search

In the TS, we use the following operators to generate a neighboring solution, L_{neig}, for the current solution, L_{curr}.

Step 1. Without violating the precedence constraints, select two activities randomly and swap their positions in L_{curr}, thus generating a new L.

Step 2. Check whether the project deadline constraint is satisfied or not by using RFDFF(L) (VADE(L)). If the answer is false, go to Step 1; otherwise, go to Step 3.

Step 3. Output L as the neighbor solution obtained, that is, L_{neig}.

The tabu list TL is managed according to the first-in-first-out rule. We update the tabu list whenever a move is performed, that is, add the reverse move to the list and remove the oldest existing move. All moves in the tabu list are forbidden. However, if a tabu move can generate a solution better than the best found so far, its tabu status may be cancelled so that the algorithm can move to this solution.

The stop criterion of TS is defined as the assumed number of feasible solutions visited, denoted as Num^{stop}. We denote the best solution found, and the number of feasible solutions visited during the search process as L_{best} and Num, respectively. A flowchart of TS is shown in Fig. 15.1.

- **Variable neighborhood search**

We use the basic VNS, which combines deterministic and stochastic changes to the neighborhood [9], to search for a desirable solution to the problem. Considering the solution representation, the neighborhood structure NS_m ($m = 1, 2, \ldots, m_{max}$), is

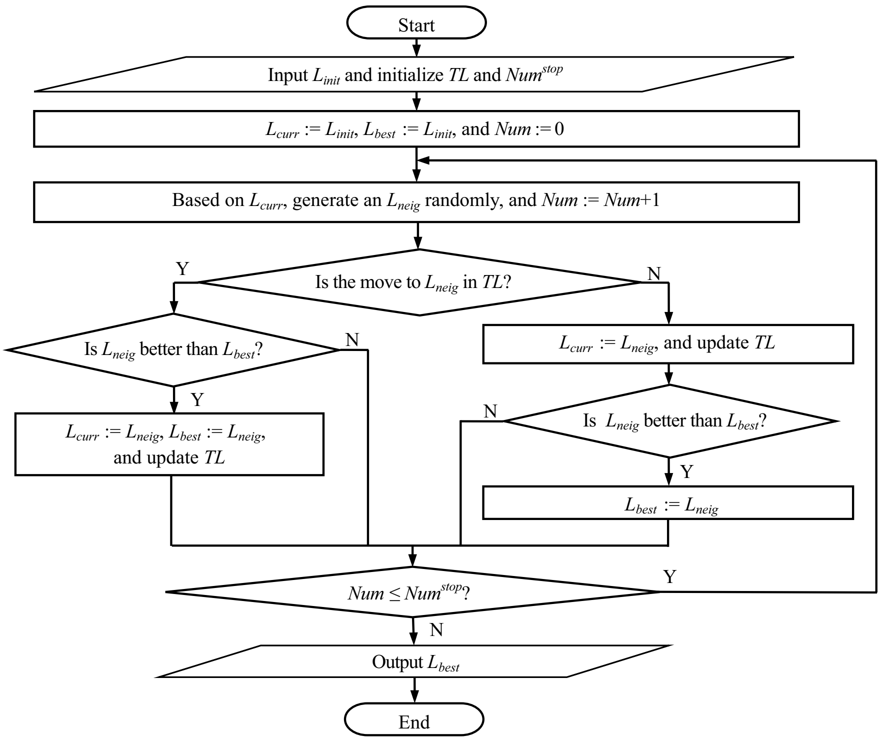

Fig. 15.1 Flowchart of the TS

defined as the set of all Ls in which only m pairs of elements are different from the corresponding elements in the current L.

Therefore, corresponding to the neighborhood structure defined above, the shaking method is proposed as follows: For L, select m pairs of elements randomly and swap their positions, thus obtaining a new L. Next, judge whether the project deadline constraint is met or not by using RFDFF(L) (VADE(L)). If the answer is true, a feasible solution, denoted as L_{rand}, is obtained; otherwise, this operation is repeated until L_{rand} is obtained.

The stop criterion for the VNS is the same as that for the TS. The neighborhood of the current solution is explored systematically according to the first improvement strategy until the local optimum solution, represented as L_{local}, is obtained. Figure 15.2 shows a flowchart of VNS.

- **A mixed version of VNS and TS**

To find a better solution, we propose a mixed version of the VNS and TS, which can have the advantages of the two algorithms. The general framework of the VNTS is similar to that of the TS. However, unlike the latter, the VNTS has a variable neighborhood structure. Therefore, during the search process of the VNTS, the shaking method is utilized to generate a neighboring solution based on different neighborhood

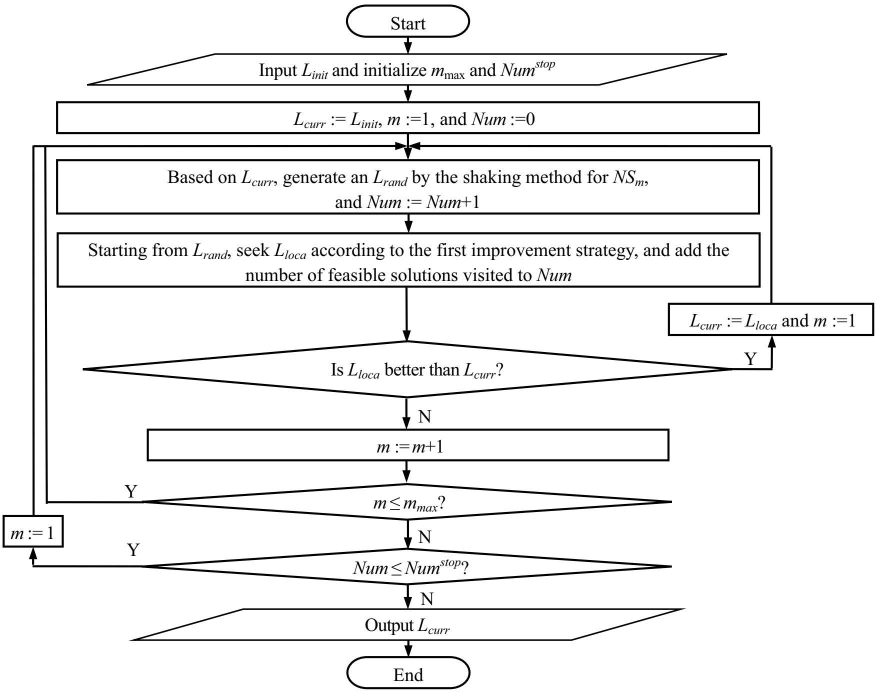

Fig. 15.2 Flowchart of the VNS

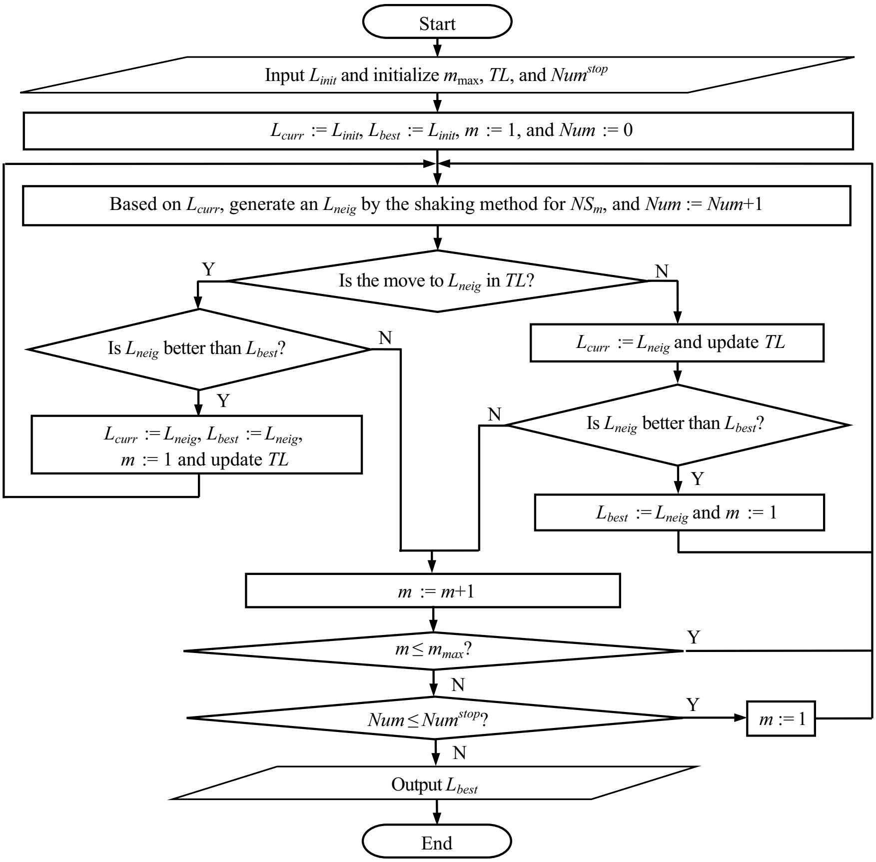

Fig. 15.3 Flowchart of the VNTS

structures, and a special tabu list is employed to store the recently visited solutions. Using the notations defined above, a flowchart of the VNTS is presented in Fig. 15.3.

15.2.3 Computational Experiment

The computational experiment uses multi-start iteration improvement (MSII) [10, 11] to generate benchmark schedules to evaluate the algorithm performance. The algorithms are tested on a data set constructed using the ProGen project generator [12]. The set consists of 50 instances, and the parameter setting used to generate the instances is represented in Table 15.1. Following prior research, the number of non-dummy activities in the project network is set at 10, 22, 34, 46, or 58, as shown in

Table 15.1 Parameter setting for ProGen

Parameter	Setting
Non-dummy activity number, $n-2$	10, 22, 34, 46, or 58
Instance number generated for each $n-2$	10
Start and end non-dummy activity number	Randomly chosen from 1, 2, and 3 with an equal probability
Maximal number of predecessors or successors	3
Mean value of activity duration, $E(d_i)$	Randomly generated from a uniform distribution, U(1, 10)
Standard variance of activity duration, $\sigma(d_i)$	Randomly generated from a uniform distribution, U(1, 4)
Relative instability weight of activity, ω_i	Randomly generated from a uniform distribution, U(0, 10)
Basic cost of activity, c_i	Randomly generated from a uniform distribution, U(10, 20)
Kind of renewable resources, K	2
Availability of resource 1, R_1	8
Availability of resource 2, R_2	8
Activity requirement for resource 1, r_{i1}	Randomly generated from a uniform distribution, U(1, 8)
Activity requirement for resource 2, r_{i2}	Randomly generated from a uniform distribution, U(1, 8)
Earned value of activity, v_i	$\rho_1 c_i$, ρ_1 is randomly generated from a uniform distribution, U(1.5, 2.5)
Payment number, H	4
Payment proportion, θ	0.8

the table. Note that the activities' duration follows a beta distribution in the reactive simulation of baseline schedules.

To investigate the effects of the key parameters, including D, α, β_i , and γ_i, on the computational results, we set the values of these parameters at three levels, listed in Table 15.2, based on a preliminary computational experiment. A sensitivity analysis of the key parameters is successfully achieved using these values. A full factorial experiment of the four parameters with three levels results in 81 replicates for each instance, hence, $50 \times 81 = 4050$ replicates for all instances.

To evaluate the performance of the algorithms, we define the following five indices.

- *NUM*: The number of instances for which the algorithm finds a solution equal to the best-known solution, that is, the best solution found by any of the algorithms.
- *ARD* (%): Average relative percent below the best solution known.
- *MRD* (%): Maximal relative percent above the best solution known.
- $ACT(s)$: Average computational time of the algorithm.
- MCT(s): Maximal computational time of the algorithm.

Table 15.2 Values of key parameters

Parameters	Value
Project deadline, D	$\rho_2 C_{max}$. ρ_2 is set at 1.3, 1.4 and 1.5, C_{max} is the length of the critical path of project network without the consideration of renewable resource constraints
Discount rate, α	0.004, 0.006, and 0.008
Cost of per unit time buffer, β_i	$\rho_3 \tau_i$. ρ_3 is set at 1.0, 1.1 and 1.2, and τ_i is randomly generated from a uniform distribution, U(1, 5)
Adjustment cost of per unit time, γ_i	$\rho_4 \varphi_i$. ρ_4 is set at 1.0, 1.1 and 1.2, and φ_i is randomly generated from a uniform distribution, U(1, 5)

All algorithms are coded and compiled with Visual C++ 2010 Express, and the computational experiment is performed on a Dell-based personal computer with a 2.5 GHz clock-pulse and 4 GB RAM. The algorithms start with the same initial solution and employ the same stop criterion. Based on a preliminary empirical test, the Num^{stop}, m_{max}, and TL length, are set to $10{,}000 \cdot n$, 3, and 10, respectively.

Table 15.3 shows the computational results obtained by solving the proactive scheduling models. The table clearly shows that, regarding the quality of the desirable solutions, TS, VNS, and VNTS remarkably outperform MSII, and the superiority increases with the number of activities. This result is not surprising and confirms to the expectation that intelligent search algorithms generally have an advantage over simple search algorithms. Moreover, the advantage is augmented as the problem becomes more complex. For the three intelligent search algorithms, the *NUM* and *ARD* indices show that for almost all instances, VNTS outperforms both TS and VNS. This is expected because the VNTS integrates the VNS to the TS reasonably. Therefore, it has an advantage over other algorithms. Regarding the TS and VNS, the two TS indices seem better than those of the VNS overall, indicating TS performance is slightly better than that of the VNS overall.

The computational times, indicated by the *ACT* and *MCT* indices, are as expected. The TS and VNTS are slower than the VNS and MSII because both the TS and VNTS require additional time to manage their tabu lists. Moreover, because the VNTS tabu list is more complex than that of the TS, the VNTS computational times are longer than those of the TS. As the number of activities increases, the computational times of the algorithms increase accordingly because more feasible solutions must be visited. The longest time for the VNTS to solve the instances is 63.42s, an acceptable time limit from a practical perspective. Therefore, the VNTS can be considered the best algorithm among the proposed three heuristic algorithms owing to the quality of the desired solution obtained and the calculation time consumed.

Based on the computational results obtained by the VNTS, the sensitivities of the proactive and reactive scheduling results to key parameters are analysed. In proactive scheduling, the effects of the project deadline, D, and the cost per unit time buffer, β_i, on the expected project NPV, NPV^{expe}, robustness, *rb*, and time buffer cost, *rc*, are shown in Table 15.4, and the effects of α on NPV^{expe} are given in Table 15.5. The results in Table 15.4 indicate that *rb* and *rc* increase while NPV^{expe}

Table 15.3 Computational results

Algorithm	$n-2$	RFDFF					VADE				
		NUM	*ARD*	*MRD*	*ACT*	*MCT*	*NUM*	*ARD*	*MRD*	*ACT*	*MCT*
MSII	10	144	0.068	0.17	7.19	8.32	156	0.064	0.35	3.09	3.248
	22	123	0.079	0.22	14.98	15.39	132	0.078	0.43	6.66	8.155
	34	99	0.093	0.26	23.58	25.69	108	0.085	0.49	20.26	21.30
	46	57	0.097	0.24	30.85	33.21	69	0.090	0.51	24.66	26.19
	58	24	0.110	0.32	42.78	45.60	42	0.096	0.55	35.57	39.48
	All instances	447	0.089	0.32	23.88	45.60	507	0.083	0.55	18.05	39.48
TS	10	195	0.061	0.16	7.80	8.91	180	0.064	0.35	3.38	3.761
	22	231	0.056	0.13	15.65	16.65	213	0.052	0.28	7.03	8.315
	34	231	0.042	0.13	24.49	26.17	204	0.046	0.22	23.14	24.44
	46	234	0.044	0.11	31.54	33.45	225	0.043	0.16	34.74	40.20
	58	216	0.042	0.12	40.28	43.22	198	0.041	0.19	46.25	49.36
	All instances	1107	0.049	0.16	23.95	43.22	1020	0.049	0.35	22.91	49.36
VNS	10	216	0.063	0.19	7.11	8.65	192	0.069	0.32	3.12	3.55
	22	219	0.056	0.18	14.24	16.33	225	0.054	0.31	6.88	7.90
	34	210	0.047	0.15	22.18	24.70	201	0.044	0.25	22.60	24.71
	46	207	0.039	0.13	28.93	30.21	183	0.037	0.19	30.59	34.23
	58	183	0.032	0.10	38.56	41.72	153	0.033	0.17	44.83	46.28
	All instances	1035	0.047	0.19	22.20	41.72	954	0.047	0.32	21.60	46.28
VNTS	10	255	0.055	0.17	8.53	9.47	282	0.058	0.25	3.92	4.37
	22	237	0.049	0.15	17.44	19.86	240	0.045	0.21	8.25	9.40
	34	270	0.038	0.14	30.19	33.61	297	0.033	0.19	29.46	32.71
	46	312	0.030	0.11	39.96	43.67	333	0.025	0.16	44.38	47.15
	58	387	0.025	0.08	51.28	57.74	417	0.019	0.12	58.67	63.42
	All instances	1461	0.039	0.17	29.48	57.74	1569	0.036	0.25	28.94	63.42

decreases with an increase in D. As β_i increases, NPV^{expe} decreases, rc increases, and rb remains unchanged. The reasons for these results are as follows: When the project deadline increases, more time buffers are added to the baseline schedule by the RFDFF (VADE), making rb and rc increase simultaneously. Subsequently, the increase in rc increases cash outflows and leads to a decrease in NPV^{expe}. The increase in β_i can cause the time buffer cost to increase directly and thus decrease the expected project NPV. However, the robustness rb remains invariant during this course because the added time buffers remain unchanged. Table 15.5 shows that

Table 15.4 Effects of D and β_i on NPV^{expe}, rb, and rc

Parameters	Values	RFDFF			VADE		
		rb	rc	NPV^{expe}	rb	rc	NPV^{expe}
D	$1.3C_{max}$	51.72	39.52	524.29	98.22	81.65	486.92
	$1.4C_{max}$	72.23	53.47	513.28	134.77	107.32	460.14
	$1.5C_{max}$	96.02	75.56	494.69	181.45	139.80	428.06
β_i	τ_i	73.32	51.08	514.35	138.15	99.63	465.31
	$1.1\tau_i$	73.32	56.18	510.75	138.15	109.59	457.42
	$1.2\tau_i$	73.32	61.29	506.88	138.15	119.55	448.81

Table 15.5 Effects of α on NPV^{expe}

Parameters	Value	NPV^{expe} (RFDFF)	NPV^{expe} (VADE)
α	0.004	510.75	457.42
	0.006	463.66	411.32
	0.008	406.94	368.23

with the growth of α, NPV^{expe} decreases monotonously for the two time-buffering methods used. This is an immediate observation when Eq. (15.1) is considered.

For the two time-buffering methods, the results in Tables 15.4 and 15.5 clearly show that the NPV^{expe}s of RFDFF are greater than those of VADE. This phenomenon can be easily explained by the rcs of VADE, which are much higher than those of RFDFF. In other words, compared with RFDFF, the VADE method adds more time buffers to the baseline schedules and causes higher time buffer costs, making NPV^{expe}s decrease. If we observe the implementation results of the baseline schedules shown in Table 15.6, we can find another important conclusion. From Table

Table 15.6 Effects of D and γ_i on NPV^{real} and $Loss^{real}$

Parameters	Values	RFDFF				VADE			
		Min-loss		Max-NPV		Min-loss		Max-NPV	
		$Loss^{real}$	NPV^{real}	$Loss^{real}$	NPV^{real}	$Loss^{real}$	NPV^{real}	$Loss^{real}$	NPV^{real}
D	1.3 C_{max}	151.45	388.52	156.21	395.82	136.39	367.15	145.68	373.19
	1.4 C_{max}	132.44	401.74	139.47	406.19	114.42	349.54	121.88	358.97
	1.5 C_{max}	122.71	379.22	128.08	384.81	92.66	335.84	95.85	342.46
γ_i	φ_i	123.21	398.58	128.41	404.86	104.08	358.36	110.12	366.34
	1.1 φ_i	135.53	389.83	141.25	395.61	114.49	350.84	121.14	357.27
	1.2 φ_i	147.85	380.47	154.09	385.47	124.90	343.12	132.15	347.95

15.6, we can see that both $Loss^{real}$s and NPV^{real}s of VADE are lower than the corresponding RFDFF results. This indicates that when using the VADE method, the baseline schedules can have higher *rb*s, and thus, their $Loss^{real}$s are lower. However, because the positive influence of $Loss^{real}$s' decrease cannot completely offset the negative effect of *rc*s' increase, the realized NPVs of VADE are still less than those of RFDFF. Based on the above facts, we conclude that RFDFF can generate better results than VADE because the latter adds too many time buffers to the baseline schedules.

In reactive scheduling, the effects of the project deadline, D, and the adjustment cost per unit time γ_i, on the realized project NPV, NPV^{expe}, and the realized loss, $Loss^{real}$, are shown in Table 15.6. Table 15.6 indicates that with the increase of D, both NPV^{real} and $Loss^{real}$ tend to decrease. When γ_i ascends, $Loss^{real}$ goes up, but NPV^{real} goes down. These results can be explained as follows. When D augments, the schedule robustness grows. This makes schedules have a higher ability to maintain stability during their execution, generating a lower $Loss^{real}$. However, because the decrease in adjustment costs cannot offset the increase of the time buffer cost, *rc*, which is also caused by the enlargement of D, NPV^{real} still continues its declining trend. Parameter γ_i reflects the adjustment cost per unit time, so when γ_i ascends, $Loss^{real}$ rises linearly, making NPV^{real} decrease simultaneously.

Comparing the two reactive models, the results in Table 15.6 are ambiguous. Both the $Loss^{real}$s and NPV^{real}s under the Min-loss model are less than those under the Max-NPV model. The reasons for this phenomenon are as follows. Based on the baseline schedule, the Min-loss model minimizes the adjustment cost without considering the cash inflows. As a result, $Loss^{real}$s under this model, which equals the sum of the adjustment costs, is necessarily not greater than those under the Max-NPV model. However, in the Max-NPV model, both cash inflows and outflows, including $Loss^{real}$s, must be taken into account in the meantime to maximize NPV. Therefore, under the Max-NPV model, the NPV^{real}s are certainly not less than those under the Min-loss model, whereas the $Loss^{real}$s may be greater than those under the Min-loss model.

Finally, Table 15.6 reveals an interesting phenomenon, described as follows. For RFDFF, NPV^{real} first increases and then decreases with an increase in the project deadline. This phenomenon can be explained as follows: when the project deadline is augmented, more time buffers can be inserted into the schedule, resulting in negative and positive effects on the NPV^{real}. The negative effect comes from an increase in the time buffer cost, whereas the positive effect is derived from a decrease in the adjustment cost. When D changes from $1.3C_{max}$ to $1.4C_{max}$, the positive effects surpass the negative ones so that the NPV^{real} becomes larger. However, when D changes to $1.5C_{max}$, the reverse occurs, making NPV^{real} decrease. Note that for VADE, because too many time buffers are inserted into schedules on the condition that $D = 1.3C_{max}$, NPV^{real} drops whenever D changes from $1.3C_{max}$ to $1.5C_{max}$. The above facts tell the project manager that in an uncertain environment, the robustness of the schedule must be maintained at a reasonable level; otherwise, it will harm project revenue.

15.3 Time-Cost-Robustness Trade-Off in Project Implementation Under Uncertainty

Considering that value chain reconstruction in uncertain environments must consider multiple objectives simultaneously, multi-objective proactive and reactive project scheduling may provide direct support for the organization of the reconstruction. Based on this fact, we introduce the proactive scheduling model and algorithm for the discrete time–cost-robustness trade-off problem (DTCRTP) in this section.

15.3.1 Optimization Model

We consider a project with a set of n activities and an associated precedence graph $G = (N, A)$ within the activity-on-node network. Set N refers to the n activities and dummy start activity 0 and dummy end activity $n + 1$. In contrast, the set $A \subset N \times N$ consists of all the pairs (i, j) of activities $i, j \in N$ with precedence relationships, where $(i, j) \in A$ denotes that activity j must be started after activity i. Each activity $i \in N$ must be executed in one of the M_i modes. The duration d_{im} of activity i in mode m ($m = 1, 2, \ldots, M_i$) is a discrete, non-increasing function of the amount of renewable resource type k ($k = 1, 2, \ldots, K$), r_{imk}, allocated to it, and the cost c_{im} consumed. Dummy activities 0 and $n + 1$ do not take any time or consume any resources or costs. Additionally, the availability of resource type k is $a_k \in \mathbb{N}$, and the occupancy cost per unit time is c_k. A solution, namely, a schedule denoted as S, consists of a set of selected modes and a set of start times for all activities.

To consider the modes of activities in the two objectives, we define two kinds of decision variables. The binary variable x_{im} takes a value of 1 if activity i is executed in mode m and 0 otherwise. The binary variable y_{it} takes the value of 1 if activity i is started at instant t ($t = 0, 1, \ldots$), and 0 otherwise. It is natural to construct constraints $\sum_{m=1}^{M_i} x_{im} = 1$ and $\sum_{t=ES_i}^{LS_i} y_{it} = 1$ to ensure that there is a unique mode and start time selected for each activity, where ES_i and LS_i represent the earliest and latest start times of activity i, respectively. Under these definitions of decision variables, the project makespan $T = \sum_{t=ES_{n+1}}^{LS_{n+1}} [t \cdot y_{(n+1)t}]$ and total cost $C = \sum_{i \in N} \sum_{m=1}^{M_i} (c_{im} \cdot x_{im})$ are reformulated.

To cope with the uncertainties during the execution of schedules, a free slack FS_i is set between activity i and its successors to absorb the activity delays caused by uncertain factors. To ensure sufficient resource supply during FS_i in a given schedule, the forward and backward recursion procedures [13] are used to derive the earliest start time es_i and latest start time ls_i, respectively, and the corresponding difference is the FS_i value. We measure the robustness of a given schedule with the weighted sum of free slacks, that is, $R = \sum_{i \in N} (w_i \cdot FS_i)$, where w_i is a weight parameter determined according to the importance of an activity to the completion of the whole project. In this case, the total cost increases because of the additional resource occupation during FS_i; thus, $C = \sum_{i \in N} \sum_{m=1}^{M_i} (c_{im} \cdot x_{im}) + \sum_{i \in N} \sum_{m=1}^{M_i} \sum_{k=1}^{K} (c_k \cdot r_{imk} \cdot x_{im} \cdot FS_i)$.

Therefore, the multi-objective optimization model of the time-cost-robustness trade-off scheduling problem is constructed as follows:

$$\text{Min } T = \sum_{t=ES_{n+1}}^{LS_{n+1}} [t \cdot y_{(n+1)t}] \tag{15.16}$$

$$\text{Min } C = \sum_{i \in N} \sum_{m=1}^{M_i} (c_{im} \cdot x_{im}) + \sum_{i \in N} \sum_{m=1}^{M_i} \sum_{k=1}^{K} (c_k \cdot r_{imk} \cdot x_{im} \cdot FS_i) \tag{15.17}$$

$$\text{Max } R = \sum_{i \in N} (w_i \cdot FS_i) \tag{15.18}$$

$$\text{s.t.} \sum_{i \in S_t} \sum_{m=1}^{M_i} (r_{imk} \cdot x_{im}) < a_k \quad t = 0, 1, \ldots; k = 1, 2, \ldots, K \tag{15.19}$$

$$\sum_{t=ES_i}^{LS_i} (t \cdot y_{it}) + \sum_{m=1}^{M_i} (d_{im} \cdot x_{im}) < \sum_{t=ES_j}^{LS_j} (t \cdot y_{jt}) \quad (i, j) \in A \tag{15.20}$$

$$\sum_{m=1}^{M_i} x_{im} = 1 \quad i \in N \tag{15.21}$$

$$\sum_{t=ES_i}^{LS_i} y_{it} = 1 \quad i \in N \tag{15.22}$$

In the optimization model, the three conflicting objectives (15.16)–(15.18) minimize the makespan and cost and maximize robustness, respectively. Constraint (15.19) where $S_t = \{i \in N | s_i \leq t \leq s_i + d_{im}\}$, ensures that the amount of resources consumed at each instant t does not exceed the maximum value. Constraint (15.20) indicates that the activities need to satisfy the precedence relationship. Constraints (15.21) and (15.22) select one mode and start time for each activity, respectively. Schedules with longer makespans, higher costs, and lower robustness fail to enter the Pareto set according to the three optimization objectives, thus ensuring that each schedule S in the Pareto set satisfies $\{S' \big| T' \leq T, C' \leq C, R' \geq R\} = \Phi$ where at least one of the inequalities holds. In other words, no schedule is better than any of the schedules in the Pareto set regarding all three objectives.

Based on this idea of the epsilon-constrained method, we transmute the makespan and cost objectives into constraints with varying critical values, and the optimization model can be rewritten as follows:

$$\text{Max } R = \sum_{i \in N} (w_i \cdot FS_i) \tag{15.23}$$

$$\text{s.t.}\quad T = \sum_{t=ES_{n+1}}^{LS_{n+1}} [t \cdot y_{(n+1)t}] \le e_T \tag{15.24}$$

$$C = \sum_{i \in N} \sum_{m=1}^{M_i} (c_{im} \cdot x_{im}) + \sum_{i \in N} \sum_{m=1}^{M_i} \sum_{k=1}^{K} (c_k \cdot r_{imk} \cdot x_{im} \cdot FS_i) \le e_C \tag{15.25}$$

Equations (15.19)–(15.22).

In the rewritten model, the critical values e_T and e_C are selected in $[T_{min}, T_{max}]$ and $[C_{min}, C_{max}]$, respectively. By discretely varying the critical values of the makespan T and cost C on the right-hand side of Eqs. (15.23) and (15.24), we derive a series of robustness-maximization models with different constraints. We solve these single-objective problems one by one and then combine the optimal solutions to acquire the optimal solution set of the multi-objective model.

When solving the multi-objective optimization model, we first select a mode for each activity, obtain its duration, and then calculate the time window by adopting the critical path method (CPM). Then, we assign a start time for each activity and finally obtain a feasible schedule. A given schedule has makespan, cost, and robustness, according to which different schedules are evaluated to obtain the optimal Pareto solution set. In this process, we propose the following three propositions to efficiently and effectively help solve the multi-objective optimization model.

Proposition 1 While choosing the execution mode for an activity, calculate the shortened duration of the activity at the expense of per-unit cost, $\overline{d}_i^c$, using the formula $\overline{d}_i^c = \frac{d_{im} - d_{i(m+1)}}{c_{i(m+1)} - c_{im}}$. If activities i and j in a project satisfy $\overline{d}_i^c > \overline{d}_j^c$, arranging activity i in crashed mode with a greater probability and activity j with a lower probability reduces the project makespan and improves project robustness at a lower cost. In other words, it is beneficial to make better trade-offs among the makespan, cost, and robustness.

Under the assumption that activity i is transformed from normal mode m to crashed mode $m + 1$, the changes in the project makespan, cost, and robustness are analyzed as follows.

- Project makespan: When the activity duration changes from d_{im} to a shorter duration $d_{i(m+1)}$, activity i can be completed earlier, contributing to earlier starting times of its subsequent activities to facilitate a shorter project makespan.
- Project cost: When the mode of activity i changes, the project cost is calculated assuming that the starting times of the other activities remain unchanged. In this situation, the project cost difference is that of activity i caused by mode changes. The smaller the cost difference between modes, the smaller the project cost increase.
- Project robustness: When the activity is executed in the crashed mode instead of the normal mode, the free slacks may not increase more than $d_{im} - d_{i(m+1)}$, and the project robustness will also increase accordingly. The larger the duration difference between modes, the higher the project robustness.

In summary, we can shorten the makespan, improve the project schedule robustness at a lower cost and promote the trade-off optimization results of the three objectives in the direction of shorter duration, lower cost, and higher robustness.

Proposition 2 If there are resource surpluses within $[t_a, t_b]$ for all kinds of resources and activities that satisfy $s_i \geq t_a$ and $s_i + d_{im} \leq t_b$, arranging the activity in crashed mode can reduce the makespan or improve robustness.

If all kinds of resources in the time period $[t_a, t_b]$ of the schedule are in surplus for executing current activities, there will be a resource surplus of length $t_b - t_a$. If $s_i \geq t_a$ and $s_i + d_{im} \leq t_b$ hold for activity i, that is, the activity is executed in the time period $[t_a, t_b]$. Therefore, it is possible to transmute the activity into the crashed mode without breaking any resource limit, enabling the successors of activity i to move forward and further shortening the project makespan. Suppose the successors cannot move forward owing to precedence constraints or resource constraints. In that case, the makespan remains unchanged, and the free slack of activity i increases by $d_{im} - d_{i(m+1)}$, which results in a robust increase in $w_i{\cdot}[d_{im} - d_{i(m+1)}]$ accompanied by an increase in the ensuing cost.

Proposition 3 For two nondominated schedules S_A and S_B with different makespans T_A and T_B, set cost C_A and robustness R_A for S_A, and cost C_B and robustness R_B for S_B. If $T_\text{B} < T_\text{A}$, $C_\text{B} < C_\text{A}$, and $R_\text{B} < R_\text{A}$ hold, we force the makespan to meet at the larger one by changing the starting time of the dummy end activity and then recalculating the corresponding cost and robustness. If these two schedules with new objectives are no longer nondominated, they initially maintain the dominating relationship.

Define set $N^B = \{i | s_i + d_{im} + FS_i = s_{n+1}\}$. Compel the makespans T_A and T_B to meet at a larger T_A, that is, $T'_B = T_A$, and $s'_{n+1} = s_{n+1} + T_A - T_B$. We then recalculate cost and robustness as follows:

$$C'_B = C_B + \sum_{i \in N^B} \sum_{m=1}^{M_i} \sum_{k=1}^{K} [x_{im} \cdot c_k \cdot r_{imk} \cdot (T_A - T_B)],$$

$$R'_B = R_B + \sum_{i \in N^B} [w_i \cdot (T_A - T_B)].$$

When these two schedules with new objectives are no longer nondominated, i.e., at least $C'_B \leq C_A$ or $R'_B \leq R_A$ holds, indicating that schedule S_B dominates schedule S_A, they exhibit a nondominated relationship at the beginning because the short makespan of S_B reduces the possibility of robustness improvement. Once these two schedules are forced to meet at the same makespan, it can be determined that schedule S_B is more cost-effective and/or more robust. Therefore, it is necessary to eliminate schedules such as S_A from the nondominated set to make it more condensed.

15.3.2 Epsilon-Constraint Method-Based Genetic Algorithm

When we set both c_k for all k and w_i for all i to zero to compel the robustness cost and robustness to take the value zero and supply sufficient resources to relax the resource constraints, the DTCRTP is simplified to assign modes and starting times of activities to identify the time-cost trade-off curve for the project network, which is exactly the P_TC problem addressed by [14]. The P_TC problem, proven to be strongly NP-hard, is a special case of the DTCRTP we proposed; therefore, the DTCRTP must also be strongly NP-hard. Owing to the NP-hardness of the DTCRTP, we designed a multi-objective heuristic method, the epsilon-constrained method based on a genetic algorithm (ECGA), to solve the constructed multi-objective optimization model.

Before resolving the time-cost-robustness optimization model, the epsilon-constraint method is first utilized to find the makespan and cost range. Second, we apply a genetic algorithm to solve the robustness-maximization problem with given makespan and cost constraints and then record the optimal solution and its three objectives. Subsequently, we vary the critical values of the makespan and cost step-by-step to obtain the optimal solutions under different makespan and cost constraints and update the Pareto set. Finally, when we simultaneously reach the minimal values of the makespan and cost, we output all Pareto solutions. The pseudocode shown below introduces the overall structure of the ECGA, and a flowchart is displayed in Fig. 15.4. Several detailed procedures are also marked within ellipses, illustrated in the following sections.

Algorithm 1. ECGA

```
For e_T = T_max down to T_min do
 For e_C = C_max down to C_min do
  While (stop criterion not met)
   Reproduction
   Crossover
   Mutation
   Update optimal schedule
  End while
Update Pareto set
Output optimal Pareto set
```

An ordered activity list, AL, and a mode list, ML, are employed to represented the schedule.

- Activity list (AL). This list, represented as $L = (l_0, l_1, \ldots, l_{n+1})$, contains n items representing activities, and a list indicates the execution order of project activities. Note that a feasible AL must satisfy precedence constraints.
- Mode list (ML). This list, $M = (m_0, m_1, \ldots, m_{n+1})$, contains n items, and the i-th item defines the mode of the i-th activity in AL.

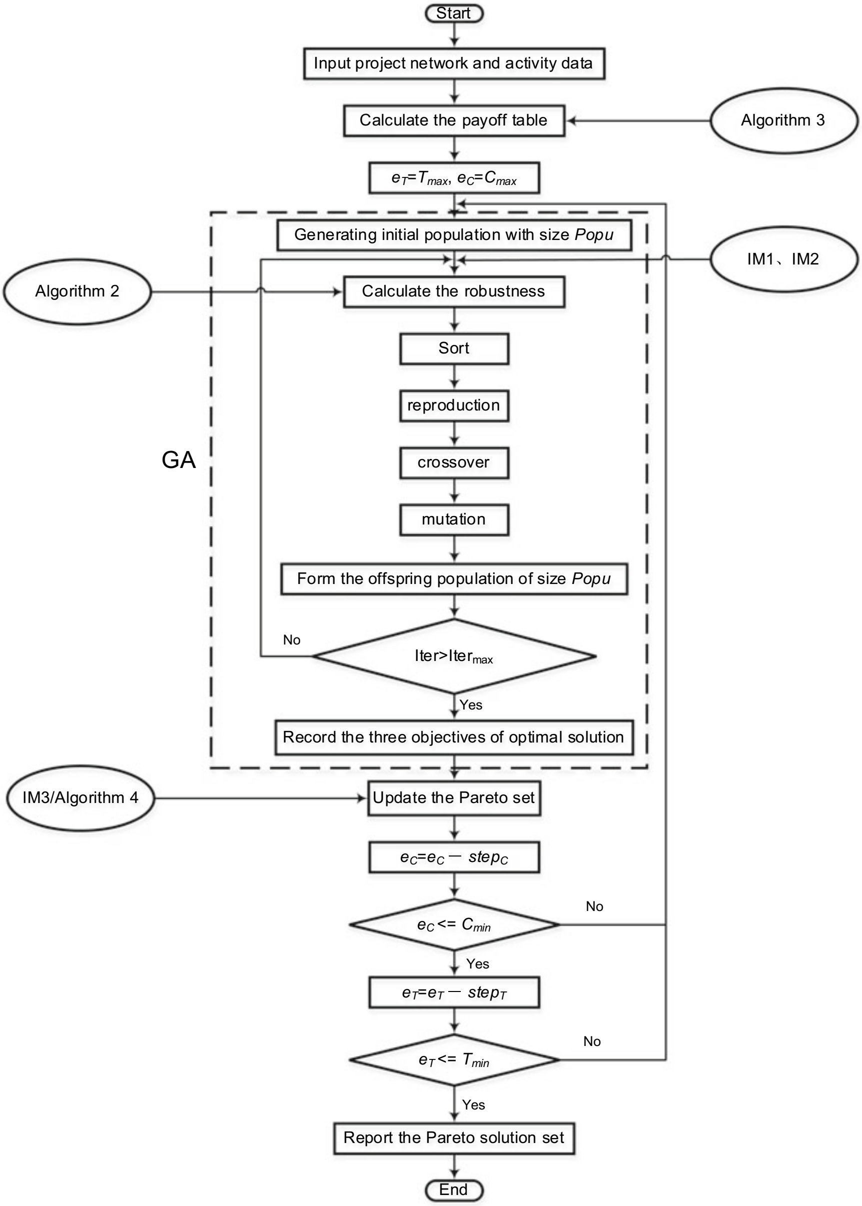

Fig. 15.4 Flowchart of the ECGA

We use f_j, D, Pred_j, and $a_k(t)$ to represent activity j's finish time, a given project's makespan that is large enough, the set of activity j's immediate predecessors, and the amount of resource k available at time t, respectively. Then, the pseudocode to decode AL and ML into a feasible schedule is displayed below.

Algorithm 2. Decoding procedure

```
Set l_0 = 1, l_{n+1} = n + 1
For t = 1 to D do
  For k = 1 to K do
    a_k(t) = a_k
Set s_0 = 0
For l = l_1 to l_n do
  Let q be the index of l
  m = m_q
    For k = 1 to K do
      t = max {f_j | j ∈ Pred_j}
      While (r_lmk > a_k(t))
        t = t + 1
      End while
      s_i = t, f_i = t + d_lm
Set s_{n+1} = max {f_j | j ∈ Pred_{n+1}}
Output feasible schedule S = {s_0, s_1, ..., s_{n+1}}
```

The optimal Pareto set of a multi-objective problem can be obtained by using the epsilon-constraint method. The method consists of two stages. First, generate the payoff table containing the range of each objective function, and then, apply the range of objectives in the payoff table to optimize the multi-objective model [15]. To derive the range of makespan and cost in this problem, we first assume sufficient resources, crash each activity, and develop a schedule using the SSGS method. The corresponding schedule makespan is the minimal makespan T_{min}, and the cost is the maximal cost C_{max}. Second, the mode that consumes minimal resources is chosen for each activity. For all activities, we select the maximal resource consumption of the minimal resources as the resource's critical value, that is, $R_k = \max_i \{ \min_m \{ r_{imk} \} \}$. Subsequently, we develop a schedule using the SSGS method. The corresponding makespan of the schedule is the maximal makespan T_{max}, and the cost is the minimal cost C_{min}.

In Fig. 15.4, the calculation of the payoff table is presented in Algorithm 3, implemented according to the following steps:

Algorithm 3. Payoff table generation

For $i = 1$ to n do
  If ($d_{im} = \min_m\{d_{im}\}$) then $x_{im} = 1$ else $x_{im} = 0$
Set $s_0 = 0$
For $i = 1$ to n do
  $s_i = \max\ \{f_j \mid j \in \text{Pred}_j\}$
Compute T and C
Set $T_{min} = T$, $C_{max} = C$
For $k = 1$ to K do
  For $i = 1$ to n do
    $a_k = \max\ \{a_k, \min_m\{\ r_{imk}\}\ \}$
    If ($r_{imk} = \min_m\{\ r_{imk}\}$) then $x_{im} = 1$ else $x_{im} = 0$
Set $s_0 = 0$, develop a schedule S by SSGS
Compute T and C
Set $T_{max} = T$, $C_{min} = C$

As we have already acquired the range of the makespan $[T_{min}, T_{max}]$ and the cost $[C_{min}, C_{max}]$, the critical values e_T and e_C can be selected from these two intervals to formulate different robustness-maximization models.

According to the three proposed propositions, three improvement measures are designed and embedded into the ECGA to improve the algorithm effectively.

IM1. In the process of generating new individuals in the population, calculate the shortened duration of the activity at the expense of per-unit cost, that is, $\overline{d}_i^c$, which is defined in Proposition 1. Afterward, select several activities with relatively larger $\overline{d}_i^c$ and arrange them in crashed mode.

IM2. In the process of generating new individuals in the population, if there are resource surpluses within $[t_a, t_b]$, and activities in normal mode that satisfy $s_i \geq t_a$ and $s_i + d_{im} \leq t_b$, crash the activities, as indicated by Proposition 2.

IM3. After updating the Pareto set, reevaluate each pair of nondominated schedules according to Proposition 3 and delete the dominated solutions in the Pareto set to make it more condensed. This improvement measure is displayed in detail in the pseudocode below, where S_{num} denotes the number of schedules in the Pareto set.

Algorithm 4. IM3

For $S_1 = 1$ to $S_{num} - 1$ do
  For $S_2 = 2$ to S_{num} do
    If ($T_1 < T_2$ and $C_1 < C_2$ and $R_1 < R_2$) then
      Set $s_{n+1} = T_2$ in schedule S_1
      Compute C_1' and R_1' of schedule S_1
      If ($C_1' \leq C_2$ and $R_1' \geq R_2$) then
        S_1 dominates S_2
    Else if ($T_1 > T_2$ and $C_1 > C_2$ and $R_1 > R_2$) then
      Set $s_{n+1} = T_1$ in schedule S_2
      Compute C_2' and R_2' of schedule S_2
      If ($C_2' \leq C_1$ and $R_2' \geq R_1$) then
        S_2 dominates S_1
Delete dominated schedules from the Pareto set

There are three nested loops in the ECGA, among which the inner layer implements the single-objective robustness-maximization optimization algorithm under a given makespan and cost constraints. The exterior and middle layers vary the critical values of the makespan and cost, respectively, step-by-step to formulate different robustness-maximization models and input them into the inner layer. The inner layer continues to output optimal solutions, from which the nondominated ones are selected and recorded to form the Pareto set for the multi-objective DTCRTP, while the dominated ones are deleted.

The inner-layer algorithm accepts critical values of the makespan and cost from the exterior and middle layers and solves the robustness maximization models under the given constraints. The main operators of the inner genetic algorithm are the initial population generation, individual sequencing, reproduction, crossover, and mutation. Additionally, the ECGA determines the range of the makespan and cost, changes the critical values of the inner-layer model, implements a series of robustness maximization algorithms, and records and conveys optimal solutions from the inner layer to the final Pareto set. In this way, the whole ECGA successfully realizes the optimization goal of the DTCRTP model, making trade-offs among the three objectives.

15.4 Summary

This chapter introduces the organization of value chain reconstruction. First, we discuss the relationship between value chain reconstruction and project management. Additionally, to point out that value chain reconstruction is often implemented in the form of a project, we analyze in depth the importance of proactive and reactive project scheduling for the organization of value chain reconstruction. Based on the aforementioned facts, we present a detailed model and algorithm for proactive and reactive project scheduling in the second section. We construct an optimization model to maximize the project's NPV and develop three heuristic algorithms: tabu search, variable neighborhood search, and a mixed version of TS and VNS. We test the developed algorithms using a randomly generated data set and analyze the influence of key parameters on the objective function value. Finally, considering that value chain reconstruction under uncertain environments generally involves multiple objectives regarding green and growth, we propose a time-cost-robustness trade-off proactive project scheduling method. Based on the problem formulation, we establish a multi-objective optimization model and abstract some properties of the studied problem. Based on the epsilon-constrained method idea, we designs a multi-objective heuristic method. The epsilon-constrained method-based genetic algorithm solves the constructed multi-objective optimization model. The models and algorithms introduced in this chapter may provide important support for implementing value chain reconstruction.

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Chapter 16
Social Responsibility Management

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Abstract Corporate social responsibility (CSR) management is a way firms achieve green growth. Increased environmental awareness and attention to environment problems in society cause enterprises to focus on social responsibility. CSR helps enterprises establish a positive relationship with stakeholders and provides relevant knowledge, capital, and a legal basis for enterprises' green growth model. This can obviously improve firms' economic performance and competitiveness. Enterprises can enhance the CSR perception of employees and leaders, enhance the driving force of external stakeholders, and increase CSR investment to promote its continuous implementation. Innovation is an important driving force for enterprises in achieving green growth. As the primary component of implementing a CSR strategy, employee innovation behavior affects the quality and efficiency of enterprises' green growth. Research shows that employees' perception of CSR can positively influence the atmosphere of CSR and employees' innovation behavior. In addition, the CSR atmosphere can also positively influence the innovation behavior. With improved CSR atmosphere, the direct positive impact of employees' perception of CSR on employees' innovation behavior is weakened. Enterprises can enhance employees' perception of CSR through strengthening CSR publicity and related practices, to enhance CSR atmosphere, which can enhance employees' innovative behavior and ultimately drive enterprises to establish a green growth model.

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16.1 Social Responsibility and Enterprises' Green Growth Model

16.1.1 Social Responsibility

In 1953, Bowen established the concept of corporate social responsibility (CSR), believing that enterprises should formulate policies and take actions based on social goals and values. Based on predecessors, Carroll further refined the connotation of CSR, emphasizing that enterprises should consider various public expectations in a specific period [1]. At present, CSR does not have a perfect and specific definition. From the perspective of economics, CSR can improve resource allocation efficiency, enhance performance, and maximize shareholders' interests. From management's perspective, CSR based on the principle of equal power and responsibility is not only a short-term behavior that enterprises must adopt under pressure from external systems, but also a favorable path to improve corporate performance [2].

Based on service groups, Davis divided CSR into ten stakeholder responsibilities, namely: shareholders, employees, government, suppliers, creditors, consumers, communities, industry associations, competitors and special interest groups [3]. Freeman proposed that stakeholders can be understood as groups with interests in an enterprise or demands on it. According to this theory, a socially responsible firm is concerned with the legitimate interests of all appropriate stakeholders, not just the benefit of the firm's shareholders [4]. Therefore, according to different stakeholders, CSR can also be divided into internal and external forms (Table 16.1).

From the above classification, it is easy to find that CSR takes environmental protection and economic growth as its core objectives, reduces pollution from enterprises' activities as its starting point, to meet the demands of different stakeholders. On this basis, it maximizes the economic benefits by green patterns and ultimately achieves green growth. According to the level of enterprise initiative to implement social responsibility, it can be refined into proactive CSR and reactive CSR. Proactive CSR refers to a company's CSR level being higher than national laws and regulations. Enterprises implementing proactive CSR will regard environmental protection and other behaviors as an important part of responsibility or charitable behavior. At this time, the company will carry out a variety of internal and external environmental protection measures, such as understanding external needs for environmental protection while disclosing complete and accurate information about environmental protection to society.

Reactive CSR pays more attention to obtaining legitimacy. The quality of products or services provided by enterprises only meets the minimum legal and regulatory requirements. The corporate environmental protection measures always lag the average industry level or relevant laws and regulations requirement.

Both will drive enterprises to attach great importance to the environmental protection requirements of stakeholders, accept supervision from society, and comply with

Table 16.1 Macro classification of corporate social responsibility

Perspective	Classification	Specific content	Represents	Model
The hierarchy of social responsibility of industrial and commercial enterprises	Inner circle	Economic responsibility	Provide products and promote employment	Concentric circles
	Middle circle	Social value responsibility	Protect the environment and safeguard our rights and interests	
	Outer circle	Improving social environment and unknown responsibilities	Eliminate social poverty	
Sequential categories in system theory	Internalization requirements	Charity responsibility	Voluntary behavior	The pyramid
		Moral responsibility	Unconstrained and expected	
	Externalization requirements	The legal responsibility	Mandatory public constraint	
		Economic responsibility	Basic responsibility	
Categories of stakeholder groups	Internal	Shareholders	Revenue maximization	
		Employees	Labor rights and interests	
	External	The government	The public interest	
		Supplier	To provide goods or services	
		Creditors	Performance of obligations and claims	
		Consumers	To provide goods or services	
		Community	Ecological protection and social harmony	
		Industry association	Comply with industry norms	
		Competitors	Fair and reasonable	
		Special interest group	Special interests	

environmental laws and regulations. They will not only get the support of stakeholders, but also establish obstacles for competitors and improve their own competitive capacity. Obviously, CSR management, as a component of a green growth model, has become an important element in enterprises' green growth.

16.1.2 Relationship Between CSR Management and Enterprises' Green Growth Model

CSR management is an important component in establishing enterprises' green growth model and achieving green transformation. Enterprise need adjusting the traditional extensive economic development model to achieve green growth goal. On the one hand, it is necessary to continuously improve the environmental awareness of practitioners. On the other hand, improving the ability of enterprises to protect the environment is an important foundation. With the increase of consumers' awareness of environmental protection and the increase of government's pressure on environmental regulation, the implementation of corresponding CSR is not only a manifestation of responsibility to stakeholders, but also an important way for enterprises to achieve green development. CSR management can simultaneously drive enterprises to implement their responsibilities for environmental protection and economic growth and help achieve green growth.

Haier has built up a set of green management, design, manufacturing, and recycling systems. Based on realizing green development goals, Haier has achieved data-driven mass customization and greatly improved its competitiveness.[1] Through energy saving transformation, GREE constantly reduces energy consumption in the process of enterprise operation. While realizing green goals, GREE saved a large amount of energy and reduced enterprise operational costs.[2] In response to the ban on plastic bags, Alibaba has continuously improved the recycling efficiency of plastic packaging and bottles. In addition, it enables traditional industries to continue to optimize through the Internet, and advocates green office, travel, consumption, recycling, and other models widely recognized by consumers.[3] CSR provides an important driving force for green growth. Specifically, CSR management drives the acquisition of knowledge, provides financial support, and a legal basis for green growth.

(1) CSR Management Drives Enterprises to Acquire the Knowledge Required for Green Growth

CSR management can drive enterprises to integrate internal and external knowledge for green innovation and help achieve green growth. Knowledge-based theory believes that knowledge is the source for enterprises to continuously obtain competitive advantages and improve performance [5]. Enterprises can not only acquire relevant knowledge directly from the outside, but also independently develop and create

[1] https://smart-home.haier.com/en/shzr/

[2] https://data.eastmoney.com/notices/detail/000651/AN202104281488465550.html.

[3] http://www.alijijinhui.org/category/104.

new knowledge. By establishing external cooperation and strengthening market links, firms can search for knowledge from other enterprises or consumers through the supply chain and translate it into applied technologies for green growth. CSR management can attract different enterprises committed to green growth to jointly achieve environmental protection goals. Successful cooperation encourages more enterprises to participate, continuously expand and strengthen the network and provides an important basis for acquiring external knowledge.

In addition, responding to consumers' demand for environmental protection is an important part of CSR management. Therefore, enterprises should strengthen consumer relationships and let them participate in CSR management processes [6] so that consumers can provide green knowledge and optimization strategies, thus providing an important knowledge base for the enterprises' green growth model. For example, Beijing GeoEnviron Engineering & Technology, Inc., is a company specializing in preventing solid waste pollution. To improve its environmental governance through CSR management, it established cooperation with the fourth Research and Design Engineering Corporation of CNNC (China National Nuclear Corporation) in technology research, construction, investment, solid waste treatment and disposal, contaminated site remediation, groundwater pollution prevention, and control and remediation projects in the fields of radioactive and non-radioactive waste, to mutually achieve green growth.[4]

CSR management requires enterprises to implement the responsibility of environmental protection and economic development, so that they'll take the initiative to create environment-related knowledge to adapt to changing external environmental requirements and use green technology to establish market strength. According to the theory of planned behavior, an individual's intentions will be influenced by his environmental motivation, the perceived external environment pressure. With the improvement of CSR management, on the one hand, enterprise can respond more effectively to the environmental demands of governments, NGOs, consumers, etc. On the other hand, using environmental protection measures generate additional income, companies will be more proactive in knowledge creation and ultimately achieve green growth.

Huawei has increased investment in energy conservation and emission reduction, formulating and implementing carbon emission reduction targets and corresponding action plans. On the one hand, Huawei created and utilized knowledge directly related to environmental protection, such as more reasonable packaging technology, which enabled it to reduce consumption by 100 tons of e-commerce logistics plastic packaging in 2020–2021. In addition, about 114,000 tons in carbon emissions were reduced in logistics transportation, and the carbon emissions of product transportation was reduced by 15% on average. On the other hand, knowledge from other fields is innovatively applied to environmental protection. For example, the HarmonyOS system allows phones that have been on the market for five years to operate smoothly,

[4] https://www.hbzhan.com/news/detail/119906.html.

and product utilization has improved.[5] In response to green and low-carbon requirements, Huawei constantly innovates relevant knowledge and improves economic earnings while protecting the environment and attaining green growth.

(2) CSR Management Provides Financial Support for Green Growth

CSR enhances the debt financing efficiency of enterprises by enhancing external trust, thus providing additional funds and power for enterprises to achieve green growth. To do this, enterprises must overcome the early stage of economic performance loss caused by investment in environmental protection [7]. To improve later environmental and economic performance, enterprises must continue to invest in green innovation. Stronger debt financing efficiency provides related financial support by integrating more funds at lower costs. When carrying out CSR management, enterprises enhance communication with stakeholders, which reduces information asymmetry for stakeholders, thus increasing social trust and improving debt financing efficiency [8].

First, enterprise CSR performance accelerates external recognition of the enterprise. Investors will consider the implementation of CSR, which can enhance enterprises' reputation and integrity [9]. In this way, enterprises' market value was improved by easily attracting additional active investors and reducing financing risks, costs, and uncertainties in the transaction process. Second, CSR management means that enterprises are willing to accept supervision and review. This causes investors to believe in the firm's environmental protection and management regulations, which increases credibility and makes the firm worthy of trust and investment. Again, implementing CSR can save time costs for investor negotiations and trust building. For example, enterprises' environmental actions are often indirectly influenced by government. Enterprises can gain support from the government and state-owned banks by disclosing CSR information on green growth, utilizing relational trust to obtain lower-cost funding [10]. Finally, enterprises in the process of implementing CSR for stakeholder relationship management will improve their level of environmental protection to avoid punishment. In other words, the government will establish relevant punitive environmental regulations to increase enterprises' pollution cost. Consumers with a green preference will avoid polluting enterprises. Therefore, implementing CSR can not only reduce government penalties, such as fines and business suspension, but also gain more support from consumers, which enables firms to allocate additional funds to green innovation and other environmental protection technologies, thus gaining competitiveness based on green practices [11].

Vanke continues to implement CSR in the real estate industry. While implementing low-carbon and environmental protection, it also continuously improves product value and achieves green growth. Based on the "green building industrialization" model developed to reduce carbon dioxide emissions, it developed a set of labeling models for decorating residential buildings. Housing industrialization has formed a systematic industrial chain: the standardization of design, the factorization of production processes, on-site assembly and integration of various industrial chains, which

[5] https://www.huawei.com/en/sustainability/sustainability-report.

won the trust of consumers, society, and investors and increased Vanke's profit and market value while improving housing quality.[6] In 2021, Vanke appeared on the list of top real estate enterprises in China with a market value of 419.11 billion CNY.

(3) CSR Management Provides a Legal Basis for Green Growth

CSR management establishes a positive relationship with stakeholders and corporate reputation [9], and such behaviors can gain legitimacy and gain additional external support to enhance green competitive advantages. This is an important basis for achieving green growth. According to new institutional theory, legitimacy is a necessary condition for enterprises to survive and develop in the environment. Achieving green growth needs to invest corresponding resources for green innovation and other activities in early stages, so obtaining multi-dimensional legitimacy through CSR management can lay a basis for reducing the uncertainty in green growth and improving its efficiency.

Through CSR management, firms achieve green growth for political legitimacy and market validity. Political legitimacy is mainly embodied in the consistency of enterprise's environmental performance and policies, regulations, and standards designated by the government. Market legitimacy is mainly embodied in the consistency of enterprise's environmental protection behavior and interests of market participants who implement environmental standards and appeal to environmental interests. Enterprises with high political and market legitimacy will have advantages in the acquisition, allocation, and utilization of environmental resources. For instance, Changan Auto follows development trends, interprets the spirit of government environmental protection policies, and plans the direction of the company's green transformation. It enhances green manufacturing effectiveness through 13 key paths, including low-carbon public welfare design, equipment energy efficiency improvement, energy intelligent deployment, energy-efficient organization, carbon sink technology, solid and liquid waste recycling, etc. To achieve efficiency, energy savings, and environmental protection in the manufacturing process, they established a globally integrated green manufacturing management system at an advanced level and built a benchmark factory for green automobile manufacturing.[7] Changan Auto appeared on the 2017 National Green Factory Demonstration List[8] and the 2020 Nanjing Environmental Protection Demonstration Enterprises and Institutions list.[9] Being selected as a demonstration enterprise means that it can gain political and market legitimacy. On the one hand, the enterprise can participate in the formulation of government environmental standards and policies. Compared with competitors, the enterprise has more first-mover advantages. On the other hand, being recognized as a demonstration project by the government sends a positive signal to firm stakeholders, thus enhancing the reputation of the enterprise and making it more

[6] https://news.ifeng.com/c/7fcVij15wi5.

[7] https://www.changan.com.cn/sociology?index=1.

[8] https://auto.ifeng.com/c/7s579yMnOh5.

[9] http://hbj.nanjing.gov.cn/njshjbhj/202010/t20201022_2456822.html.

recognizable to consumers. The cumulative sales volume of Changan Auto in 2021 was 2.3 million units, up 14.8% year on year.[10]

16.2 The Implementation Path of CSR

16.2.1 To Enhance Perception of CSR with Internal Members

(1) Employees' Perception of CSR

CSR, as an important strategic support for modern enterprise development, is necessary to internalize corporate core values into action ideas through employees' perception. In the early stage, existing practice and research mainly focused on the macro aspects of an organization, including increasing competitive advantages and improving organizational outcomes. It focused on financial performance, product quality, corporate reputation and consumer loyalty, etc. Although there are numerous existing studies, their results are often inconsistent. Therefore, recently attention increasingly focuses on stakeholders as the starting point of individual micro-level research, mainly in two directions: first, focusing more on organizational commitment and emotional commitment, organizational identification, emotional identity, job satisfaction and performance; second, focusing more on individual perception's influence on behavior, particularly the influence of employee perceptions on individual and organizational behavior [12].

Presently, research based on group classification mainly focuses on three categories: customers, managers and employees. On the one hand, it focuses on evaluating customer satisfaction; on the other hand, it focuses on the cognition and strategic choice of enterprise managers. In addition, studies are beginning to focus on the impact of CSR on the attractiveness of a job for potential employees, the well-being and personal development of existing employees.

Research based on exploring the internal organizational mechanisms focuses on clarifying the influence of organizational attitudes on individual behavior. It concentrates on two aspects: first, deep-level behaviors such as citizen organizational behavior and work engagement under positive emotions such as organizational trust, social exchange, and social identity; second, superficial behaviors such as antiproductive behavior and intention to leave involving negative emotions such as lack of organizational identity, commitment, and ethics.

The internal mechanism based on individuals is increasingly concerned with how employees' perception of CSR affects individual behaviors. No matter where an enterprise is and what its stage of development, the establishment of its concept, implementation of its strategy, and construction of its culture, creating an atmosphere for innovation, are inseparable from employee engagement, including managers. Only when all employees have a deep perception of CSR and take the initiative to

[10] https://new.qq.com/omn/20220110/20220110A08QQI00.html.

implement it with minimum deviation, can they achieve the same frequency resonance with corporate development. This is also true for the development of enterprise innovation. The importance of individual perception as an antecedent condition of individual behavior becomes prominent. High-quality perception without deviation can effectively reduce internal communication costs and improve performance; therefore, it is very necessary to study individual perception mechanisms, types, directions, and related theory, and effect assessment.

At present, the influence mechanism for how CSR perception affects individual behavior is divided into three types. The first is "stimulus-organism-response"; that is, with a certain degree of conditional external stimulation, individuals receive such stimuli, and then respond to the external stimulation. For example, employees perceive that the enterprise actively implements its social responsibilities and are satisfied with firm behavior, thus improving their loyalty. The second type is "benefit/need-action", which refers to taking certain actions based on survival needs, relationships, or existing contributions. For example, the enterprise provides security to satisfy the sense of belonging or meaningful existence of employees based on firm characteristics, to stimulate a series of positive behaviors from employees [13]. The third type, "cognition-emotion-attitude-behavior," is more proactive than the first type. Employees' perception of CSR can stimulate organizational pride, thus generating a more stable attitude and binding force, which helps to reduce resignation behavior [14]. The direction of CSR perception's influence on individual behavior can be divided into four types. The first type is "outward-inward-upward." For example, enterprises carry out social responsibility activities to enhance trust in others and improve personal organizational leadership [15]. The second type is "forward-reverse," which means to reduce individual hypocritical charitable behavior through subjective norms, such as individual and demonstrative norms, and positive perceptions, such as internal and external collaborative perceptual behavior control. In addition, there is the third type of "independent incentive-controlled incentive" and the fourth type of "participation-escape", which explain the consistency of CSR requirements and the differentiation of individual behavior [16].

CSR, as a recent hot field in management research, has been of great interest to scholars, entrepreneurs, the public, and government. Theoretical research has developed rapidly with the widespread participation of the public. The main theories surrounding the attitude-behavior model are the social identity, stakeholder, social learning, social exchange, organizational support, and affective events theories. The cognitive processes based on differentiation and polycentricity mainly include theories such as heuristic theory and deontic justice theory, signal theory, emotional evaluation theory, self-determination theory, agency theory, existence, relatedness and growth theory, etc. Along with the deepening of theoretical research, CSR practice has deepened. In the early stage, implementing CSR is a way to improve organizational performance. Enterprise can attain external benefits to improve enterprise social reputation, and CSR has already been a pioneering competitive tool to secure resources for optimizing management. So far, there is no doubt that it has become the core strategy for enterprises to achieve green growth and sustainable development, which is a core environmental goal [17].

(2) Leader's Perception of CSR

CSR is one of the important standards to measure corporate performance. The perception of CSR has undergone a transformation process. CSR is regarded as a burden for it increases cost at the initial stage, a basic responsibility as time goes by, and currently an important competitiveness for enterprises. This transformation indicates that enterprises retain a certain misunderstanding of social responsibility at the beginning. Enterprise believed that enterprises must invest human, material, and financial resources to implement social responsibility. If the enterprise's development strategy is reasonably combined with CSR, it will also become a powerful tool of competitiveness. As important makers and executors of corporate strategy, leaders play an important role in CSR implementation, which depends on leaders' perception of CSR. This depends on the effectiveness of CSR for the enterprise and the advantages that it brings [18].

Perception is individual's internal response to the external environment. Individuals' evaluation or judgment of change in the external environment affects their intentions or attitudes. The effectiveness of CSR on enterprises will affect leader's perception of CSR. First, CSR has become an important way to realize enterprise legitimacy. CSR has been recognized by various stakeholders and there are many CSR standards for multinational enterprises in international trade. Therefore, CSR is not only one of the important competitive aspects of firms, but also a barrier to international trade. When leaders become aware of CSR's importance, their perception increases. CSR for self-development will also influence leaders' perception of CSR. Self-determination theory explains that motivation is an important driving force for people to complete tasks, and executives will not only pursue external targets, such as profit and reputation, but also internal targets, such as personal growth and a sense of belonging. Thus, an important way of strengthening leader's perception is to increase CSR's benefit for leaders [19]. Some companies have established a Chief Sustainability Officer (CSO) to better implement CSR. Such implementation gives leaders positive or negative signals that influence the opportunity or threat motivation level. The resulting perception, such as excellent enterprise CSR performance and a gain in social recognition, will not only enhance leadership's sense of honor, but enhance career and compensation prospects, motivating them towards better CSR performance.

16.2.2 Increasing Enterprise Investment in CSR Through External Driving Forces

(1) External Driving Force

CSR's implementation path includes not only the drive of internal members, but also motivation from the external environment [20]. Existing studies have classified the external driving forces of CSR into various categories, but the core ones all include the coercive force of public policy, social pressure, market competition, and the pulling force of demand. Coercive force of public policy derives from the government's laws and regulations and the standards of industry associations; it is the basic power of enterprises to implement social responsibility. For example, the government will require listed companies to publish annual CSR reports and impose appropriate penalties for compliance failure, so companies will implement CSR and publish the results for legitimacy, whether they benefit from them or not. Social pressure comes from multivariate supervision; media supervision is one important channel that helps firms establish a positive image, or results in a damaged image. Driven by this mechanism, monitoring by the media and public opinion gradually strengthens the awareness of CSR to enhance the social image of enterprises and reduce the reputational damage caused by improper governance. Companies are often active in implementing CSR. The driving force of market competition is defined as gaining stronger competitiveness by catching up with their CSR competitors to gain a better image and a greater market share. The pulling force of demand means that consumer demand for products is important motivator for enterprises to carry out CSR. In addition, relevant requirements for products and consumers cause enterprises to prove CSR implementation or environmental protection. Therefore, strengthening the supervision and control of multiple stakeholders over enterprises is of great significance to improving the external driving forces and the level of corporate CSR.

The joint communique of the Roundtable Summit of the Second Belt and Road Forum for International Cooperation of April 27, 2019, stated that to achieve sustainability, countries must strengthen cooperation in project preparation and performance, making sure that projects were investable, bankable, economically viable, and environmental-friendly. The summit called on all market participants in the Belt and Road Cooperation to implement their CSR and abide by the UN Global Compact.[11] On December 31, 2008, the Shanghai Stock Exchange, in the Notice on The Annual Report of Listed Companies for 2008, required three types of companies (the sample companies of the "Shanghai Corporate Governance Board," the companies issuing overseas-listed foreign capital stock, and financial companies) to publish social responsibility reports.[12] The number of CSR reports collected through online inquiry, voluntary delivery by enterprises, and download from company websites has increased from 582 in 2009 to 1926 in 2021, indicating that enterprises' CSR level has improved under the motivation of public policies.[13]

(2) CSR Input

CSR investment involves different business scopes, which can be divided into internal and external CSR investment according to business content. Internal CSR investment mainly includes investment to optimize existing operating processes, reduce carbon emissions in operations, and improve the working environment, etc. External CSR inputs include investment to those related to responding to the call of environmental protection policies and improving social welfare. CSR input is closely related to CSR content. According to differences in stakeholder importance, enterprises will

[11] https://baijiahao.baidu.com/s?id=1631981775639675300&wfr=spider&for=pc.

[12] http://www.sse.com.cn/aboutus/mediacenter/hotandd/c/c_20150912_3988269.shtml.

[13] https://new.qq.com/omn/20211118/20211118A060JA00.html.

invest in different CSR businesses. Enterprises will focus on requirements from both the government and consumers, because this directly relates to external business conditions and product sales. Therefore, they will invest more resources to respond to government and consumer needs [14]. The top enterprises in an industry will focus more on their social image and actively participate in CSR activities because they want to receive greater attention. For example, in response to the government's call during the COVID-19 outbreak, both Internet and manufacturing companies have been involved in fighting the epidemic. Internet companies have used big data, artificial intelligence, and other technologies to help control and monitor the epidemic.[14] Some manufacturing companies have temporarily transformed. They started production of masks, protective suits, goggles, and other equipment used for epidemic prevention, which required enterprises large investments. In addition, enterprises also consider consumers' demand for products, especially related to environmental protection. Enterprises continue to invest resources in green product and green process innovation to reduce the pollution in the production process, and design structures and channels for easily recycling to maximize the interests of consumers.[15]

Alibaba continuously implements CSR to achieve green growth through its investment in Internet technology. On September 27, 2019, Alipay Ant Forest earned the "Champions of the Earth Award," the highest environmental honor of the United Nations. On the same day, the Secretariat of the United Nations Framework Convention on Climate Change (UNFCCC) also announced that Alipay Ant Forest won the Lighthouse Award, the highest award for addressing climate change, for its innovative path and positive demonstrative role in addressing global climate change. In three years, the 500 million Ant Forest users have reduced carbon emissions by 7.92 million tons, and 122 million trees have been planted in desertification areas. Alipay launched a new era of public initiatives in environmental protection with its corporate power. In addition, Alipay given the Internet+ industry a new mission that technology should be used for social welfare. Alipay has even contributed ideas for companies to play to their strengths and use innovative paths to engage society in small actions that address big sustainability issues.[16] To protect the ecology of the Yellow River, Sinopec invested more than 600 million CNY in its refineries during the "13th Five-Year Plan". With continuous investment, all the water discharged from the sewage plant meets the standard requirements in recent years. In addition, the enterprise strengthened noise detection, reducing noise pollution, and comprehensively improving the surrounding environment.[17]

The implementation of a CSR path requires both internal and external causes of common drive as well as specific performance by companies investing in related resources to meet the needs of different stakeholders while also promoting enterprise image, enhancing their competitiveness. On this basis, a virtuous circle is formed, and by reinforcing its strengths, it will further enhance CSR practice.

[14] https://www.alihealth.com/

[15] https://new.qq.com/omn/20200425/20200425A0AB8Z00.html.

[16] https://tech.huanqiu.com/article/9CaKrnKmV0s.

[17] http://www.cb.com.cn/index/show/gs/cv/cv135345012031/p/s.html.

16.3 The Significance of CSR for Enterprises' Green Growth from the Employee Perspective

In the process of CSR implementation, Haier actively responds to the government's call and goal of green development, integrates green development into operations, leads the transformation of old and new driving forces with green actions, and cultivates a green atmosphere. To implement its CSR strategy, Haier has created platforms such as HCH[18] and RenDanHeYi.[19] It encourages its employees to participate in the innovation process, so that every employee becomes a creator and applies different technological innovation to the field of green development. Innovation is an important driver for enterprises to achieve the goal of green growth. As part of enterprises' green growth model, social responsibility management enables employees to fully participate in the implementation of CSR strategy, enhance employees' perception of CSR (PCSR), and create a good CSR atmosphere (CSRA). It is one of the important ways to effectively stimulate employees to participate in the innovation process, improve enterprise value creation, and apply innovative technology to achieve green growth goals. Therefore, this study primarily addresses the following issues: how to create a good CSRA by enhancing employees' PCSR; how to transform the CSRA into green-oriented innovative employee behavior; how the CSRA level moderates the direct impact of employees' PCSR on innovation behavior (IB).

16.3.1 Theoretical Basis and Hypothesis

As one of the inevitable trends in the development of global enterprises, CSR practices by employees are mostly focused on the macro field and external stakeholders such as consumers, and there is a lack of research on the specific practitioners of CSR management, i.e., employees. The existing research on employees mainly focuses on civic organization and return to production behaviors. In addition, existing studies on CSR lacks internal mechanism research in the micro field [21]. At the same time, there are still insufficient studies on the antecedents and mediators of the employees' PCSR [14, 16]. Therefore, by studying the micro-mechanism of internal employees' PCSR and its effects on employees' IB, this study explores how the external CSRA affects them under both mediating and moderating conditions. We attempt to adopt an analysis relying on individual-environment-behavior. This study clarifies the impact of interaction between employees' PCSR and the external CSR environment on personal behavior. Enterprise can obtain more drivers implementing CSR by strengthening employees' PCSR and IB. The quality and efficiency of enterprise green growth have a profound impact.

[18] http://www.ihaier.com/?lang=en.

[19] https://www.haier.com/global/press-events/news/20180929_142473.shtml?from=search.

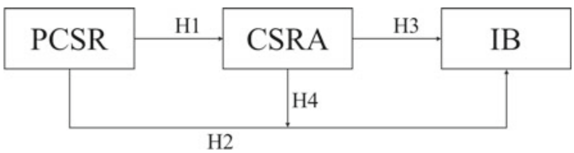
Academic circles are also accumulating relevant research results to guide green innovation development in different cultures and situations. At present, relevant theoretical achievements mainly focus on stakeholder, system, social cognition, social information processing, social exchange, and self enhancement theories. Stakeholders, as an important driver of enterprise value chain reconstruction [22], have been studied to form a stakeholder theory that has become an outstanding representative of the many concepts. This theory was put forward by SRI (Stanford Research Institute) in 1963 and has gone through three research stages since then, namely, the firm dependency view of stakeholders, the strategic management view, and the dynamic evolution view. The theory posits that enterprise development must consider that the interests of all stakeholders, such as employees, customers, and communities, must consider environmental protection, and promote social development. It is clearly pointed out that enterprise development must focus on the simultaneous improvement of environmental benefits while paying attention to growth in economic benefits. In terms of research methods, according to Donaldson and Preston, methods are conducted mainly from descriptive, instrumental, and normative perspectives [23]. In addition to positively summarizing guidance for CSR to green growth, the results must also coordinate different subjects to bear the consequences of negative implementation. If information fraud and environmental damage were condemned through public reaction, government penalties, and legal sanctions, companies will lose competitiveness. To achieve green growth and meet the demands for services of various stakeholders requires implementing green innovation. Enterprise staffs are direct and important stakeholders. Individual innovation from employees is the starting point and foundation of enterprise green innovation.

Employees' PCSR, employees' innovative thinking, and enterprises' atmosphere are important factors that provide employees with innovation resource inputs. In this way, employees are more willing to implement CSR, the CSRA has also been improved, and employees can better transform their IB into product and technology innovation. IB brings enterprise with long-term development driven by green growth. Therefore, it is particularly important to study how employees' PCSR affects their IB, exploring the nature of enterprises' green growth model.

Based on the above analysis, the following hypotheses are proposed:

H1: Employees' PCSR has a positive effect on the CSRA.
H2: Employees' PCSR has a positive effect on employees' IB.
H3: CSRA has a positive effect on employees' IB.
H4: CSRA weakens the positive relationship between employees' PCSR and IB (Fig. 16.1).

Fig. 16.1 Theoretical model



16.3.2 Data Collection and Results Analysis

A total of 300 questionnaires were distributed online and offline for different employee groups in different industries in different regions. Invalid samples were removed from the study, and all the questionnaires with the same answers, incomplete questionnaires, and those failing to pass the screening item tests were removed. 265 questionnaires were recovered with a rate over 88.3%. This allows the influence of employees' PCSR on employees' IB to be investigated; personal information of all interviewees is effectively protected during the investigation. In addition to demographic variables, a 7-point Likert scale is used to measure the other variables in the study, from "1" to "7" respectively representing "strongly disagree" to "strongly agree". Through one-way ANOVA, Composite Reliability (CR) of latent variables is determined and Cronbach's α values are both greater than 0.7, indicating good reliability. Average variance extract (AVE) is greater than the critical value 0.5, and higher than the load value under other variables. The square root of AVE is greater than the correlation coefficient between the variable and other variables, so each variable has good aggregation and discriminative validity. The results show that effective research can be carried out on employees' PCSR (Table 16.2).

The independent sample T test meets the significance level of $\alpha = 0.05$, and the Pearson correlation coefficient is greater than 0.6. The significance of the common and factor loading test is 0.000, and KMO is greater than 0.7, meeting the research conditions. The standard moderating effect verification process is achieved by constructing interaction terms, which can be obtained by multiplying the antecedent variable by the moderating variable and examining its effect on the outcome variable. The structural equation model is established; the smartPLS3.2.8 software is used for research and analysis. The results show that all the regression is significant, which support the above research hypothesis. It shows that employees' PCSR can be effectively transmitted through the CSRA, causing employees to have a more stable attitude and internal driving force to continuously enhance innovation to meet the needs of corporate economic growth and green support of sustainable environmental circulation (Fig. 16.2; Table 16.3).

There is a significant correlation between the interaction terms of CSRA and employees' PCSR and employees' IB indicating that CSRA plays a moderating role in the relationship between employees' PCSR and IB. On the one hand, Employees need to continuously learn and improve their abilities to stimulate IB. On the other hand, CSRA can solve the problem of declining IB caused by insufficient external driving force of external enterprises.

Table 16.2 Cronbach's alpha, Rho_A, composite reliability, and AVE

	Cronbach's alpha	Rho_A	Composite reliability	AVE
CSRA	0.834	0.856	0.878	0.551
IB	0.942	0.944	0.95	0.614
PCSR	0.948	0.949	0.953	0.547

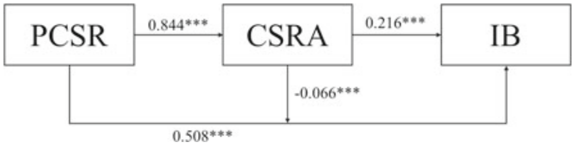


Fig. 16.2 Theoretical model result

Table 16.3 Factor loading

	CSRA	IB	PCSR
CSRA1	0.849		
CSRA2	0.822		
CSRA3	0.806		
CSRA5	0.842		
IB1		0.742	
IB2		0.746	
IB3		0.791	
IB4		0.794	
IB5		0.823	
IB6		0.796	
IB7		0.837	
IB8		0.798	
IB9		0.817	
IB10		0.818	
IB11		0.755	
PCSR1			0.741
PCSR2			0.791
PCSR3			0.777
PCSR4			0.831
PCSR5			0.735
PCSR6			0.77
PCSR7			0.782
PCSR8			0.719
PCSR9			0.793
PCSR10			0.74
PCSR11			0.733
PCSR12			0.763
PCSR13			0.721

16.3.3 Conclusions and Implications

Innovation and development are the eternal pursuit of enterprise survival, and a green environment is the foundation of enterprise and social survival. Enterprise stakeholders are increasingly aware that they must be unified to achieve all-win economic, social and environmental benefits. Employees, as internal stakeholders, are the "zero-kilometer" starting point of enterprise innovation and the "last mile" end point of strategy implementation. Therefore, enhancing employee innovation is one of the important supports for the enterprises' green growth model. How employees' CSR awareness as a core subject affects the developing a CSRA determines whether the direction of enterprise innovation can meet the expectations and requirements of stakeholders. The research results show that CSRA has a mediating effect on employees' PCSR and employee IB. It also shows that rational macro CSRA and effective use can effectively shape the employee's understanding of CSR and the employee's IB. Employees' PCSR is affected by personal psychology and personality traits, so the impact of CSRA on employees' IB is not positive, which provides a research direction for exploring how companies in different cycles and industries play the role of CSRA.

CSRA represents the comprehensive view of employees on how the enterprise manages stakeholder interests. This view exerts a subtle influence on employees' cognitive and emotional states directly through psychological adjustment, and then exerts a profound influence on employees' work attitude and behavior. A favorable CSRA can not only provide good learning resources and a harmonious working environment for employees, but also stimulate their creative ideas. It can allow employees to feel support and care from enterprises, for them to gain trust and support, organize team innovation enhancing psychological security, and inspire employees to innovate, actively exploring and facing uncertain and risky challenges. Favorable CSRA improves sense of worth, encouraging employees to harmonize their personal values with their work innovation achievements and social responsibilities, to take multiple measures to stimulate employees' IB and provide value transformation and support both internally and externally for the green growth of enterprises.

16.4 Summary

The existing research on social responsibility management focuses on CSR. Although the CSR concept has not been unified, the core focuses on how to better meet the demands of both stakeholders and enterprises; it has carried out a variety of classifications on this basis. As an important part of the green growth model, CSR has become an important part of enterprise competitiveness. Social responsibility management can further provide enterprise with the knowledge and capital to foster green growth. The promotion of CSR not only needs support from government, industry, media, and other external factors, but also needs the cooperation and support from enterprise employees. By enhancing employees' PCSR, IB can effectively drive green growth. CSRA is an external driving force that lays an important foundation for enterprises implement of social responsibility. Actively cooperating with employees is the critical path. This requires not only reasonable supervision from all walks of life, but also requires employees to combine their personal development goals with CSR goals to enhance the CSRA. Ultimately, enterprises will be guaranteed achieving green growth through social responsibility management.

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Chapter 17
Performance Management

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Abstract Enterprises' green growth performance evaluation can objectively reflect the implementation of green growth model and sets detailed targets for green growth. By evaluating the gap between the implementation level of the green growth model and external requirements, enterprises can identify the weak links in the process of operation and put forward corresponding improvement measures to achieve green growth. This chapter mainly covers four aspects. First, it introduces the content and importance of performance management in enterprises' green growth model, and selects evaluation indices based on environmental and economic performance. Second, it reviews three performance models, that is, the life cycle analysis (LCA), data envelopment analysis (DEA), and green growth maturity model. Finally, we use the green growth maturity model to evaluate the green growth performance of some representative listed enterprises in China. According to the results, we set different stage targets for the enterprises' green growth model and provide corresponding development suggestions to improve enterprises' green growth performance.

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17.1 Enterprises' Green Growth Performance

17.1.1 Concept of Enterprises' Green Growth Performance

Rapid economic growth has caused serious environmental degradation and resource depletion. An increasing number of countries and scholars are paying greater attention to how to evaluate enterprises' green growth performance. To realize sustainable development, enterprises must balance their environmental protection and economic growth goals. Companies have a responsibility not only to generate economic profits but also to protect the environment, which is included in their performance appraisals. Enterprises' green growth coordinates "green" and "growth". Enterprises' green growth performance considers financial and environmental performance indices, so enterprises can not only meet the existing requirements of economic development but also consider the need to create a strong environmental foundation for future generations.

(1) Comprehensive Evaluation of Economic and Environmental Performance

The relationship between economic and environmental performance is becoming synergistic. Traditional economic performance conflicts with environmental performance. To improve their environmental performance, enterprises will invest much capital and equipment, which has a negative impact on their economic performance. The main way to solve this contradiction is for the government to subsidize enterprise environmental protection efforts.

Some scholars have noted that environmental behavior can create benefits for enterprises, so they can simultaneously improve their environmental and economic performance [1]. First, improving enterprise environmental performance contributes to a certain extent to environmental protection, which helps to enhance enterprise legitimacy, improve enterprise reputation, and earn greater financial support. Second, based on green product innovation, enterprises can reduce energy consumption and the use of raw materials by using pollution control technology, thus reducing operational costs. Finally, enterprises provide differentiated green products, which can help enterprises occupy unique places in the market, improve their competitive advantages, and increase their profitability. Scholars have also found a nonlinear relationship between environmental and economic performance [2]. Enterprises can achieve a green growth model in which environmental performance and economic benefit can simultaneously be improved through reasonable operation strategies.

The comprehensive enterprises' green growth performance management considering the coordination of corporate economy and environment varies along with different corporate goals [3]. On the one hand, to achieve the goal of the green growth of the whole supply chain, enterprises can reversely drive suppliers to improve their manufacturing capacity through enterprise performance management for green growth. By reducing resource waste and environmental pollution, enterprises can maximize environmental performance within an acceptable cost range, enhance their market image, and achieve better economic performance, thus realizing the green management of supply chain. On the other hand, enterprises can improve their internal environmental performance by using green growth performance management to find abnormal phenomenon, especially high energy consumption activities. As the world's leading information and communication technology (ICT) infrastructure and intelligent terminal provider, Huawei in 2020 calculated each stage of its carbon emissions for its equipment based on the product life cycle analysis method. The company found that network and user-side devices had the largest carbon footprints due to their power consumption. Based on these results, if Huawei reduced the energy consumption of its ICT products from the source and increased its renewable energy use, it would significantly reduce the carbon footprint of its products. Doing so would reduce equipment operating costs while improving customer satisfaction, further improving market competitiveness, and achieving green growth.[1]

(2) Key Factors for Enterprises' Green Growth

The factors for enterprises' green growth include green product design and innovation, corporate social responsibility, and the coordination of green value chain stakeholders, as well as the resistance in the implementation of green growth model. First, green product design and innovation are the key factors used to measure enterprises' green growth because of creating good ecological technology and realizing the collaborative growth of enterprises in the region. According to Long, green product design and innovation have improved environmental performance in Shandong, Jiangsu and Shanghai, China. Green product innovation around raw materials have affected the environmental performance of enterprises in Shanghai, and green product innovation has improved the environmental performance of enterprises in Jiangsu. These indices have a positive impact on local economic performance [4]. Rabadan noted that the development of enterprise green innovation is the most beneficial way to improve enterprises' green growth performance. Enterprises can achieve green growth provided they invest sufficiently in green R&D, innovate ecological technology, and collaborate in the development and application of enterprise green innovation [5].

Second, enterprise social responsibility is an important index affecting enterprises' green growth performance. If an enterprise wants to establish a positive corporate image among stakeholders, good economic performance is far from sufficient. Because resources are limited, enterprises should prioritize improving their environmental performance. At the same time, multiple channels such as new media should be used to convey important information about environmental performance improvements to stakeholders to obtain further resources from the community and the society and to achieve enterprises' green growth [6].

Furthermore, coordinating the relationship between stakeholders in the green value chain can provide further support for enterprises to manage their green growth

[1] https://www-file.huawei.com/-/media/corp2020/pdf/sustainability/sustainability-report-2020-en.pdf.

performance. For example, support from senior management will help the organization to respond to the sustainable development initiatives and achieve enterprises' green growth. Further opportunities are available for senior management to be directly involved in budget formulation, especially in small and medium-sized enterprises (SMEs). Clarifying the relationship between executive support and green growth can improve SMEs' ability to implement the green growth model, thus significantly improving their enterprises' green growth performance.

Finally, improving enterprises' green growth faces different obstacles, such as poor partnerships between enterprises and their low loan capacity. Enterprise partnerships in ecological technological innovation have various impacts on the performance management of green growth. The low level of partnerships in the agri-food sector has adversely affected green growth performance, especially for small enterprises. An open green innovation strategy can help enterprises reduce the uncertainty and risk related to green innovation and the ecological innovation process [5]. Lending is an important tool for reducing resistance by increasing incentives to adopt a green growth model and reducing uncertainty in business activity. Wellalage and Kumar [7] noted that corporate environmental performance has a positive impact on the corporate loan scale but has no impact on loan terms and the mortgage loan ratio. Therefore, enterprises should regard environmental protection activities as a business strategy and combine them with enterprise core business objectives to improve access to credit and overcome the obstacles to achieving green growth goals.

17.1.2 The Importance of Performance Management in the Implementation of Enterprises' Green Growth Model

(1) Responding to External Entity Requirements for Green Growth

The performance management of enterprises' green growth is intended to realize the coordinated development of green and growth. In addition, it must consider the requirements of different external subjects, including the government, shareholders, consumers, etc.

Performance management should respond to the government's requirements for enterprises' green growth, including the implementation of government environmental protection policies and government supervision of enterprises. On the one hand, responding to the effective implementation of government environmental policies will prompt enterprises to implement environmental policies into specific indices of performance management and carry out assessments. In the early stage, this behavior will increase the investment in environmental protection and operating costs. Nevertheless, enterprises can still achieve long-term benefits by implementing green and sustainable development, including the implementation of environmental protection policies, and ensure the simultaneous growth of environmental protection performance and economic performance. Specifically, improving corporate environmental performance is a potential source of improving competitive advantage, as well as improving productivity, reducing costs, and discovering new market opportunities. In addition, R&D support of government, policy-related funds and discount loans can offset corporate investment in resources, energy, labor, and information. Moreover, government support can reduce the risks and uncertainties of the implementation of the enterprise green growth model and contribute to the positive planning of enterprises' green growth [8].

In response to the government's call for environmental protection, Contemporary Amperex Technology Co., Limited (CATL) has compiled management documents, such as Solid Waste Discharge Control and Management Procedures. These environmental protection requirements are higher than The Pollution Control Standards of General Industrial Solid Waste Storage and Disposal Sites. CATL has led more than 40 industrial chain and supporting enterprises to settle in Ningde City, Fujian Province, and its 50% market share has driven 50 billion CNY in investment. Moreover, CATL has boosted local revenue, created jobs, and improved local environmental performance by implementing a green growth model that exceeds government standards. Now CATL has become the world's leading lithium–ion battery R&D and manufacturing company. It was not only listed on Forbes China's Most Innovative Enterprises list in 2020 but also won the first prize of the Fujian Provincial Standard Contribution Award in 2020.[2]

On the other hand, responding to government requirements for enterprise supervision, taking the initiative to accept the government's supervision and dynamically adjusting performance standards according to government feedback can better serve the enterprises' green growth model. Enterprises can regularly publish reports for the government, the public and investors to discover performance rankings and policy changes, such as the National Passenger Car Information Exchange Association (CPCA).[3] As an unofficial enterprise information platform, CPCA has registered the green growth information independent report of several automobile enterprises. Thus, for the first time, the public and investors can obtain the performance information from enterprises. CATL, together with enterprises such as United Auto Battery and Hunan Brunp Recycling Technology, formulated environmental self-monitoring plans, strictly implemented monitoring requirements, and uploaded monitoring data to the self-monitoring management system of pollution source enterprises in Fujian province for information disclosure. These measures caused enterprises to attach more importance to their environmental performance.

In 2020, CATL promoted 218 energy-saving and emission reduction programs, which covered equipment technology, step utilization, recycling and disassembly, material recycling and regeneration, etc. The company invested 3.569 billion CNY in R&D, which resulted in a yearly investment increase of 19.29%, accounting for 7.09% of the total revenue. With this massive investment in R&D and construction along with its diversified green project management and self-testing, CATL

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[2] https://www.catl.com/uploads/1/file/public/202110/20211020162903_ugmls6osai.pdf.

[3] http://www.cpcaauto.com/news.php?types=csjd&anid=130.

has improved its environmental performance and reduced its carbon emissions by approximately 130,000 tons, which is an increase of 170% compared with 2019. By responding to the government's policy implementation and supervision requirements, CATL formulated the enterprise's developmental goals and implemented them into performance management to ensure the smooth implementation of the enterprises' green growth model. As a result, CATL has surpassed its competitors in many aspects and established certain competitive advantages.[4]

Second, performance management improves consumer satisfaction by responding to consumers' requirements, thus improving environmental and economic performance to achieve the goal of green growth [9]. Consumers' environmental protection requirements can be conveyed to enterprises by taking the initiative to participate in the green product design of enterprises or by providing suggestions for improvement. Generally, consumer satisfaction can be measured, and performance management generally attaches great importance to customer satisfaction. Furthermore, consumer environmental requirements establish specific environmental performance guidelines for the enterprise, enhance customer satisfaction, guide the consumer to recognize and support the enterprise product or service more, and eventually cause the enterprise to enhance its market competitiveness and improve its environmental and economic performance simultaneously, which is one of the ways to achieve a green growth model [10].

In its 2018 Global Social Impact Report, Starbucks showcased the company's sustainability achievements, which were to build a global network of farmers and pioneer green buildings as its stores. According to a report by Starbucks in 2020, in its stores in Canada, Europe, the Middle East and Africa, Japan and the United States, 1.3% of the beverage sales used a reusable cup, the customer's personal cup or cup a "used here", which allowed the consumer to truly participate in the enterprise green growth model. At the same time, the 2025 environmental protection plan of Starbucks shows its corporate green performance expectation and corporate green growth commitment to consumers.[5]

(2) Providing the Internal Development Impetus for the Implementation of Enterprises' Green Growth Model

Performance management can evaluate the internal environmental performance of enterprises, promote enterprises to formulate positive environmental strategies, and smoothly promote the implementation of enterprises' green growth model. First, performance management can provide the impetus for the implementation of green growth model by promoting enterprises to establish an effective system. On the one hand, enterprise performance can reflect the level of enterprise environmental and resource management, which will force enterprises to establish a sound enterprise resource management system to make reasonable use of resources. Specifically,

[4] https://www.catl.com/uploads/1/file/public/202110/20211020162903_ugmls6osai.pdf.

[5] https://stories.starbucks.com/uploads/2021/04/Starbucks-2020-Global-Environmental-and-Social-Impact-Report.pdf.

establishing a resource management system can provide timely and effective feedback for resource information and provide an important decision-making basis for the dynamic adjustment of resource allocation and the proportional use of resources. The establishment of a sound environmental management system also affects enterprise performance. A reliable environmental management system echoes the green growth goal of an enterprise and is constantly adjusted according to the expansion of the enterprise scale. On the other hand, performance management promotes enterprises to establish a human resource management system adapted to the green growth model by assessing the environmental performance of enterprise members. Such a human resource management system not only includes recruitment, training, evaluation, and incentive but also encourages enterprises to form an organizational culture that is environmentally aware. A green organizational culture plays a positive mediating role in the relationship between a green human resource management practice and environmental performance.

Second, performance management drives enterprises to actively explore relevant technologies for performance appraisal, especially technologies represented by the next generation information, big data, and the Internet of Things, which provides the impetus for enterprises to implement a green growth strategy. General performance management provides optimized solutions for enterprises through analyzing historical data. The emergence of the Internet of Things can give enterprises much multidimensional data with high environmental precision. At the same time, the generation of a large dataset for the enterprise and the provision of a basis to achieve multi-dimensional objectives help to improve green performance [11].

Haier established a clear corporate green growth target in 2020, proposed Haier carbon neutrality and ecological Internet of Things and improved its environmental performance compared with 2019. Among the improvements, its comprehensive energy consumption output value decreased 4.56% yearly, and its water consumption unit output value decreased 4.24% yearly. By applying ten energy-saving and carbon reduction technologies, Haier China Industrial Park balanced its carbon emissions in 2020 and generated a carbon allowance of 0.25 million tons per year. In addition, Haier successfully built nearly 700,000 Haier Industrial Internet platforms in 2019 by realizing the concept of the industrial park, which enabled 2993 enterprises to increase their efficiency by 30% on average, increased their output value by 11.7 billion CNY and greatly improved their green performance.[6]

In 2019, Gree Electric Appliances (GREE) put forward the concept of a “GREE Zero-carbon Health Home” and established the green and intelligent product strategy of “everything is connected, and everyone responds”. “GREE Zero-carbon Health Home” uses four G-IEMS local energy systems—internet power generation, power storage, electricity, tube electricity four systems.[7] These systems rely on the photovoltaic and original power grid connected model of the electricity storage model.

[6] https://imagegroup1.haier.com/csr/W020210610579462926791.pdf?spm=net.31741_pc.hg2020_sr_download_20200908.3.

[7] http://gree.com.cn/ltjkj.

With the help of the Internet of Things, a family ecological resource "thing connection" has been built by GREE, which contains five life management functions: car application, air, food, water, and security. This concept of environmental protection and intelligence aligns with the pursuit of low-carbon ecological furniture by individuals and families and has gradually improved GREE's green growth performance. By improving management energy saving and technology energy saving, GREE has improved its green performance by saving approximately 1793 tons of standard coal and reducing approximately 4698 tons of carbon dioxide emissions.[8]

(3) Identifying Potential Risks in the Implementation of Enterprises' Green Growth Model

Performance management uses data analyses to identify the risks and uncertainties that enterprises face when they implement a green growth model. Relevant studies show that enterprise risk management could reduce the risk of corporate social responsibility (CSR) as they improve their green performance, which shows that enterprises face certain risks when they implement a green growth model and realize the simultaneous improvement of environmental and economic performance [12]. Performance management can evaluate the status quo of the implementation of enterprises' green growth model and discover discrepancies with corporate strategic objectives, environmental regulation requirements, consumer demand, competitors' performance, and other dimensions, while removing potential risks in a timely fashion and discovering the mission-oriented and problem-oriented direction for improvement. Moreover, performance management provides a basis for enterprises to implement value chain reconstruction and reduces the uncertainty of improving environmental and economic performance.

Specifically, driven by performance management, enterprises will actively implement enterprise risk management (ERM). Studies show that ERM could significantly improve enterprise economic performance and enterprise value, mainly because combining ERM with enterprise green development can help identify risks in both economic and environmental protection [13]. Physical asset management (PAM) which consists of physical asset risk management, performance evaluation, life cycle management and strategy, evaluates enterprise economic and environmental performance from multiple dimensions by focusing on abnormal data. Doing so improves green performance and provides a reference for reducing the risk of adverse impacts on the performance, achieving green growth targets for enterprises and optimizing ultimate costs.

To evaluate business results, market competitiveness and customer satisfaction, Huawei identified risks in cooperation with end-product users and ecological partners. By benchmarking the industry's advanced management concepts and control standards, BYD adheres to the principle of respecting laws, regulations, and institutional norms. In doing so, it effectively prevents risks in the process of enterprise

[8] http://static.cninfo.com.cn/finalpage/2021-04-29/1209855232.PDF.

development and helps the company to operate in a standardized, legal, and healthy way.[9]

17.1.3 Performance Evaluation Indices for Enterprises' Green Growth

(1) Enterprises' Green Environmental Indices

The enterprises' green environmental index measures the enterprise's environmental protection level and participation in environmental protection measures from the perspectives of energy input, waste discharge, growth change and environmental protection investment. At the social level, it includes material consumption indices, including labor productivity, energy consumption per unit of GDP, per capita urban household electricity consumption; and the oxide emission indices of carbon, sulfur, and nitrogen. At the enterprise level, factors including energy utilization efficiency and the proportion of waste per unit product can directly reflect the implementation degree of the green growth model. The influencing factors of enterprise green environmental protection can generally be divided into five categories. They are the background and characteristics of the enterprise industry, the environmental output of the enterprise products/services, the enterprise resource base, the local basic environmental protection level, imminent environmental crises, and future environmental policy. Among these, energy efficiency and the environmental investment are deemed as important indices. Therefore, the results of the performance evaluation should be combined with the enterprise industry and environment to reflect its green environmental protection level more objectively.

In Huawei's sustainability report 2020, the company chose the carbon emission per unit sales revenue, the installed power capacity using clean energy, the administrative energy saving, the landfill rate of product waste, the illegal discharge of wastewater and waste gas and the supplier's carbon emission reduction targets as indices to measure the performance of enterprises' green growth. Therefore, enterprises can improve their environmental performance by reducing greenhouse gas emissions, phasing out fossil fuels, and actively cooperating with the government to implement carbon tax and carbon emission–trading policies.[10]

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[9] https://www.byd.com/sitesresources/common/tools/generic/web/viewer.html?file=%2Fsites%2FSatellite%2FBYD%20PDF%20Viewer%3Fblobcol%3Durldata%26blobheader%3Dapplication%252Fpdf%26blobkey%3Did%26blobtable%3DMungoBlobs%26blobwhere%3D1514448067235%26ssbinary%3Dtrue.

[10] https://www-file.huawei.com/-/media/corp2020/pdf/sustainability/sustainability-report-2020-en.pdf.

(2) Enterprises' R&D Construction Indices

The enterprises' R&D construction index measures the enterprise tangible and intangible assets as well as the employee training, product R&D and enterprise construction investments from the macro perspective. Without green technology innovation and green R&D investment, enterprises have difficulty achieving green growth. To determine the specific investment standards, enterprises should combine the overall level of the green R&D construction in the industry and learn from excellent benchmark enterprises by taking advantage of knowledge externalities. The 2020 Haier Environmental Report evaluates environmental performance from four aspects, all measured per unit output value: energy consumption, water consumption, wastewater production and chemical oxygen demand emissions. In the same year, Haier invested 40 million CNY in environmental management, 32 million CNY in pollution prevention and control, and 60 million CNY in energy conservation and consumption reduction. In addition, they achieved green growth by saving energy and reducing emissions.[11]

(3) Enterprises' Economic Growth Indices

Enterprises often use economic growth indices, such as business revenue, profit, and debt, to describe the importance they attach to sustainable operation. Specifically, enterprise economic performance is often measured by total asset turnover, marginal profit rate, debt ratio, dividend payout rate, main business profitability, gross profit margin, net profit growth rate, growth rate of net assets, quick ratio, etc. In addition, the sustainable growth rate, as a key factor that reflects a certain economic growth, is also often used to measure the economic performance of an enterprise. The sustainable growth rate is usually influenced by external market environment, internal financial resources, and environmental management level [14].

(4) Enterprises' Social Environmental Indices

The enterprises' social environmental index should consider not only the implementation of government policies but also stakeholder interests. These indices are used to measure the contribution of enterprises in creating a good social environment, and then describe the contribution of enterprise social benefits to enterprises' green growth performance. In 2020, Huawei chose more than 4000 suppliers worldwide for a network security risk assessment and tracking management, signed data-processing agreement with over 5000 suppliers and conducted data-processing due diligence. They take the network security service coverage, 60-min accident recovery and success rates of critical incident protection as indices to measure its "security and credibility", reflecting Huawei's contribution to building a good social environment.[12]

[11] https://imagegroup1.haier.com/csr/W020210610579462926791.pdf?spm=net.31741_pc.hg2020_sr_download_20200908.3.

[12] https://www-file.huawei.com/-/media/corp2020/pdf/sustainability/sustainability-report-2020-en.pdf.

17.2 Performance Evaluation Model for Green Growth

17.2.1 Data Envelopment Analysis

Data Envelopment Analysis (DEA) is a mathematical programming method that is used to evaluate the relative efficiency of a group of homogeneous Decision-Making Units (DMUs) with multiple inputs and outputs. DEA model evaluates each DMU based on a weighted output and input ratio through a set of linear programming models. If the model result reaches the maximum value, the DMU is regarded as efficient, and vice versa; if not, the DMU is regarded as inefficient. According to the model results, the inefficient DMUs can be improved more specifically.

DEA model has been widely used in the energy and environment research. It can effectively evaluate economic, energy, environmental, and comprehensive energy efficiencies, but research is still lacking on the evaluation of the green growth model. Therefore, based on the characteristics of enterprises' green growth, this chapter briefly introduces several basic DEA models that can evaluate green growth performance.

(1) CCR and BBC Models for the Evaluation of Enterprises' Green Growth Performance

Suppose n DMUs consume the same m inputs and produce the same s outputs. For each j DMU ($j = 1, 2, \ldots, n$), it has inputs x_{ij} ($i = 1, 2, \ldots, m$) and outputs y_{rj} ($r = 1, 2, \ldots, s$). Model (17.1) is obtained to identify the efficiency of the evaluated $DMU_o(o \in [j = 1, 2, \ldots, n])$ with multiple inputs and outputs.

$$\theta_o = \max \frac{\sum_{r=1}^{s} v_r y_{ro}}{\sum_{i=1}^{m} u_i x_{io}}$$
$$s.t. \begin{cases} \frac{\sum_{r=1}^{s} v_r y_{sj}}{\sum_{i=1}^{m} u_i x_{ij}} \le 1, \; j = 1, 2, \ldots, n \\ v_r \ge 0, \; r = 1, 2, \ldots, s \\ u_i \ge 0, \; i = 1, 2, \ldots, m \end{cases} \tag{17.1}$$

This model can be transformed into linear programming Model (17.2), which is the classical CCR model.

$$Min\theta_o$$
$$s.t. \begin{cases} \sum_{j=1}^{n} \lambda_j x_{ij} \le \theta_o x_{io}, i = 1, 2, ..., m \\ \sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{ro}, r = 1, 2, ..., s \\ \lambda_j \ge 0, j = 1, 2, ..., n \end{cases} \tag{17.2}$$

Banker et al. assumed variable returns to scale and proposed Model (17.3), which is the classic BCC model. It differs from the CCR model only in its limitations on λ, which limits the size of the model.

$$
\begin{aligned}
&Min\theta_o \\
&s.t.\begin{cases}
\sum_{j=1}^{n} \lambda_j x_{ij} \le \theta_o x_{io},\ i = 1, 2, \ldots, m \\
\sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{ro},\ r = 1, 2, \ldots, s \\
\sum_{j=1}^{n} \lambda_j = 1 \\
\lambda_j \ge 0,\ j = 1, 2, \ldots, n
\end{cases}
\end{aligned}
\tag{17.3}
$$

The effectiveness of the DEA model results depends on the input and output variables, which are also the most critical factors affecting enterprise development. Therefore, the input and output selection of DEA model is very important. Some scholars have considered enterprise social responsibility as a necessary factor for enterprises' green growth. In addition, some scholars have taken the company scale, economic performance and harnessing effect as the enterprise inputs and the environmental investment and pollutant emission as the outputs. According to the measurement of enterprise environmental efficiency, inefficient enterprises indicate that their environmental information is not fully disclosed. If the efficiency of the whole industry is at a low level, the whole industry lacks the concept of improving enterprises' green growth performance [15].

(2) Radial DEA Model for the Evaluation of Enterprises' Green Growth Performance

The radial DEA model is proposed based on the concept of "relatively effective evaluation", which emphasizes the adjustability of input and output. The model focuses the error on the input and output functions, which significantly reduce the error caused by an unnecessary parameter estimation and effectively avoid the subjective factor. The radial DEA model can be expressed as Model Eq. (17.4).

$$
\begin{aligned}
&Min\theta_o \\
&s.t.\begin{cases}
\sum_{j=1}^{n} \lambda_j x_{ij} + s_j^- = \theta_o x_{io},\ i = 1, 2, \ldots, m \\
\sum_{j=1}^{n} \lambda_j y_{rj} - s_j^+ = y_{ro},\ r = 1, 2, \ldots, s \\
\lambda_j \ge 0,\ j = 1, 2, \ldots, n \\
s_j^- \ge 0,\ j = 1, 2, \ldots, n \\
s_j^+ \ge 0,\ j = 1, 2, \ldots, n
\end{cases}
\end{aligned}
\tag{17.4}
$$

s^- is the surplus variable, and s^+ is the slack variable. They are used to represent the difference between the green growth efficiency that the enterprise can achieve at the present stage and the optimal green growth efficiency that the enterprise can achieve theoretically. When the DMU is inefficient, the enterprise needs to improve its efficiency by projecting it onto a relatively effective plane, to achieve effective enterprises' green growth.

In the existing studies, the radial DEA model is usually used to calculate energy use efficiency. Among them, Wu et al. applied the improved radial DEA model to analyze the production efficiency of Chinese coal enterprises at the microscopic level. They found that most mines need significant improvement, especially those close to the downtown area, where mines farther away are generally more efficient [16].

(3) Non-Radial DEA Model for the Evaluation of Enterprises' Green Growth Performance

Non-radial DEA models often divide outputs into expected and unexpected outputs. Two important concepts of disposability, "natural disposability" and "management disposability", are the basis for evaluating enterprises' green growth performance by the non-radial DEA model. In the case of "natural disposability", enterprises choose to decrease inputs to reduce unexpected outputs and make DMUs effective. This phenomenon means that enterprises regard economic performance as the first standard, and they adopt negative ways of addressing environmental regulations, such as reducing the operational scale to maximize their green performance. In the case of "management disposability", enterprises increase inputs to reduce unexpected outputs and improve the efficiency of DMU. Doing so means that enterprises regard environmental performance as the primary standard, and enterprises will use green policies and technologies to improve their environmental efficiency. This response is a relatively positive pursuit of enterprises' green growth performance, which considers both economic benefits and environmental benefits.

The non-radial DEA model separates the relaxation variable of the i input into positive and negative parts (d_i^{x+} and d_i^{x-}) to illustrate the two kinds of disposability. The efficiency of the k DMU can be redefined in terms of nature and management disposability, and Model (17.5) can be obtained.

$$Max \sum_{i=1}^{m} R_i^x (d_i^{x+} + d_i^{x-}) + \sum_{r=1}^{s} R_r^g d_r^g + \sum_{f=1}^{h} R_f^b d_f^b$$

$$s.t. \begin{cases} \sum_{j=1}^{n} \lambda_j x_{ij} - d_i^{x+} + d_i^{x-} = x_{io},\ i = 1, 2, \ldots, m \\ \sum_{j=1}^{n} \lambda_j g_{rj} - d_r^g = g_{ro},\ r = 1, 2, \ldots, s \\ \sum_{j=1}^{n} \lambda_j b_{fj} + d_f^b = b_{fo},\ f = 1, 2, \ldots, h \\ \sum_{j=1}^{n} \lambda_j = 1 \\ \lambda_j \geq 0,\ j = 1, 2, \ldots, n \\ d_i^{x+} \geq 0,\ i = 1, 2, \ldots, m \\ d_i^{x-} \geq 0,\ i = 1, 2, \ldots, m \\ d_r^g \geq 0,\ r = 1, 2, \ldots, s \\ d_f^b \geq 0,\ f = 1, 2, \ldots, h \end{cases} \tag{17.5}$$

In Model (17.5), the maximum value is adjusted according to the data range. In general, R_i^x, R_r^g and R_f^b are defined as:

$$R_i^x = (m + s + h)^{-1}(\max\{x_{ij}|j = 1, 2, \ldots, n\} - \min\{x_{ij}|j = 1, 2, \ldots, n\})^{-1}$$

$$R_r^g = (m+s+h)^{-1}(\max\{g_{rj}|j=1,2,\ldots,n\} - \min\{g_{rj}|j=1,2,\ldots,n\})^{-1}$$
$$R_f^b = (m+s+h)^{-1}(\max\{b_{fj}|j=1,2,\ldots,n\} - \min\{b_{fj}|j=1,2,\ldots,n\})^{-1}$$

Based on the concept of sustainable development, some scholars have used a non-radial DEA model to investigate the energy and environmental performance of China's manufacturing industry from 2006 to 2014. They evaluated it by unified efficiency under natural and managerial disposability. The empirical results show that the efficiency value of most manufacturing industries in light industries is slightly higher than that in heavy industries, while the investment effect of light industries is greater than that of heavy industries, and many enterprises in heavy industries have little investment potential in green growth [17]. According to the results, China should increase R&D investment to improve the efficiency of light industries, and policy support needs to be focused on promoting innovation in emerging industries.

17.2.2 Life Cycle Analysis Models

(1) Life Cycle Analysis (LCA)

An LCA is used to improve the evaluation of the product or service green performance model. This model covers a product or a service from production/creation, to transport/training, to use/execution, and finally to the whole process of recycling/feedback. Doing so covers not only the interests of stakeholders such as suppliers, customers, and third parties but also material consumption, process choices, energy consumption, service costs and even recycling.

An LCA can apply existing mature assessment methods to enterprises' green growth models. As a method gradually promoted by ISO14040 and ISO14044 in 2006, an LCA aims to identify opportunities for improving the green performance of a product or service at all stages of its life cycle and to provide comprehensive environmental indices as technical and marketing references for environmental efficiency. An LCA includes a variety of segmentation green performance indices of a product or service, including carbon dioxide emissions, land potential acidification, eutrophication of freshwater/ocean acidification potential, land, fresh water/ocean eutrophication, photochemical smog, ozone depletion, human potential toxicity, abiotic depletion potential and the potential for metal consumption, etc.

The evaluation scope of an LCA is also quite mature. At the present stage, an LCA mainly focuses on agricultural and animal husbandry enterprises and food processing industry, while cutting-edge research gradually extends to industries such as construction, electric vehicles, new materials, and new energy. For example, Huawei uses the carbon footprint in an LCA to evaluate the carbon emission intensity of different products at different stages.[13] When using an LCA for a green performance evaluation, it is necessary to pay attention to the differences and connections between each of the stages. Different factors in each stage will affect the evaluation of enterprise green growth in an LCA. However, an LCA can identify and amplify the advantages and benefits of the same resource and service in different regions and scenarios. Therefore, many scholars try to use an LCA to evaluate the environmental efficiency of new energy vehicles, to demonstrate more comprehensively the difference in the environmental efficiency between new energy vehicles and internal combustion vehicles in different regions and scenarios [18]. Using LCA models to measure a company's products or services requires specialized software because the process is complex, and the data involved are massive. Automakers enterprises such as Ford, Audi, and BMW use Gabi, an enterprise measurement software for enterprises' green growth produced by Sphera, to measure the overall environmental efficiency of different vehicle models.[14]

Multiple methods, multi-dimensional data and diversified tools can improve the accuracy of an LCA of green growth patterns. A simple LCA of green performance is faced with problems such as dependence on database and software, inability to quantify social impact, difficulty in simulating specific environment, lack of decision-making under different conditions, etc. Combining an LCA with different methods, such as the multi-criteria decision-making method (MCDA) or a four-quadrant matrix, can better remedy the defects and more accurately reflect the green performance of different products, especially when evaluating the green performance of new energy vehicles from an industrial perspective. Using MATLAB, Monte Carlo simulation or other methods to quantify the uncertainty of LCA inventory data can simulate all links of the whole product or service to reduce the uncertainty. However, when the supply chain risk increases, the LCA green performance measure will cause the distortion under the environmental rebound effect or strict emissions monitoring [19]. To solve this matter, a working solution is to combine the material flow analysis (MFA) along the value chain to the quantitative product, material inventory and material changes over time, tracking the whole value chain and equipment at the end of the environmental benefits.

The green performance of products or services can be measured more comprehensively by dividing product stages and determining index weights with the help of LCA definition. A comprehensive evaluation needs to assign weight to each environmental index and the commonly used comprehensive evaluation means include an analytic hierarchy process (AHP), the multi-grade fuzzy method, the input–output model, a Spearman partial rank correlation coefficient evaluation, DEA, etc. Among them, many studies have examined the combination of an LCA and a DEA to measure the green performance of different products and services. These studies have mainly focused on the enterprises' green growth performance evaluation in the primary and

[13] https://www-file.huawei.com/-/media/corp2020/pdf/sustainability/sustainability-report-2020-en.pdf.

[14] https://sphera.com/product-sustainability-data/.

secondary industries, such as transportation, food manufacturing and wine making. Meanwhile, these studies have studied on energy efficiency.

Therefore, how to evaluate the green performance of the tertiary industry has become a challenge. A stable enterprise green supply chain and continuous green innovation can maximize the effectiveness of enterprises' green growth performance, but it requires sufficient data. The environmental performance evaluation system based on big data covers different fields such as management, computer, and environmental science and statistic, and the specific evaluation process includes the improvement and integration of a DEA, an LCA, artificial intelligence and other methods. In the evaluation process, unstructured information is collected, sorted, grouped, and summarized to the greatest extent possible to reduce the loss of information [20]. For example, the Alliance for Research on Corporate Sustainability (ARCS) provides colleges, such as Harvard Business School, with 13,000 companies' annual data including environmental performance and environmental behavior to do research, so the uncertainty of information can be avoided to some extent.[15]

(2) Life Cycle Inventory (LCI) and Life Cycle Inventory Analysis (LCIA)

The LCI evaluates the life-cycle efficiency inventory of products or services from the perspective of material flows, while the LCIA uses the LCI results to evaluate the inventory and environmental efficiency of potential products or services. However, the LCI usually lacks geographical representation and temporal correlations, which leads to the lack of geographical and temporal information in environmental efficiency measurement. To minimize the shortcoming, for example, when conducting an LCI evaluation for furniture manufacturing, all processes and components used in the furniture industry, such as transportation, beech laminate and steel frame, should be considered first. To simulate the composition, the use and disposal should also be considered of the furniture model specified by the manufacturer and LCI data per unit, such as kg, ton, meter, and hour.

Likewise, in evaluating the environmental efficiency of the process of coke production, field research in raw materials or manufacturing sites is conducted to obtain the coke production life cycle phase LCI data. Then, commercial inventory databases, expert estimation or archival research are used to collect and refine the data such as raw materials extraction, production, and emissions, etc. Finally, LCIA is used to measure the environmental efficiency of the entire production process. By integrating the LCI and LCIA methods, the information of the materials and energy used in coke production, the related emissions, potential technological advantages, and environmental trends can be discovered to evaluate enterprises' green growth performance.

(3) Life Cycle Cost (LCC)

An LCA generally focuses on the evaluation of the green performance of a certain product or service. However, the green growth performance of an enterprise includes economic performance. To provide an energy saving, environmental protection and

[15] https://corporate-sustainability.org/about/.

affordable solution for each enterprise, cost is an indispensable component. The LCC method follows the life cycle concept of an LCA and supplements the evaluation of the whole life cycle cost of an LCA. It regards the whole system as a single economic role and evaluates all the costs of the whole life cycle. Some LCC studies have only used the life cycle concept to separate finance and the environment, without too much consideration of the impact of the green performance on the economic l performance. The most representative cost is the private life cycle cost, which divides the cost into tangible and intangible costs. Tangible costs include the purchase cost, operational cost, and recovery/resale value, while the purchase cost, also known as the total cost of ownership, includes the purchase price, sales tax, ownership fee, subsidy, or tax refund. Intangible costs include those of various restrictions, such as driving limits and consumer evaluations. Some LCC studies have included the impact of green performance into the economic performance evaluation, that is, the impact of the environment on costs is considered in the form of carbon emission costs, carbon prices and the carbon index.

However, the LCC and LCA methods still differ, and these important differences are important to address. First, for LCC and LCA to match, they must have the same temporal boundary. For example, if a city's one-year domestic waste treatment process is considered in an LCA, the temporal LCC span should also be based on the same year. Second, the LCA and LCC methods should select the same functional unit to make the results comparable. Third, distribution methods are key issues in an LCA, because these methods have an essential impact on the results of an LCA. The LCA and LCC methods should adopt the same distribution method to make the results logical.

Considering the environmental cost is also the key to be considered when measuring the LCC of a certain product or service. The reasons for ignoring the environmental cost are as follows. First, no model is universally recognized, and no model is entirely suitable for all countries. Second, if the corresponding punishment standards and laws for emission pollution are missing, the missing calculation basis will lead to the distortion of the results of LCC, which will lead to the deviation of the evaluation of green development of enterprises. Therefore, when the data availability increases, environmental costs can be easily added to the LCC results.

(4) Social Life Cycle Analysis (SLCA)

An SLCA is aimed at measuring the social benefits in a complete cycle of the product/service for stakeholders, including workers, consumers, the local community, society, the government, and the participant value chain upstream and downstream, such as investors, suppliers, distributors, competitors, etc. SLCAs are still in the development and research stage, because their evaluation has problems, including the difficulties of the definition of functional units, the limited selection of methods, limited data availability, and the lack of a unified consensus on the impact assessment method. Nevertheless, the SLCA results are relevant to stakeholders, who are element enterprises should consider when improving their green performance. Meanwhile, an SLCA should be combined with the LCA and LCC methods to form an LCSA, and in-depth research should be conducted with multi-criteria decision-making (MCDM) and other methods.

An SLCA evaluates the relationship between a company and its stakeholders based on the LCI checklist, which needs to be defined using the following steps. First, an SLCA needs to identify the stakeholders and the stakeholder groups. Second, it is necessary to determine the impact categories of an SLCA, that is, stakeholder preferences or the social themes or attributes in which they are interested, which can specify the indices the SLCA will use to determine the data types needed to evaluate each subcategory. Finally, because an SCLA is a model for evaluating an enterprise and its stakeholders, it must collect the required data from the relevant stakeholders, generally including child labor, freedom of assembly, working hours, employee health and safety, the cooperation with local government and the promotion of local employment. Thus, the data availability of an SLCA is quite different from that in an LCA and the specific data remain limited. Moreover, site-specific data are important because of the significant cultural and economic differences between countries, so substituting stock data from one country is not appropriate in SLCAs.

17.2.3 Maturity Models

(1) Maturity and Performance Measurement

The maturity model aims to describe the characteristics of a process or activity at different stages, which describes the development of the research subject from an initial stage to a higher stage and has been used mainly in areas such as quality management or software. New methods have emerged to study the maturity model, such as the comprehensive index, principal component analysis, multi-objective decision, Derfel, and expert evaluation methods as well as generalized least squares, but the evaluation standards of each method are not uniform. Among these methods, the TOPSIS model, as a widely used multi-objective decision-making method, can provide a perception analysis principle that is more direct; it also requires a relatively smaller sample size and has greater application value.

The maturity model is an analytical and positioning tool that facilitates the learning and performance evaluation of organizational management practices. It consists of a series of discrete maturity levels for a set of processes in one or more domains. The model represents the processes and typical trends that an enterprise must go through to achieve a certain goal. However, many unresolved issues remain in the research and practice of maturity models. There is no consensus on the number of maturity levels that should be specified, such as the number of maturity stages ranging from 3 to 6, and the separation criteria for different maturity levels are not well defined.

(2) Green Performance Evaluation Under the Environmental Management Maturity Model

Environmental management aims to mitigate the impact of organizational activities on the environment, while organizations can reduce their impact on the environment through products, processes and policies that reduce energy consumption and waste generation, promote the use of environmentally friendly and green resources. However, not all enterprises have adopted the same intensity of green practices. Because environment management practice is complex and diverse, enterprises have different attitudes in facing the environmental problems. Hence, it is necessary to consider different levels of environmental management maturity (EMM) and build an environmental management maturity model to measure enterprise green performance level.

By assessing EMM, enterprises can understand their current advantages and disadvantages, define their future environmental strategies, and take measures that are more advanced to improve their environmental performance. Doing so can help enterprises enhance their competitive advantages and achieve enterprises' green growth. Using a maturity model to study the heterogeneity of enterprise green behavior is helpful to deeply understand the current situation and trend of enterprise environmental management in different countries and improve enterprise management efficiency. Among them, quality management is an important premise affecting EMM, and environmental management can affect green supply chain management. These practices ultimately affect the enterprises' green growth performance.

In addition, EMM assumes an intermediary relationship between quality management and enterprise green supply chain management practice. The practice of green supply chain management also assumes the intermediary relationship between green supply chain management level and enterprises' green growth performance. Nevertheless, environmental legislation, the corporate environmental impact, the corporate green image, market share, process implementation, economic benefits, senior management commitment, staff training, external communication on environmental issues and other factors should be included in the structural design of EMM [21].

EMM can be divided into five stages: disorder, simple, standard, orderly, and lean. Enterprises in the disorder stage lack environmental awareness and their environmental management measures are chaotic. Enterprises in the simple stage have environmental awareness for only a single project not for the whole production and operation process, so they need to further improve their environmental management. Enterprises in the standard stage begin to consider enterprise environmental management systematically and comprehensively. Enterprises in the orderly stage apply environmental management to the whole process of production/service and take corresponding measures to improve the environmental level in each process. Enterprises in the lean stage sacrifice economic interests to achieve the purpose of environmental protection; this stage is not conducive to the implementation of green performance to a certain extent. However, the change of the green maturity of an enterprise is not necessarily linear. The growth of each maturity index in each stage is not uniform over time, and each maturity index gradually influences each other as the stages change, which must be considered [22].

(3) Green Performance Evaluation Under Maturity Models from Different Perspectives

In addition to the classical EMM, maturity models from different perspectives play different evaluation roles in enterprises, with the goal of enhancing enterprise green performance.

Enterprise green technology innovation is gradually becoming more prominent because of the wide usage of ISO14001 in enterprises. The maturity and integrity of ISO14001 consistently promote the willingness of enterprises to innovate green technology, and enterprises will invest more in environmental research and development. In addition, under the positive environmental policy, whether the adoption or retention of an ISO14001 certificate or will help to encourage enterprises to carry out green technology innovation. Doing so will help to realize the improvement of enterprise green growth performance and the positive relationship between enterprise maturity stage and the development of green technology innovation ability. In particular, the green technology options that companies have at different stages of maturity are important to both researchers and practitioners.

According to the concept of a natural resource base, the strategic and competitive advantage should be "rooted in promoting the natural ability of sustainable economic activity". Therefore, each enterprise has a different quality of competitive ability to protect the environment, save energy and reduce resource use and waste. The competitive ability of an enterprise is derived from specific value-added tasks and the amount of resources it uses, for example, environmental design, knowledge stock, tangible assets, human capital, technology, etc. All these factors ultimately converge in enterprise green manufacturing. The maturity of enterprise green manufacturing can be divided into four stages. The first stage is "compliance driven", in which the only goal of enterprise green practices is to comply with relevant environmental policies. The second stage is "ecological opportunism". In this stage, managers begin to understand the advantages brought by green manufacturing and track the effectiveness and productivity of internal operation in order to develop synergies between green performance and economic performance. The third stage is "green innovator". In this stage, enterprises gradually begin to see and show the value of their operation saving and green products to customers and the market, seek to design innovative products and processes, improve the overall environmental protection degree of products/processes, and enhance the enterprises' green growth performance. The fourth stage is "green manufacturing leaders", and enterprises who are good at green innovation of products/processes and are eager to play the role of green manufacturing leaders in the industry, are classified in this stage [23].

Enterprises face organizational obstacles when they fully implement ecological innovation and operational obstacles when they implement and globally integrate it. These include the lack of models, methods and support tools and lead to distortion of the enterprises' green growth performance measurement. The maturity model of ecological innovation which starts from the strategic, structural, resource and cultural dimensions solves the problem that ecological innovation evaluation lacks mature and standard evaluation methods. However, when applied to enterprises in different industries, the level of the eco-innovation maturity model will change. Therefore, the maturity measurement standard must be adjusted according to different industries.

17.3 Application of the Enterprises' Green Growth Performance Maturity Evaluation Model in Chinese Enterprises

17.3.1 Index Selection and System Design

Enterprise environmental protection includes the environmental performance of environmental protection and the financial indices of enterprises to reduce emissions. We referred to some enterprise social responsibility reports (2016 edition). After considering the differences in the enterprise production processes and enterprise characteristics, we selected the secondary indices for environmental and economic performance that all enterprises can evaluate, including 6 items: percentage reduction of carbon dioxide emission per ten thousand CNY, carbon dioxide emission per ten thousand CNY (ton/ten thousand CNY; 2016), percentage reduction of comprehensive energy per ten thousand CNY, comprehensive energy consumption per ten thousand CNY (ton/ten thousand CNY; 2016), proportion of environmental input, and labor productivity.

Enterprise long-term development is inseparable from investments in research and construction. We chose the proportion of enterprise construction investment, the proportion of enterprise R&D investment, the proportion of enterprise training investment and the number of enterprise patents as the secondary indices of enterprise R&D construction indices.

Considering that enterprises are divided into listed and unlisted enterprises, we especially omitted the shareholders' interests and equity, which are generally considered, when we considered the secondary indices of corporate financial growth. We believe that enterprise assets, liabilities, profits, and operating income can reflect the enterprise financial condition most comprehensively and intuitively. In terms of the enterprise financial growth index, we considered six secondary indices: net profit growth rate, profit rate of the main business, asset–liability proportion, return on net assets, value preservation and appreciation rate of assets, and growth rate of the main business.

Government-formulated environmental policies have a strong macro-control and constraint effect on the economy. Policies such as R&D subsidies, tax offsets and intellectual property rights protection provide welfare and funds for enterprise product and technology R&D personnel, thus promoting long-term development. When corporate stakeholders see that, compared with competitors, enterprises have implemented environmental protection that is more effective, R&D investment that is more reliable, and marketing strategies that are better, they will have a favorable impression of the enterprises, which also aligns with the performance of excellent green enterprises. We compared the industry average with the enterprise value to indicate the leading degree of the enterprise to the industry. A higher degree means a higher contribution to society, because the enterprise consumes fewer resources and produces more results. Finally, we used customer satisfaction to represent the stakes of enterprise green stakeholders. Ultimately, four secondary indices were considered in terms of the enterprise social environment index: the proportion of enterprise comprehensive energy consumption per ten thousand CNY to industrial energy consumption, the proportion of enterprise R&D investment to industrial investment, the proportion of the enterprise operating income growth rate to the industrial growth rate, and customer satisfaction. The overall enterprise green growth performance index system for green growth is shown in Table 17.1.

17.3.2 Data Selection and Preprocessing

(1) Data Selection

After considering enterprise size, industry, and ownership differences, as well as the data availability of the enterprise green performance indices in Table 17.1, we collected 56 CSR reports about enterprises in 2016 and extracted 2000 enterprises from the "social responsibility" entry on the China Stock Market and Accounting Research Database (CSMAR). After screening, we used data from 80 companies from different industries with different sizes and ownerships. We selected the corresponding data from the China Statistical Yearbook 2017 as the industry data and considered the corresponding values from different industries.

(2) Data Preprocessing

The data to which enterprises corresponded to in each secondary index may not be directly disclosed; instead, they may choose to disclose similar data. We explain the data that need to be unified and calculated:

(a) Carbon Dioxide Emissions and Comprehensive Energy Consumption Per Ten Thousand CNY

Some enterprises directly disclosed the detailed data, but some enterprises disclosed only their carbon dioxide emissions or standard coal consumption. Based on the actual production situation, the transformation equation is given here: carbon dioxide emission per ten thousand CNY = comprehensive energy consumption per ten thousand CNY * 2.7725 = standard coal consumption/total operating income * 2.7725 = energy consumption per unit product * total sales * 2.7725.

According to the IPCC data, the carbon content of brown coking coal is 25.8 kg/GJ. The molecular weight of this process changes from 12 to 44 because the carbon is oxidized into carbon dioxide, and the corresponding carbon dioxide emission factor

Table 17.1 Enterprises' green growth performance index system

	First grade index	Second grade index
Enterprises' green growth performance	Enterprises' environmental protection index X_1	Percentage reduction of carbon dioxide emission per ten thousand CNY X_{11}
		Carbon dioxide emission per ten thousand CNY X_{12}
		Percentage reduction of comprehensive energy per ten thousand CNY X_{13}
		Comprehensive energy consumption per ten thousand CNY X_{14}
		Proportion of environmental input X_{15}
		Labor productivity X_{16}
	Enterprises' R&D construction index X_2	Proportion of enterprise construction investment X_{21}
		Proportion of enterprise R&D investment X_{22}
		Number of enterprise patents X_{23}
		Proportion of enterprise training investment X_{24}
	Enterprises' financial growth index X_3	Net profit growth rate X_{31}
		Profit rate of main business X_{32}
		Asset–liability proportion X_{33}
		Return on net assets X_{34}
		Growth rate of main business X_{35}
		Value preservation and appreciation rate of assets X_{36}
	Enterprises' social environmental index X_4	Proportion of enterprise comprehensive energy consumption per ten thousand CNY to industrial energy consumption X_{41}
		Proportion of enterprise R&D investment to industrial investment X_{42}
		Proportion of enterprise operating income growth rate to industrial growth rate X_{43}
		Customer satisfaction X_{44}

was calculated as 94,600 kgCO_2/TJ. The carbon dioxide emission factor of standard coal can be calculated as 2.7725 tCO_2/TCE, that is, 2.7725 tons of carbon dioxide emission per ton of standard coal.

(b) Proportion of Environmental Input

For the enterprises that did not disclose directly the proportion of their environmental input, the amount related to the environmental input in the CSR report was selected as the amount of the enterprise investment in the environment. The formula is as follows: the proportion of environmental input = environmental input/total operating cost = total enterprise environmental investment/total operating cost.

(c) Labor Productivity

The formula is as follows: labor productivity = total revenue/number of employees.

(d) Proportion of Enterprise Construction Investment

For the enterprises that did not disclose directly the proportion of enterprise construction investment, we chose the difference between the "net fixed assets" in 2016 and 2015 in the enterprise financial statements as the enterprise construction input in 2016. The formula is as follows: the proportion of enterprise construction investment = construction input/total operating cost = total enterprise construction investment/total operating cost.

(e) Proportion of Enterprise R&D Investment

For the enterprises that did not disclose directly the proportion of enterprise R&D investment, we selected the value of "development expenditure" in the enterprise financial statement in 2016 as the R&D investment of the enterprise in 2016. The formula is as follows: the proportion of enterprise R&D investment = R&D input/total operating cost = total enterprise R&D investment/total operating cost.

(f) The Proportion of Enterprise Training Investment

For the enterprises that did not disclose directly the proportion of enterprise training investment, we selected the amount related to employee training in the CSR report as the enterprise training investment. The formula is as follows: the proportion of enterprise R&D investment = training input/total operating cost = total enterprise training investment/total operating cost.

(g) Value Preservation and Appreciation Rate of Assets

The formula is as follows: value preservation and appreciation rate of assets = (total assets + net profit)/total assets of the previous year.

(h) Proportion of Enterprise Comprehensive Energy Consumption Per Ten Thousand CNY to Industrial Energy Consumption

Based on the China Statistical Yearbook 2017, the industry of each enterprise was searched according to its main business. If the industry could be found, the comprehensive energy consumption per ten thousand CNY of the enterprise was compared with that of the industry. For example, the coal industry belongs to the secondary industry. If the industry to which the enterprise belongs was not found, the former was still compared with the latter. The formula is as follows: proportion of enterprise energy consumption per ten thousand CNY to industry energy consumption = enterprise energy consumption per ten thousand CNY / industry energy consumption per ten thousand CNY.

(i) Proportion of Enterprise R&D Investment to Industrial Investment

Based on the China Statistical Yearbook 2017, each enterprise industry was searched according to its main business. We selected the industrial R&D investment proportion data from the Statistical Bulletin of National Science and Technology Investment in 2016 published by the China National Bureau of Statistics. If the industry was found, the proportion of enterprise R&D investment was compared with the proportion of industry R&D investment, such as the coal industry. If the industry was not found, the former proportion was still compared with the latter proportion. The formula is as follows: the proportion of enterprise R&D investment to industrial investment = the proportion of enterprise R&D investment / the proportion of industry R&D investment.

(j) Proportion of the Enterprise Operating Income Growth Rate to the Industrial Growth Rate

Based on the China Statistical Yearbook 2017, each enterprise industry was searched according to its main business. If the industry was found, the proportion of the enterprise operating income growth rate was compared with the proportion of the industry operating income growth rate, such as the coal industry. If the industry was not found, the former proportion was still compared with the latter proportion. The formula is as follows: the proportion of the enterprise operating income growth rate to the industrial growth rate = the proportion of the enterprise operating income growth rate / the proportion of the industry operating income growth rate.

17.3.3 Construction of the Green Growth Performance Maturity Evaluation Model

The entropy method was used to determine the weight, and a cluster analysis was used to determine the hierarchy. After clustering, the cluster center combined with the enterprise performance maturity stages of the green growth can predict the hierarchy of enterprise green growth performance. Jointly, the two can determine the key indices and total maturity of the enterprises' green growth performance maturity evaluation model.

(1) Weight Distribution of the Enterprise Green Growth Performance Indices

We used the entropy method based on a min–max standardization to calculate the weight. "Entropy" is used to indicate the uniformity of a certain energy distribution in space. Entropy was originally a physical concept in thermodynamics used to measure the degree of disorder in a system, which is uniformly expressed by S. In system theory, systems with greater entropy are more chaotic and carry less information, and vice versa. By calculating the entropy of the index information, the index weight is determined according to the influence of the relative change degree of the index on the whole system, because indices with large relative change degrees have large weights. The final weight of the enterprises' green growth performance maturity indices is shown in Table 17.2.

Higher weights mean that the index has a greater influence on the comprehensive evaluation. The five indices with the highest weights were selected as the key indices affecting enterprise green growth performance: customer satisfaction (X_{44}), net profit growth rate (X_{31}), percentage reduction of comprehensive energy per ten

Table 17.2 Weight of each index

	Name of each index	Weight
Index weight	Percentage reduction of carbon dioxide emission per ten thousand CNY	0.010690192
	Carbon dioxide emission per ten thousand CNY	0.013472382
	Percentage reduction of comprehensive energy per ten thousand CNY	0.159232124
	Comprehensive energy consumption per ten thousand CNY	0.013331071
	Proportion of environmental input	0.029325724
	Labor productivity	0.009413026
	Proportion of enterprise construction investment	0.026607638
	Proportion of enterprise R&D investment	0.024791699
	Number of enterprise patents	0.011492203
	Proportion of enterprise training investment	0.012647978
	Net profit growth rate	0.186328552
	Profit rate of main business	0.092500733
	Asset–liability proportion	0.084060583
	Return on net assets	0.014989045
	Growth rate of main business	0.009786213
	Value preservation and appreciation rate of assets	0.027881455
	Proportion of enterprise comprehensive energy consumption per ten thousand CNY to industrial energy consumption	0.017921718
	Proportion of enterprise R&D investment to industrial investment	0.020826771
	Proportion of enterprise operating income growth rate to industrial growth rate	0.009610933
	Customer satisfaction	0.225089959

thousand CNY (X_{13}), profit rate of main business (X_{32}) and asset–liability proportion (X_{33}). These five indices determined 74.6% of enterprises' green growth performance maturity and can explain most of the variables of the enterprises' green growth performance index system.

(2) Stage Division

SPSS25 was used to conduct the K means clustering analysis on the standardized data and the clustering results obtained under the different cluster numbers were compared. When the number of clusters was 6, the indices that contributed significantly to classification in the ANOVA table (Sig < 0.05) obtained the maximum number (18). The final cluster center obtained is shown in Table 17.3, and the ANOVA is shown in Table 17.4. The ANOVA table shows that X_{23} and X_{33} made no significant contributions to the classification, while the other indices contributed significantly to the classification, indicating that this classification is effective. Hence, we selected 6 as the final cluster number.

The six clusters corresponded to different enterprises. Cluster 1 corresponded to the enterprises that focused on financial input–output. Cluster 2 corresponded to

Table 17.3 Final clustering center

	Cluster					
	1	2	3	4	5	6
X_{11}	0.11658	−1.24827	0.17317	0.04399	0.03039	−0.04406
X_{12}	−0.21045	−0.04274	0.01918	−0.31007	−6.23007	0.26462
X_{13}	0.46114	−2.11560	0.20402	0.27426	0.29830	0.08117
X_{14}	−0.19718	−0.26566	0.04478	0.34606	−6.32751	0.24447
X_{15}	−0.35958	−0.07034	−0.31550	−0.40429	0.83531	0.67367
X_{16}	−0.13619	0.02724	−0.11660	8.74792	−0.05577	−0.13576
X_{21}	−1.28545	−0.27421	−0.14743	0.14386	3.69957	0.26800
X_{22}	1.21896	−0.04367	−0.40979	−0.07331	0.92492	0.77658
X_{23}	0.83388	−0.11987	−0.06677	−0.37708	−0.16487	0.15792
X_{24}	6.80761	−0.05709	−0.19038	−0.56902	−0.32443	0.15507
X_{31}	0.21057	−1.43939	0.05560	0.22544	0.17206	0.23302
X_{32}	−0.16592	−1.80214	0.06366	0.03078	1.87091	0.26179
X_{33}	1.33631	0.21813	−0.06172	0.81781	0.27122	−0.03354
X_{34}	0.19432	−1.29509	−0.00621	0.7478 4	0.16869	0.30251
X_{35}	8.43817	−0.02992	−0.11488	0.08004	0.00171	−0.12288
X_{36}	0.47016	−0.96274	−0.15389	0.15707	−0.01009	0.54547
X_{41}	0.46707	−2.32565	0.19563	0.19714	0.20981	0.16043
X_{42}	0.13717	−0.18059	−0.45396	−0.23575	5.00810	0.78105
X_{43}	8.57420	0.04727	−0.12819	0.17231	−0.03196	−0.12370
X_{44}	0.44265	0.91553	−0.35844	0.23166	1.35058	0.42118

Table 17.4 ANOVA table

	Cluster		Deviation		F	Sig
	Mean square	df	Mean square	df		
X_{11}	2.170	5	0.921	74	2.356	0.049
X_{12}	8.119	5	0.519	74	15.643	0.000
X_{13}	5.876	5	0.671	74	8.764	0.000
X_{14}	8.418	5	0.499	74	16.877	0.000
X_{15}	3.247	5	0.848	74	3.829	0.004
X_{16}	15.526	5	0.019	74	837.804	0.000
X_{21}	3.701	5	0.817	74	4.528	0.001
X_{22}	4.858	5	0.739	74	6.571	0.000
X_{23}	0.348	5	1.044	74	0.333	0.891
X_{24}	9.817	5	0.404	74	24.284	0.000
X_{31}	2.791	5	0.879	74	3.175	0.012
X_{32}	4.957	5	0.733	74	6.766	0.000
X_{33}	0.604	5	1.027	74	0.589	0.709
X_{34}	2.559	5	0.895	74	2.860	0.020
X_{35}	14.439	5	0.092	74	157.020	0.000
X_{36}	2.757	5	0.881	74	3.129	0.013
X_{41}	7.036	5	0.592	74	11.883	0.000
X_{42}	9.855	5	0.402	74	24.532	0.000
X_{43}	14.940	5	0.058	74	257.217	0.000
X_{44}	3.470	5	0.833	74	4.165	0.002

enterprises concerned with their green input and output. Cluster 4 corresponded to enterprises focused on employee involvement. Cluster 5 corresponded to enterprises that attach great importance to long-term development. Compared with Cluster 6, Cluster 3 corresponded more to enterprises that paid more attention to green indices, while the enterprises in Cluster 6 paid more attention to financial indices. This cluster had only three enterprise types because only three enterprises corresponded to the three clusters in these clusters. The representative enterprise from Cluster 1 was China Power Construction Corporation (enterprise green growth maturity = 0.4661, rank = 56). The representative enterprise of Cluster 4 was Qingdao Haier (enterprise green growth maturity = 0.5045, rank = 46). The representative enterprise of Cluster 5 was China Three Gorges Corporation (enterprise green growth maturity = 0.3082, rank = 80).

The enterprises' green growth performance maturity ranking was constructed according to the maturity of enterprises' green growth performance from large to small. We find the following characteristics in the ranking:

(1) Cluster 6 occupied the middle and low ranking, with China Three Gorges Corporation ranked 80th, and the State Power Investment Corporation ranked 17th.
(2) Cluster 2 occupied the middle and upper ranking, with Yankuang Energy Group Company Limited Ranked the lowest at 39th and China National Chemical Corporation ranked the highest at 7th.
(3) Cluster 3 occupied most of the rankings and the highest position. Shanghai Pudong Construction Co., Ltd. ranked 71st, was the lowest, and China Nonferrous Metal Industry's Foreign Engineering and Construction Co., Ltd. ranked 1st.

After the exclusion of specificity, Clusters 2 3 and 6 partially overlapped in the ranking of the corresponding firm communities. We selected the average value of the enterprise performance maturity for green growth in those clusters as the dividing line of the maturity level. These results were 0.5884 (Cluster 2), 0.5424 (Cluster 3) and 0.4570 (Cluster 6). The final maturity level was divided into 4 stages, 0–0.4570 was the fourth stage (80 to 59), 0.4570–0.5424 was the third stage (58 to 34), 0.5424–0.5884 was the second stage (33 to 22) and 0.5884–1 was the first stage (21 to 1).

The core indices used to measure enterprises' green growth performance are customer satisfaction, net profit growth rate, percentage reduction of comprehensive energy per ten thousand CNY, profit rate of main business and asset–liability proportion. These five indices yielded an enterprises' green growth performance maturity of 74.6%. Meanwhile, the weights of the other 15 indices in the system were each less than 0.03, so they were not considered. However, the asset–liability proportion made no significant contribution to the classification (Sig > 0.05), so we removed the index from the maturity model. The final enterprises' green growth performance maturity evaluation model and its classification are shown in Table 17.5.

17.3.4 Representative Enterprise Evaluation and Management Enlightenment

Shaanxi Coal and Chemical Industry Group Co., LTD., referred to as Shaanxi Coal & Chemical, is a large state-owned energy and chemical enterprise in China. Jinduicheng Molybdenum Co., LTD., referred to as Jinduicheng Molybdenum, is the largest molybdenum company in Asia and one of the world's leading molybdenum companies, with major production bases located in Shaanxi, China. We selected the relevant data of these two representative enterprises from 2016, which are shown in Table 17.6.

Shaanxi Coal & Chemical did not identify their investment in R&D or staff training, so in the data-processing step, we used 0. The ultimate green growth maturity of the two enterprises is shown in Table 17.7, and the rank is in brackets. According to Table 17.7, this paper makes the following suggestions for the two enterprises to implement the green growth model:

Table 17.5 Enterprises' green growth performance maturity evaluation model and its classification

Level	First	Second	Third	Fourth
Maturity value	(High green growth) 0.5884–1	(Achieve certain green growth) 0.5424–0.5884	(Green growth is taking shape) 0.4570–0.5424	(Green growth has not taken shape) 0–0.4570
Customer satisfaction	(Ideal customer satisfaction) 96.3–100%	(High customer satisfaction) 94.1–96.3%	(Medium customer satisfaction) 87.4–94.1%	(Low customer satisfaction) 87.4%>
Net profit growth rate	(Substantial increase in net profit) 8.7%<	(Stable increase in net profit) 5.2–8.7%	(Net profit fluctuates) −25.8–5.2%	(Unrealized net profit growth) −25.8%>
Percentage reduction of comprehensive energy per ten thousand CNY	(Energy consumption greatly reduced) 8.40%<	(Energy consumption significantly reduced) 4.58–8.40%	(Energy consumption reduced) 0.11–4.58%	(Energy consumption fluctuates) 0.11%>
Profit rate of main business	(High profitability) 6.97%<	(Above average profitability) 5.20–6.97%	(Average profitability) 1.89–5.20%	(Low profitability) 1.89%>

(1) Shaanxi Coal & Chemical and Jinduicheng Molybdenum are both highly polluting enterprises. They have made some gains in pollution control, but they still need to accelerate the implementation of the green growth model.

(2) The net profit growth rate of Shaanxi Coal & Chemical and Jinduicheng Molybdenum differs little, but the net profit of Shaanxi Coal & Chemical is not positive. The two enterprises should achieve green development and stable net profit growth to meet national policies.

(3) Jinduicheng Molybdenum and Shaanxi Coal & Chemical differ greatly in the profit rate of their main businesses. The low profit rate of the main business for Jinduicheng Molybdenum may be the result of problems such as high operating costs, difficulty reducing mining costs and technology bottlenecks. Jinduicheng Molybdenum should reduce its main business cost by increasing its R&D investment (currently, R&D investment accounts for only 0.07% of total expenditures).

(4) Shaanxi Coal & Chemical and Jinduicheng Molybdenum demonstrate a large gap in customer satisfaction. The low customer satisfaction of Shaanxi Coal & Chemical may be caused by low feedback efficiency and low positive input, which may be caused by customer feedback not timely or not meeting customer needs to a certain extent. Shaanxi Coal & Chemical needs to establish a more complete customer feedback and response mechanism to ensure the rights and interests of its green stakeholders.

Table 17.6 Initial enterprise data

Index	Shaanxi Coal Chemical Industry Group Co. Ltd.	Jinduicheng Molybdenum Co. Ltd.
Percentage reduction of carbon dioxide emission per ten thousand CNY	0.09453	0.09876
Carbon dioxide emission per ten thousand CNY	0.360425	0.199652825
Percentage reduction of comprehensive energy per ten thousand CNY	0.08574	0.09876
Comprehensive energy consumption per ten thousand CNY	0.13	0.07201184
Proportion of environmental input	0.016680145	0.000192557
Labor productivity	118.2347668	186.4452522
Proportion of enterprise construction investment	−0.12077774	0.161337476
Proportion of enterprise R&D investment	0	0.000753439
Number of enterprise patents	181	38
Proportion of enterprise training investment	0	0.031599026
Net profit growth rate	−2.86365733	1.431298112
Profit rate of main business	0.132190739	0.006617531
Asset–liability proportion	0.524291559	0.201183324
Return on net assets	0.073701559	0.003886487
Growth rate of main business	0.019087129	0.064058059
Value preservation and appreciation rate of assets	0.999644319	1.01328194
Proportion of enterprise comprehensive energy consumption per ten thousand CNY to industrial energy consumption	0.314138991	0.345635594
Proportion of enterprise R&D investment to industrial investment	0	0.099136748
Proportion of enterprise operating income growth rate to industrial growth rate	0.108850539	1.334366864
Customer satisfaction	0.85	0.995

Table 17.7 Enterprise' green growth performance maturity and index results

Enterprise	Shaanxi Coal Chemical Industry Group Co. Ltd.	Jinduicheng Molybdenum Co. Ltd.
Maturity value	0.504964461 (Third)	0.599367354 (First)
Customer satisfaction	85% (Fourth)	99.5% (First)
Net profit growth rate	−2.86% (Third)	1.43% (Third)
Percentage reduction of comprehensive energy per ten thousand CNY	8.57% (First)	9.88% (First)
Profit rate of main business	13.22% (First)	0.66% (Fourth)

The enterprises' green growth performance maturity can objectively reflect the implementation level of the green growth model, and help the enterprises formulate goals for the green growth model. It can also provide corresponding developmental suggestions from the perspectives of operating costs, R&D investments, customer satisfaction, etc. Overall, the enterprises' green growth performance maturity for green growth can help enterprises to better implement the green growth model.

17.4 Summary

Performance management is a guarantee to implement enterprises' green growth model. This chapter introduces the importance of performance management, and explains the economic and environmental targets of enterprises' green growth performance. This chapter also introduces maturity performance evaluations models to measure enterprises' green growth, including LCA, DEA, and green growth maturity model. Green growth maturity model is used to evaluate the implementation level of an enterprise' green growth model with data of some representative listed enterprises in China. The results help enterprises discover their gap with other competing enterprises, and provide a decision-making reference for enterprises to achieve green growth goals with high quality and efficiency.

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