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# Measuring and Integrating Risk Management into Green Innovation Practices for Green Manufacturing under the Global Value Chain

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**Abstract:** How to solve the contradiction between economic growth and ecological environmental protection is a practical problem that should be solved urgently at present. The development of green technology in the manufacturing industry must rely on technology innovation. However, the process of implementing green innovation in the manufacturing industry is full of high uncertainty and risk. First, the green innovation risks were divided into global green R&D risk, global green manufacturing risk, global green marketing risk, and global green service risk from the perspective of the process. Then, this study established a management criteria system of green innovation risk identification in the manufacturing industry under the global value chain (GVC). Furthermore, three methods were applied to identify the green innovation risk of the manufacturing industry under the GVC. Finally, this paper put forward the countermeasures to the green innovation risk of the manufacturing industry under the GVC. The empirical research results of this paper are as follows: From the perspective of the green innovation process, four risks are classified in this study, namely, global green R&D risk, global green manufacturing risk, global green marketing risk, and global green service risk. Among the four stages of green innovation risk, green marketing risk is the highest, followed by green service risk, and green R&D risk and green manufacturing risk are the least. Global green service risk and green R&D risk can be reduced mainly through risk diversification and risk reduction. Global green manufacturing risk and green marketing risk can be reduced mainly through risk diversification and secondary through risk reduction.

**Keywords:** manufacturing industry; green innovation; innovation risk; risk management

## 1. Introduction

In the process of transforming resources into products, the manufacturing industry not only consumes the limited resources on earth but also releases a large amount of greenhouse gases into nature [1]. The global warming caused by greenhouse gases has brought great threats and challenges to human production and life. Resources and environment are common challenges facing mankind, and sustainable development has increasingly become a global consensus [2]. Against the backdrop of tackling climate change, promoting green growth and implementing green policies is the common choice of all major economies in the world, and developing a green economy has become important national strategies [3]. Developed countries have implemented reindustrialization strategies to rebuild new competitive advantages of the manufacturing industry. The utilization efficiency of resources and energy has become an important factor in measuring the competitiveness of the national manufacturing industry. Green trade barriers have also become an important means for some countries to seek

competitive advantages [4]. However, the increasingly serious environmental pollution and the gradual rise of green consumption wave make it urgent to change the economic development mode.

With the construction of an innovative and resource-conserving country, the concept of green development featuring harmonious coexistence between man and nature is particularly important to realize sustainable development [1–3]. Although the rapid growth of the industrial economy has made remarkable achievements, the extensive growth mode with high consumption, high emission, and low efficiency has also brought a series of serious resource, environmental, and ecological problems [4,5]. How to solve the contradiction between economic growth and ecological environmental protection is an urgent problem. The traditional manufacturing industry, which has made great contributions to economic development, is facing such problems as serious oversupply, excessive consumption of resources, high emission of pollutants, and weak innovation [6]. These problems seriously restrict the coordinated development of economic construction and ecological civilization construction. The manufacturing industry needs to improve the product quality and introduce or research and develop energy-saving and environmental protection technology for green transformation and upgrading.

The comprehensive implementation of green manufacturing is one of the current important strategic tasks and the only way to develop into a manufacturing power. The made in China 2025 action plan emphasizes green development as an important guideline in the manufacturing transformation process [7]. Green manufacturing should build an efficient, clean, and circular green manufacturing system by strengthening the R&D of advanced energy-saving and environmental protection technology. Green innovation has become the core mechanism to reconcile the sharp contradiction between environmental protection and economic development, as well as the key to realize the green development of the manufacturing industry [8]. Green innovation of the manufacturing industry is the green technology, product, and process innovation of the manufacturing industry, as well as the corresponding process of organization, management, and system innovation [9]. Resource conservation and environmental protection embedded in the traditional technology innovation model have become the inevitable requirement of sustainable economic development [3–5]. As the main body of green innovation, manufacturing industry innovation efficiency is not only related to its own survival and development but also to the improvement of the overall quality and comprehensive competitiveness. The action mechanism between the green innovation system and the economic system affects the benign operation and coordinated development of a region and even the whole society. As one of the important ways to achieve the goal of greenhouse gas emission reduction, the innovation of green technology has been widely recognized. Green innovation in the manufacturing industry can alleviate the over-dependence of economic development on resource use and the damage of pollution emission to the ecological environment by improving production efficiency, energy conservation, and emission reduction [7–9].

Although green innovation can create economic, social, and ecological value, it is also a high-risk activity that needs to protect the value of green innovation through risk management [10]. The process of green innovation is full of high uncertainty. Therefore, managing the risk of green innovation in the manufacturing industry is of great theoretical and practical significance to reduce the possibility of risk occurrence and the severity of consequences. In order to create comprehensive value, it is necessary to manage green innovation risk scientifically and effectively [11]. The identification of green innovation risk can not only determine whether different risk factors affect green innovation activities but also determine the degree of influence [12]. A response strategy to green innovation risk not only provides reference for future measures to deal with green innovation risk but also enables innovation subjects to complete green innovation activities [13].

Although many studies on global value chain (GVC), green innovation, and innovation risk have achieved fruitful results, the research on green innovation risk of the manufacturing industry is relatively weak against the background of GVC. At the same time, there are still some problems: (i) Most of the studies on green innovation have been conducted from the perspective of the object and

content of green innovation, and few studies have been found from the perspective of risk management. (ii) Although some scholars have studied the impact of the GVC on the manufacturing industry, there is relatively little studies on what risk the GVC bring to green innovation. There is a lack of criteria and process research on green innovation risk identification in the manufacturing industry under the GVC. (iii) Although many scholars have done a lot of studies on the risk management of technology innovation and product development, the empirical study on green innovation risk of the manufacturing industry under the GVC is not mature enough. In fact, with the increasing demand of global climate change for green innovation, the empirical study on green innovation risk management in the manufacturing industry has become more and more important. In view of the above analysis, factors that comprehensively consider the GVC, green innovation, and risk management should be fully considered through multiple perspectives.

This study aims to identify green innovation risk factors and analyze the characteristics of green innovation risk in the manufacturing industry under the GVC. Furthermore, this paper establishes a criteria system for green innovation risk identification of the manufacturing industry under the GVC. Three approaches are applied to evaluate the green innovation risk in the manufacturing industry worldwide, thereby enriching the research system of green innovation risk management. Finally, the risk response strategies are proposed for dealing with the risk in the process of green innovation. This paper not only helps the manufacturing industry to grasp the status of risk at any time and take corresponding measures to deal with them but also makes a risk management plan for green innovation and improves the success rate of green innovation in the manufacturing industry.

The structure of this paper is as follows: Section 2 reviews the literature on green innovation risk management. The process of green innovation risk identification under the GVC is proposed in Section 3. Section 4 designs the identification method of green innovation risk. Section 5 studies the risk level of green innovation in the manufacturing industry under the GVC. Global green R&D risk, global green manufacturing risk, global green marketing risk, and global green service risk are analyzed in Section 6. Section 7 formulates a response strategy of green innovation risk in the manufacturing industry under the GVC. The following conclusions and future research directions are effectively discussed in Section 8.

## 2. Literature Review

### 2.1. Green Innovation in the Manufacturing Industry

Many scholars studied the driving factors of green innovation and believed that green innovation is more influenced by government regulation, market pull, and technology drive. Sastoque et al. [14] believed that the alliance of enterprises with universities and other research institutions gives them the opportunity to share professional knowledge. How to create a new advanced manufacturing industry by focusing on the technology readiness level (TRL) could be further analyzed. Blühdorn et al. [15] believed that different forms of environmental governance are a kind of ecological political management that is conducive to the free consumption society, which is urgently needed to realize the social-ecological transformation. Tu et al. [16] measured the public participation impact on environmental protection and ecological efficiency in China. Horbach [17] summarized the driving factors of green innovation into four aspects, including technology promotion, market pull, regulatory incentive, and internal factors.

For example, Cleff et al. [18] pointed out that the enterprise scale is significantly positively correlated with product integration innovation, and the strategic market target has a significant impact on green product innovation. Brunnermeier et al. [19] studied the manufacturing industry in the United States and found that there is a link between pollution prevention costs and green innovation. Ziegler et al. [20] pointed out that environmental management tools have a significant positive impact on green product innovation after conducting an interview with product managers in Germany. De Vries et al. [21] thought that high pollution emission levels lead to strict environmental policies, which in turn stimulate green innovation. Hamamoto [22] believed that the pressure of

environmental regulation could stimulate green technology innovation. Rehfeld et al. [23] pointed out that customer satisfaction is significantly positively correlated with product innovation in terms of market pull. Wagner [24] found that consumer information and environmental identification are significantly positively correlated with product innovation. Demirel et al. [25] pointed out the impact of external government policies and internal incentives on technology and the environment in different types of green innovation. Ustaoglu et al. [26] studied the market share policy through the implementation of green innovation in Turkey. Eaton [27] pointed out that the key role of green innovation in the transition of a green economy is the allocation of economic capital stock and the promotion of innovation and environmental policies on technology change. Meltzer et al. [28] believed that new technologies that can cope with climate change and reduce carbon dioxide emissions play an important role in the development of the United States, especially its R&D capacity. El-kassar et al. [29] tested a holistic model that describes the relationship between green innovation and its drivers to improve corporate performance and competitive advantage. Fernando et al. [30] extended the concept of green business based on an original conceptual framework, which proposed that service innovation capability can mediate the relationship between sustainable organizational performance and environmental innovation. Xie et al. [31] found that green process innovation has a positive impact on green product innovation through the content analysis of data of 209 listed companies of the high pollution manufacturing industry, and both green process innovation and green product innovation can improve the financial performance. Fujii et al. [32] investigated the determinants of sustainable green technology inventions and found that green patent publications increase due to the increase in the share of R&D expenditure and economic growth.

Further, some scholars studied the evaluation of green innovation. LeBlanc et al. [33] took the eco-industrial development project as an example to select the factors influencing the healthy development of the project and evaluate the potential of eco-industrial development. Deif [34] verified the system model through an industrial case and then proposed how to improve the comprehensive qualitative answer to the green question manufacturing system and the future quantitative research roadmap. Lanoie et al. [35] focused on the possible impact of environmental policies on environmental efficiency and the classification of strength and weakness. Wong et al. [36] discussed the impact of green process innovation and green product innovation on green efficiency and economic efficiency, respectively. Similarly, Wong [37] analyzed the performance of green innovation and also classified green product innovation and green process innovation. Ghisetti et al. [38] chose nine indicators of energy consumption, environmental pollution, and two other aspects, and made a distinction between energy efficiency innovation and environmentally beneficial innovation. Ren et al. [39] measured the green innovation efficiency of Chinese industrial enterprises based on an SBM model. Guo et al. [40] used the three-stage DEA model to measure the green innovation efficiency of different provinces in China. Liu et al. [41] used a RAM model to comprehensively consider environmental efficiency, production efficiency, and comprehensive efficiency to measure the sustainability level of the coal industry. Rumanti et al. [42] took small and medium-sized enterprises in Indonesia as a case study to build a new green innovation model of knowledge sharing and open innovation.

In addition, Govindan et al. [43] analyzed the overview of multi-criteria decision-making methods for green supplier evaluation and selection. Further, Yin et al. [44] analyzed the innovation of green building technology under the cooperation of industry, university and research institute. Lin et al. [45] used the DEA model to evaluate the green innovation efficiency of the manufacturing industry. Yin et al. [46] analyzed the influence of the relationship of green integrated supply chain in manufacturing enterprises on the quality and speed of green new product development. Ho et al. [47] combined artificial neural networks (ANNs) and fuzzy rule sets to realize knowledge discovery and decision support in high-quality manufacturing using artificial intelligence.

## 2.2. Green Innovation Risk Management

In general, the risk of green innovation can be classified from the perspectives of risk sources, risk characteristics, and risk processes. This study sorted out the representative classification viewpoints from the main classification perspectives, as shown in Table 1.

**Table 1.** The classification of green innovation risk.

Risk Classification	Risk Factor	Reference Source
Risk sources	Manage risk and cost-related risk as well as environmental, technical, and market risk	[48–50]
	Environmental risk, technology risk, management risk, and market risk	[51,52]
	Technology risk, market risk, transportation capacity, competition risk, and policy risk	[53,54]
Risk characteristics	Technology risk, management risk, and marketing risk	[55,56]
	Technology risk, manufacturing risk, market risk, management risk, and financial risk	[57,58]
	Technology risk, market risk, cooperative risk, financial risk, and institutional risk	[59,60]
Risk processes	Development risk, manufacturing risk, and marketing risk	[61,62]
	Research risk, manufacturing risk, and market service risk	[63]
	Development risk, manufacturing risk, and market risk	[64]

The classification of the risk management process by the International Standards Association, American Project Management Organization, Australian And New Zealand Standards, and American Sponsor Committee is basically the same, including environmental analysis, risk identification, risk assessment, risk response, and risk internal control [65–68]. For identifying green innovation risk, the flowchart method, fault tree method, and scenario analysis method are usually used. Baryannis et al. [69] used the flowchart method to identify risk and emphasized the correlation between risk factors. Ribeiro [70] used the literature review method to summarize relevant risks. As for innovation risk assessment, Nazam et al. [71] used the trigonometric fuzzy method to evaluate the risk in the process of green innovation and proved the practicability of the model with empirical evidence. Liu et al. [72] used the FCE-AHP method to combine AHP with fuzzy theory to measure the level of technology risk. In terms of dealing with green innovation risk, the American Sponsors Committee takes risk avoidance, risk reduction, risk dispersion, and risk acceptance as the ways to deal with risk in the risk management framework [73]. Lai [74] constructed a two-dimensional matrix to select risk response models. Fan [75] emphasized that the risk attitude should be considered comprehensively when choosing risk response models. In addition, Gosmann et al. [76] established an early-warning system suitable, including several subsystems for risk control and elaborated on the operation process of the early-warning system.

## 3. Construction of Green Risk Identification System

### 3.1. Process of Green Innovation Risk Identification

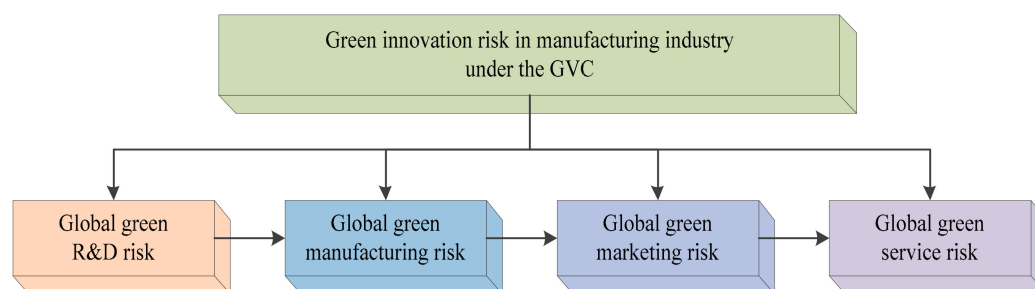
The green innovation risk of the manufacturing industry has the following characteristics [48–64]. (i) Each stage of green innovation in the manufacturing industry faces various risks. Changes in the internal and external environment bring complex uncertainties, which reflects the dynamic nature of innovation risk. (ii) The risk faced by green innovation in the manufacturing industry can be measured by experts according to practical experience and scientific theories. (iii) Green innovation activities in the manufacturing industry can be divided into different stages. Green innovation risks start from one stage and affect subsequent innovation links. (iv) The ambiguity of green innovation risk is mainly manifested in the different degrees and ways of coping with green innovation. Therefore, measuring the risk of green innovation in the manufacturing industry can be described by the fuzzy theory. (v) Whether the external environment changes or the internal environment is uncertain, the manufacturing industry that carries out green innovation is objective and inevitable.

Green innovation is characterized by process, innovation, benefit, and risk, and risk is one of the most important and essential features of green innovation. There are many ways to divide green innovation risk, such as by source, by feature, and by process. The risks in the green innovation stage of manufacturing are mainly pre-development risks, technical risks, production risks, and market risks, while environmental risks and financial risks will affect the whole process of green innovation [65]. To be specific, in the process of green innovation, green R&D, green production, market related factors are the most important longitudinal influence factors. If the emphasis is placed on the green level of the enterprise, the green R&D factors are reflected in green technology experience and green technology competitiveness. Green production factors mainly include green production capacity and capital strength. Market related factors are reflected in marketing ability, market knowledge, producer popularity, and degree of competition, such as green R&D auto parts in the automobile manufacturing industry. In terms of project level, the green R&D factor mainly refers to the complexity and capability of green technology. Green production factors include technical problems and standardization problems. Market related factors refer to the comparative advantage of green innovative products in the eyes of users and the price of innovative products, such as green R&D in the building materials industry. Scholars generally believe that the risks in the development stage are mainly green technology risks, such as the existence of green technology problems, low green development capacity, or high green development cost [66]. In the stage of commercial green production, the main risk is that the existing technology, equipment, and materials cannot meet the needs of mass production, or that the quality of green products is poor and the production cost is high. In the marketing stage, risks are reflected in market capacity, distribution channels, changes in consumer demand, market competition, and other aspects. Some scholars believe that there are three typical risks in the process of manufacturing green innovation: green R&D risk, green commercialization risk, and market application risk. Green R&D risk refers to the risk that may appear in the R&D stage, mainly including technical risk, financial risk, personnel risk, and so on. The commercialization risk of green technology achievements refers to the risk that may occur from the end of technology R&D to the mass production process. Market risk includes the uncertainty faced by market participants engaged in economic activities.

Many scholars summarized the research on the linear model of green innovation. The result of the research is that green innovation is a linear process of research, development, manufacturing, and marketing, and the chain model of green innovation is established [67]. The main chain is defined as potential market, research and production exploration, specific design and test, secondary design and production, market and service. If the manufacturing industry carries out green innovation activities, it inevitably goes through such important stages as R&D, manufacturing, marketing, and service in traditional innovation. Under the influence of the current international economic situation, manufacturing is an irreplaceable and important part of the global value chain. Global value chains (GVCS) have also created irreplaceable favorable conditions for green innovation in manufacturing in terms of providing international resources and markets. Therefore, the analysis of green innovation in manufacturing must take into account the important background of global value chains. Green innovation risks can be classified according to risk characteristics, risk sources, and processes. The classification of green innovation risk in this paper is based on the process perspective. Many scholars believe that green innovation risks are mainly contained in pre-development, technology, production, and market services, while environmental and financial risks run through [68]. The most common risks in the green R&D phase are technical, financial, and personnel aspects, while the risks that run from R&D to production exist in the commercialization of technological achievements. Marketing and service-related risk refers to the risk to the people who participate in the market for product innovation. Therefore, green innovation risks from the process perspective mainly include R&D risks, manufacturing risks, marketing risks, service risks, and other important stage risks.

Based on the above analysis, this study analyzes each stage of the green innovation process and combines the innovation risk classification from the process perspective. Four types of green innovation risk under the GVC are summarized, namely, global green R&D risk, global green manufacturing risk,

global green marketing risk, and global green service risk [65–68]. A flowchart is used to illustrate the logical correlation between each risk factor, as shown in Figure 1.



**Figure 1.** Flowchart of green innovation risk identification in the manufacturing industry under the global value chain (GVC).

As shown in Figure 1, each type of green innovation risk includes different risk factors. The risk of green innovation is defined as the possibility of the suspension, termination, or failure of green innovation activities due to the uncertainty of the external environment of green innovation and the lack of the strength of the enterprises implementing green innovation on the basis of R&D clean energy and development of energy-saving and emission reduction technologies, as well as the losses caused. R&D risks stem from changes in personnel, finance, technology, and green policies in the R&D process [51–60]. Manufacturing risk also involves personnel and financial risk, followed by production risk [55–58,61,62]. Marketing risk also involves human and financial risk and is affected by markets and low-carbon policies [55–62]. Similarly, service risks arise from personnel, finance, and after-sales services [48–50,64].

In general, in the creative phase of green innovation, policy makers formulate green innovation plans according to the development of technology or market demand. Due to the uncertainty of technology development and the difficulty in grasping customer demand, green innovative products may not meet the actual needs of customers, or the technology is too advanced and does not match the market demand, which brings risks to the innovation process. In the process of R&D, the risk of green technology has the greatest impact, which is reflected in the advancement, difficulty, and complexity of technology, the uncertainty of the technology life cycle, and the emergence of alternative technologies. At the same time, only with sufficient R&D funds and technical R&D personnel as a guarantee, to promote the green innovation activities smoothly. The green production stage is the economic activity of green technology before the formal production according to the R&D results, including a series of experiments to solve the problems related to the production of green technology (such as process, raw materials, quality). The main green risks in this stage are unreasonable design principles, the unstable performance of technical achievements, poor reliability, poor production process, and the inability to produce green products to meet the needs. Green manufacturing risk mainly refers to the risk in the transition process from trial production and small batch production to large batch production. In this process, due to the uncertainty of related factors and changes in the system, the innovation fails. The shift from small batch production to large batch production has put forward new requirements for processes, equipment, and raw materials. Therefore, the main risks in this stage are the degree of process adjustment, the technical performance requirements of green new products on raw materials, and the degree of supply of raw materials and components. In the marketing stage, market risk has a great impact, which is caused by the fact that the new green products produced by green innovation do not meet the market demand and are not accepted. The main reason for this is market uncertainty. The root cause is the change of market demand, the low degree of consumer recognition, the fierce market competition, and the difficulty in using the existing marketing channels. The service risk of green innovation refers to the pre-sale, sale, and after-sales service provided to cooperate with the sale of green products. It can promote the movement of green product flow and currency flow without causing crises and accidents of green product flow and currency flow. In order to avoid the risk of

green innovation service, the manufacturing industry is required to provide support services for the sales of green products to bring customers a satisfactory experience, rather than generate complaints. Therefore, this paper combines the characteristics and classification of green innovation risk to analyze the identification process of green innovation risk under the GVC.

### 3.2. Criteria System of Green Innovation Risk Identification

In the process of risk identification, the following principles should be followed [77,78]. (i) GVC and green innovation should be considered comprehensively to reflect the nature of risk as much as possible. (ii) The establishment of the risk identification criteria system should fully consider the independence of the risk criteria. (iii) The risk identification criteria system is not only simple, practical, and easy to operate but also provides reference for the manufacturing industry in green innovation practice. (iv) The risk identification criteria system should fully reflect the role of the four major links in promoting green innovation and integrating international resources.

#### 3.2.1. Global Green R&D Risk

For highly professional activities, the development of green R&D requires the relevant personnel to have rich knowledge and experience. Unlike managers, developers are generally good at specific tasks in the field of green R&D [52]. Without enough R&D personnel, innovation activities will be difficult to sustain. When developing green products, adequate R&D funding is equally important. It can effectively reduce the weakness of green innovation caused by insufficient capital to ensure the green R&D [51–53]. Once the funding chain breaks, R&D activities will be suspended or failed, and the green technology will gradually lose its advantage and eventually be overtaken by competitors. On the one hand, the leading level, maturity level, and difficulty level of green technology directly affect the success or failure of green R&D [54]. On the other hand, the short life cycle means that the utilization value of green technology does not exist for a long time, which leads to the benefits of green R&D that cannot make up for the costs [56–58]. Because the green technology is easy to be replaced, the impact of the replacement technology accelerates the elimination of green technology. Many studies have pointed out that the success rate of green technology transfer is positively correlated with green R&D [51–56], and the failure is caused by the insufficient strength or immature technology of the party providing the technology. Poor protection of intellectual property also poses a risk to green R&D. Intellectual property rights ensure that enterprises have sufficient incentive to innovate products to gain benefits. In international trade, once a green enterprise innovation cannot be effectively protected, its followers will surely get the same benefits without paying any price [59,60]. Therefore, global green R&D personnel, R&D funds, R&D stability, application stability, ease of international transfer, and international protection of patents in the manufacturing industry have been fully incorporated into global green R&D risk identification.

#### 3.2.2. Global Green Manufacturing Risk

In order to ensure the mass of green products, sufficient manufacturing staff and capital are necessary. In general, large-scale enterprises are relatively strong in capital, technology, production, market, and other aspects [49–52,55,56], and they are comfortable with risk response. When the manufacturing industry is carrying out green innovation, green new products have certain constraints on the technology performance of raw materials [51]. Only with a high quality of raw materials can the quality performance of products be guaranteed. Otherwise, it is difficult to meet consumer requirements and sell new green products; thus, this eventually causes serious consequences for the manufacturing industry [56]. The GVC links the organizations that participate in the global value creation and realizes the green product value together through the division of labor and cooperation. Among them, production outsourcing can help enterprises to focus resources and energy on advantageous businesses [50]. The innovation of a new green product can greatly change the existing production model [50–52]. Only with the supporting green technology and green equipment can the normal



production of green products be guaranteed. However, the acquisition of green related equipment or the transformation of green related technology is bound to cause an increase in production costs. At the same time, the carbon emission limit, carbon tax, and other constraints can increase the cost burden in the production process. The increase in production cost is bound to raise the price of products and weaken the market competitiveness of products. Therefore, manufacturing personnel, manufacturing capital, production scale, product quality level, outsourcing scale, technical transformation degree, and manufacturing cost increase are included in global green manufacturing risk identification.

### 3.2.3. Global Green Marketing Risk

The lack of adequate protection of marketing resources can increase the risk of the whole marketing activities and have a negative impact on the marketing of green new products [61]. After the product is launched, it should meet the needs of consumers. Once the needs of consumers change, the uncertainty of marketing will be increased [55–57]. Consumer desire for green products can generate a potential consumer market and become a good opportunity for the manufacturing industry to invest in green innovation. If it fails to reach the expected market share, it will make it difficult to cause certain losses and risks to the manufacturing industry [59–61]. Too many competitors, too strong ability, and unfair competition are the market factors. The intensity of market competition is related to the effect of new green product marketing and determines the nature and size of the marketing risk [60,62]. Many studies have shown that opening up new marketing channels is much more ineffective than using existing marketing channels [58–60]. Therefore, a high degree of possession of existing marketing channels is an important way to achieve success in new product marketing. The commercialization of green technology means that the developed technology can be realized into products and put into the market for international trade [60]. Only in this way can the success of green innovation be reflected. In global trade, green barriers and green competition are the international trade protection methods [59,79]. These standards and protective barriers not only restrict the integration of the manufacturing industry into the global market but also hinder the green innovation. Only by breaking through it can green innovation be defended. Therefore, marketing personnel, marketing funds, international demand level, international competition intensity, international marketing channel share, internationalization level, and trade barrier intensity are regarded as global green marketing risks.

### 3.2.4. Global Green Service Risk

Human capital is the core resource of service activities, which directly affects the efficiency of the green innovation service [48]. Money capital is the basic resource element for the success of the green innovation service [50]. The coverage of service outlets is an important factor to reflect the service capability of the manufacturing industry. A perfect service network can improve service efficiency and assist in the successful promotion of product innovation activities [48]. A multinational survey found a positive relationship between a firm ability to internationalize operations and the integrity of its global supply chain system. Globalization has a great impact on the green supply chain, which not only concerns the difficulty of the global promotion of new products but also increases the frequency of emergencies [64]. Supply chain disruption makes the supply chain full of risk and makes it difficult to predict the complexity. At the same time, the green supply chain management of large multinational enterprises also blocks the development of the manufacturing industry [52]. After-sales technical service provides installation and configuration, operation instructions, and fault maintenance for sold goods, as well as information inquiry, customer information acquisition, consultation, and technical training. Technology services can help enterprises win high customer satisfaction, which plays a huge role in promoting the market share of green new products [47,64]. Therefore, service personnel, service capital, service network coverage, supply chain globalization level, and global after-sales technical service capability are regarded as global green service risks.

Based on the above analysis, this study constructs a criteria system of green innovation risk identification of the manufacturing industry under the GVC. Under the GVC, green innovation risk

in the manufacturing industry can be divided into four stages: global green R&D, global green manufacturing, global green marketing, and global green service. It is further refined into the element level to reflect the impact of the criteria level on the overall risk of green innovation. The criteria system of green innovation risk identification of the manufacturing industry under the GVC is shown in Table 2.

**Table 2.** The criteria system of green innovation risk identification of the manufacturing industry under the GVC.

Criteria	Main Criteria	Subcriteria	Abbreviations
Risk identification of green innovation in the manufacturing industry under the GVC	Global green R&D risk: C <sub>1</sub>	Proportion of global green R&D personnel investment	C <sub>11</sub>
		Proportion of global green R&D funds investment	C <sub>12</sub>
		Stability of global green technology R&D	C <sub>13</sub>
		Stability of global green technology application	C <sub>14</sub>
		The ease of international transfer of green technology	C <sub>15</sub>
		International Protection of green technology patents	C <sub>16</sub>
	Global green manufacturing risk: C <sub>2</sub>	Proportion of global green manufacturing personnel investment	C <sub>21</sub>
		Proportion of global green manufacturing investment	C <sub>22</sub>
		Global green manufacturing product production scale	C <sub>23</sub>
		Quality and performance level of global green manufacturing products	C <sub>24</sub>
		Global outsourcing scale of green products	C <sub>25</sub>
		Global green manufacturing technology transformation degree	C <sub>26</sub>
	Global green marketing risk: C <sub>3</sub>	Increase of global green manufacturing cost	C <sub>27</sub>
		Proportion of global green marketers	C <sub>31</sub>
		Proportion of global green marketing investment	C <sub>32</sub>
		International demand level of green products	C <sub>33</sub>
		International competition intensity of green products	C <sub>34</sub>
		International marketing channel share of green products	C <sub>35</sub>
	Global green service risk: C <sub>4</sub>	Commercialization and internationalization of green technology	C <sub>36</sub>
		Intensity of green technical barriers to trade in the international community	C <sub>37</sub>
Proportion of global green service personnel investment		C <sub>41</sub>	
Proportion of global green service investment		C <sub>42</sub>	
Global green service network coverage of the manufacturing industry		C <sub>43</sub>	
		Global level of green product supply chain	C <sub>44</sub>
		Global after sales technical service capacity of green products	C <sub>45</sub>

In order to clearly define the connotation of indicators in Table 2, relevant connotations are defined as follows.

In terms of global green R&D risks, the proportion of global green R&D personnel in the manufacturing industry refers to the proportion of relevant R&D personnel in the total global workforce of a manufacturing enterprise when conducting global R&D of green products. The proportion of global green R&D investment in the manufacturing industry refers to the proportion of R&D investment in the global R&D of green products in the operating income of manufacturing enterprises. The stability of global green technology R&D in the manufacturing industry refers to the degree to which manufacturing enterprises can successfully carry out green innovation activities in global R&D of green products without accurately capturing and predicting the maturity, advanced degree, difficulty, and complexity of green technology development. The stability of global green technology applications in the manufacturing industry means that technologies developed by manufacturing enterprises during global green innovation will be replaced by new technologies in the future, and the time interval is uncertain. It also includes the possibility that technologies developed by manufacturing companies during global green innovation will be replaced by other, more advanced technologies. The ease of international transfer of manufacturing green technologies means that manufacturing enterprises can transfer green innovative technologies from one party to another. The success or failure of the regional diffusion of green product technology and the transformation of results is limited by the supply capacity of the main supplier of technology. Another reason is the maturity of the technology itself.

International protection of manufacturing green technology patents refers to the efforts to limit the abuse of intellectual property rights, usually through the coordination of international organizations among governments to give green technology patent protection.

In terms of global green manufacturing risks, the proportion of global green manufacturing personnel input in the manufacturing industry refers to the proportion of manufacturing personnel in the global workforce of the enterprise. The proportion of global green manufacturing capital investment in the manufacturing industry refers to the proportion of capital investment of manufacturing enterprises in the global operating revenue of the enterprise. The global production scale of green manufactured goods refers to the total amount of production factors, such as land, labor, machinery, and equipment, that are put into the production of green products. The quality and performance level of global green manufacturing products refers to the level of quality and performance of green products produced by manufacturing enterprises worldwide. Global outsourcing of manufacturing green products refers to the transfer of one or more modules by manufacturing enterprises to relevant enterprises in other regions. The global green manufacturing technology transformation degree of the manufacturing industry refers to the manufacturing enterprises to produce better green products and rely on higher technology and technology for the existing equipment and technology transformation. The increase in the global cost of green manufacturing refers to the extent that the green products produced by manufacturing enterprises are limited by different green-related taxes and emission requirements in different regions when they are put on the international market.

In terms of global green marketing risk, the proportion of global green marketer investment in the manufacturing industry refers to the proportion of the number of marketers in the total global workforce of the enterprise. The proportion of global green marketing fund investment in the manufacturing industry refers to the proportion of marketing funds in the operating revenue of manufacturing enterprises. The manufacturing green product international demand level refers to the total amount of products that consumers are willing and able to buy in the international green product market. The international competitiveness of green products in the manufacturing industry refers to the degree of satisfaction and appreciation of green products by consumers in the global market. The international marketing channel share of manufacturing green products refers to the proportion of green product sales of manufacturing enterprises in the global green product market. The commercialization and internationalization level of green technology in the manufacturing industry refers to the degree to which the achievements of green technology R&D in manufacturing enterprises are transformed into green products, and various international and domestic resources are fully utilized for cross-border economic cooperation. The intensity of green technical barriers to trade refers to the degree to which the existing trade protection in the international community hinders the sale of products with green technical content in the international market.

In terms of global green service risks, the proportion of global green service personnel input in the manufacturing industry refers to the proportion of the number of service personnel in the manufacturing enterprise to the total number of employees in the enterprise. The proportion of global green service fund investment in the manufacturing industry refers to the proportion of service fund amount in the operating revenue of manufacturing enterprises. Global green service network coverage of the manufacturing industry refers to the proportion of the number of green service outlets provided by manufacturing enterprises in the total market area. The globalization level of the green product supply chain in the manufacturing industry refers to the cross-circulation degree of business flow, logistics, information flow, and capital flow in the global scope when manufacturing enterprises start from purchasing raw materials and components of green products, manufacturing intermediate products and end products, and delivering green products to consumers through sales channels. The global after-sales technical service capability of manufacturing green products refers to the quality and efficiency of the service provided by manufacturing enterprises for installation, configuration, use guidance, and fault handling, as well as information query, customer information acquisition, consultation, and technical training of the green products sold.

#### 4. Research Methodology

The main purpose of this section is to determine the weight of the risk of green innovation in the global value chain of manufacturing enterprises through the F-AHP comprehensive evaluation method, and then calculate the corresponding levels of each risk evaluation index by combining fuzzy theory, subjective and objective time weight, and attribute weight.

##### 4.1. Criterion Weight Method

The weights of various criteria for the green risk assessment under the GVC of the manufacturing industry are different. In this paper, the analytic hierarchy process (AHP) proposed by T.L. Saaty was adopted to calculate the weight distribution for green innovation risk assessment [80]. The decision-making process of AHP can be divided into many aspects, as shown in Supplementary Material 1.

##### 4.2. Criterion Value Method

###### 4.2.1. Fuzzy Value of Qualitative Criterion

Fuzzy underlying information is defined as shown in Supplementary Material 1.

(i). Fuzzy set of identification criteria. The TFN set {Very low risk, Low risk, Medium low risk, Medium risk, Medium high risk, High risk, Very high risk} is used to construct the corresponding relationship. Language variables and their corresponding TFNs are shown in Table 3.

Table 3. Fuzzy linguistic variable.

Linguistic Variables	Abbreviations	TFNs
Very low risk	VP	(0.0, 0.0, 0.1)
Low risk	P	(0.0, 0.1, 0.3)
Medium low risk	MP	(0.1, 0.3, 0.5)
Medium risk	M	(0.3, 0.5, 0.7)
Medium high risk	MG	(0.5, 0.7, 0.9)
High risk	G	(0.7, 0.9, 1.0)
Very high risk	VG	(0.9, 1.0, 1.0)

(ii). Identification criteria assignment.  $m$  experts are invited to identify criteria  $n$  in the criteria system. By converting the language variable into the corresponding TFN, the TFN  $x_{ij}$  of the  $i$  expert on the  $j$  identification criterion can be obtained, namely,  $x_{ij} = (x_{ij}^L, x_{ij}^M, x_{ij}^U)$ , where  $i = 1, 2, \dots, m$  and  $j = 1, 2, \dots, n$ . Then, the assignment matrix of the initial recognition criterion can be obtained.

$$R_{ij} = \begin{bmatrix} (x_{11}^L, x_{11}^M, x_{11}^U) & (x_{12}^L, x_{12}^M, x_{12}^U) & L & (x_{1n}^L, x_{1n}^M, x_{1n}^U) \\ (x_{21}^L, x_{21}^M, x_{21}^U) & (x_{22}^L, x_{22}^M, x_{22}^U) & L & (x_{2n}^L, x_{2n}^M, x_{2n}^U) \\ & M & M & M \\ (x_{m1}^L, x_{m1}^M, x_{m1}^U) & (x_{m2}^L, x_{m2}^M, x_{m2}^U) & L & (x_{mn}^L, x_{mn}^M, x_{mn}^U) \end{bmatrix} \quad (1)$$

Finally, several experts in the risk identification group are invited to assign values to the criteria according to their own experience, and the original risk identification data is obtained.

###### 4.2.2. Data Acquisition of Quantitative Criteria

(i) Calculate the original value of the quantitative criterion. The original value of original risk identification is calculated using the established quantitative criterion measurement method.

(ii) Normalize the original value. Due to the different dimensions of the quantitative criteria of green innovation risk, the criteria should be normalized before comprehensive identification.  $x_{ij}^*$  is the original value, and  $x_{ij}$  is the dimensionless value of the quantitative criterion.  $\max x_j^*$  and  $\min x_j^*$

are the maximum and minimum values of the quantitative criteria of green innovation risk in the manufacturing industry under the same GVC. The relationship between these factors is as follows [60]:

$$\text{Positive criteria : } x_{ij} = \frac{x_{ij}^* - \min x_j^*}{\max x_j^* - \min x_j^*}, \quad (2)$$

$$\text{Negative criteria : } x_{ij} = \frac{\max x_j^* - x_{ij}^*}{\max x_j^* - \min x_j^*}. \quad (3)$$

#### 4.3. Comprehensive Time Sequence Weight

In the process of green innovation risk identification, the weight vector  $\lambda(t) = (\bar{a}(t_1), \bar{a}(t_2), \dots, \bar{a}(t_p))^T$  of the time series reflects the preference degree of the manufacturing industry for the time series.

##### 4.3.1. Time Weight Based on Time Degree and Ideal Solution

**Definition 1.** Let  $\varphi = \sum_{k=1}^p \frac{p-k}{p-1} \lambda(t_k)$  be a time degree vector  $\lambda(t) = (\bar{a}(t_1), \bar{a}(t_2), \dots, \bar{a}(t_p))^T$ , where  $0 \leq \varphi \leq 1$ . When  $\varphi = 0$ , then  $\lambda(t)^+ = (0, 0, \dots, 1)^T$ , which is called positive ideal time weight vector. When  $\varphi = 1$ , then  $\lambda(t)^- = (1, 0, \dots, 0)^T$ , which is called a negative ideal time weight vector.

Let  $d(\lambda^1(t_k), \lambda^2(t_k))$  be a Euclidean distance between time weight vector  $\lambda^1(t_k)$  and  $\lambda^2(t_k)$ ,  $d(\lambda^1(t_k), \lambda^2(t_k))$  can be expressed as follows:

$$d(\lambda^1(t_k), \lambda^2(t_k)) = \sqrt{\sum_{k=1}^p |\lambda^1(t_k) - \lambda^2(t_k)|^2}. \quad (4)$$

Then, the Euclidean distance of  $\lambda(t) = (\bar{a}(t_1), \bar{a}(t_2), \dots, \bar{a}(t_p))^T$  can be expressed as follows:

$$d(\lambda(t_k), \lambda(t_k)^+) = \sqrt{\sum_{k=1}^{p-1} \lambda(t_k)^2 + (1 - \lambda(t_p))^2}, \quad (5)$$

$$d(\lambda(t_k), \lambda(t_k)^-) = \sqrt{(1 - \lambda(t_1))^2 + \sum_{k=2}^p \lambda(t_k)^2}. \quad (6)$$

The ideal time weight vector can be expressed as follows:

$$C = \frac{d(\lambda(t_k), \lambda(t_k)^-)}{d(\lambda(t_k), \lambda(t_k)^+) + d(\lambda(t_k), \lambda(t_k)^-)}. \quad (7)$$

Then, a model (M-1) based on TOPSIS thought and ideal solution can be expressed as follows:

$$\left\{ \begin{array}{l} \max C(\lambda) = \frac{\sqrt{(1 - \lambda(t_1))^2 + \sum_{k=2}^p \lambda(t_k)^2}}{\sqrt{\sum_{k=1}^{p-1} \lambda(t_k)^2 + (1 - \lambda(t_p))^2} + \sqrt{(1 - \lambda(t_1))^2 + \sum_{k=2}^p \lambda(t_k)^2}} \\ \text{s.t. } \varphi = \sum_{k=1}^p \frac{p-k}{p-1} \lambda(t_k), \sum_{k=1}^p \lambda(t_k) = 1, \lambda(t_k) \in [0, 1], k = 1, 2, \dots, p \end{array} \right. \quad (8)$$

### 4.3.2. Time Weight Based on Time Degree and Information Entropy

According to entropy theory, the larger the information entropy is, the less information it contains. Information entropy reflects the amount of information absorbed by the time weight vector, and it has the characteristics of symmetry, additivity, and extremum. The expression is as follows:

$$F(\lambda(t_k)) = -\sum_{k=1}^p \lambda(t_k) \ln \lambda(t_k), k = 1, 2, \dots, p. \quad (9)$$

Further, a nonlinear programming model (M-2) can be established according to the maximum entropy principle, and the model can be denoted as follows:

$$\left\{ \begin{array}{l} \max F(\lambda(t_k)) = -\sum_{k=1}^p \lambda(t_k) \ln \lambda(t_k) \\ \text{s.t. } \varphi = \sum_{k=1}^p \frac{p-k}{p-1} \lambda(t_k), \sum_{k=1}^p \lambda(t_k) = 1, \lambda(t_k) \in [0, 1], k = 1, 2, \dots, p \end{array} \right. \quad (10)$$

### 4.3.3. Comprehensive Time Weight

According to the principle of emphasizing the present rather than the past, the greater the degree of closeness, the higher the importance of current risk information. In order to maximize the closeness degree of the time weight vector, a model was optimized on the basis of the (M-1) and (M-2) models, and a nonlinear programming model (M-3) combining the information entropy principle with the ideal solution was established. This model can make the results of green innovation risk identification much more comprehensive and accurate. The model (M-3) can be expressed as follows:

$$\left\{ \begin{array}{l} \max G = \theta \frac{\sqrt{(1-\lambda(t_1))^2 + \sum_{k=2}^p \lambda(t_k)^2}}{\sqrt{\sum_{k=1}^{p-1} \lambda(t_k)^2 + (1-\lambda(t_p))^2} + \sqrt{(1-\lambda(t_1))^2 + \sum_{k=2}^p \lambda(t_k)^2}} - (1-\theta) \sum_{k=1}^p \lambda(t_k) \ln \lambda(t_k) \\ \text{s.t. } \varphi = \sum_{k=1}^p \frac{p-k}{p-1} \lambda(t_k), \sum_{k=1}^p \lambda(t_k) = 1, \lambda(t_k) \in [0, 1], k = 1, 2, \dots, p \end{array} \right. \quad (11)$$

where  $\theta \in [0, 1]$ . The model (M-3) can be solved via Lingo software, and the time vector  $\lambda(t) = (\bar{a}(t_1), \bar{a}(t_2), \dots, \bar{a}(t_p))^T$  can be obtained.

## 4.4. Integration Method

### 4.4.1. Expert Weighting Method

The criteria information in column  $j$  of green innovation risk identification matrix  $R_{ij}$  of the manufacturing industry in China under the GVC is aggregated by the weighting method. The group comprehensive identification value  $\bar{x}_j = (\bar{x}_j^L, \bar{x}_j^M, \bar{x}_j^U)$  of the expert group for each criterion  $x_j$  is obtained, where  $j = 1, 2, \dots, n$  and  $n$  is the total number of the identification criteria. Since the proportion of experts is the same, the calculation formula is given as follows

$$\bar{x}_j = \frac{1}{m} (x_{1j} \oplus x_{2j} \oplus L \oplus x_{mj}) \quad (12)$$

where  $m$  is the total number of experts, and  $x_{mj}$  is the TFN corresponding to the identification result of the  $m$  expert on the  $j$  criterion. According to the following formula, the expert opinion aggregation result is calculated.

$$S_{C_i} = W_{C_i} R_{C_i} \quad (13)$$

where  $S_{C_i}$  is the comprehensive identification result of green innovation risk criteria  $C_i$  of the manufacturing industry in China under the GVC.  $W_{C_i}$  is the weight matrix of criterion  $C_i$  at the next level, and  $R_{C_i}$  is the result matrix of expert opinion aggregation in the next layer of criterion.

#### 4.4.2. Deviation Maximization Method

The idea of deviation maximization is an idea that maximizes the distance between objects as far as possible [81]. Some scholars applied it as an evaluation method in many scientific fields to achieve a good evaluation effect. The specific steps of this method are defined as shown in Supplementary Material 1.

#### 4.4.3. Average Method

The average value method is a method that uses the average value to solve problems. The specific steps of this method are defined as shown in Supplementary Material 1. To sum up, to fully reflect the equations and parameters definition, a symbol table for this method is defined as shown in Table S3 in Supplementary Material 2.

### 5. Empirical Study

The energy-saving and emission reduction targets of the manufacturing industry vary according to the nature of the enterprise. As we all know, the process/process manufacturing industry consumes a large amount of energy (more than 50% of the total), accounts for a high proportion of the production cost of enterprises, and is the primary target of energy conservation and emission reduction in the manufacturing industry. However, the overall energy consumption and emissions of a large number of discrete manufacturing industries (such as aerospace, automotive, electronics, equipment manufacturing) cannot be ignored either. The research on the principle, method, and technology of energy-saving manufacturing is also of great significance and value to the discrete manufacturing system. At the same time, the price rise caused by the decrease of energy quantity, consumers desire for low-energy products, and the implementation of related green laws and regulations at home and abroad have all put forward the requirements for high-efficiency and energy-saving production of discrete manufacturing systems. This requires controlling the risk of green innovation in discrete manufacturing and providing a solid guarantee for promoting the discrete manufacturing system.

#### 5.1. Determination Weights of Identification Criteria

According to the pearl criteria system of green innovation risk identification established in Section 3, the hierarchical structure of green innovation risk identification of the manufacturing industry in China under the GVC can be constructed. In view of the overall risk, 15 experts were invited from Chinese manufacturing enterprises and seven government departments to form a risk assessment group. Enterprise experts are from the green product R&D department, green process R&D department, green manufacturing department, green marketing department, green service department, and green management department. Government experts are from the green government administration. Expert opinions were solicited through questionnaires and in-depth interviews with experts in the risk assessment team. Finally, the green innovation risk judgment matrix of the manufacturing industry in China under the GVC is obtained as follows:

$$W_C = \begin{bmatrix} 1.000 & 1.254 & 1.763 & 1.143 \\ & 1.000 & 1.267 & 1.326 \\ & & 1.000 & 1.824 \\ & & & 1.000 \end{bmatrix}. \quad (14)$$

The weight of the four criteria layers is  $(0.310, 0.265, 0.234, 0.191)^T$ . A consistency test was carried out, and there were  $CI = 0.032$ ,  $RI = 0.900$ , and  $CR = 0.036 < 0.1000$ . At this time, the judgment matrix

met the consistency requirement. Similarly, the discriminant matrix of the criterion of the element layer was obtained, as shown below.

$$W_{C_1} = \begin{bmatrix} 1.000 & 1.164 & 1.442 & 1.293 & 1.314 & 1.508 \\ & 1.000 & 1.541 & 1.295 & 0.864 & 1.523 \\ & & 1.000 & 1.268 & 1.986 & 0.863 \\ & & & 1.000 & 0.873 & 0.764 \\ & & & & 1.000 & 1.206 \\ & & & & & 1.000 \end{bmatrix} \quad (15)$$

The weight of six criteria in the global green R&D risk factor layer is  $(0.210, 0.189, 0.164, 0.136, 0.152, 0.149)^T$ . A consistency test was carried out, and there were  $CI = 0.099$ ,  $CR = 0.080 < 0.1000$ , and  $RI = 1.240$ . At this time, the judgment matrix met the consistency requirement. Similarly, the discriminant matrix of the criterion of the element layer was obtained, as shown below.

$$W_{C_2} = \begin{bmatrix} 1.000 & 1.365 & 1.268 & 1.496 & 0.986 & 1.378 & 1.164 \\ & 1.000 & 1.697 & 0.533 & 1.362 & 0.856 & 1.863 \\ & & 1.000 & 1.499 & 1.893 & 1.531 & 1.267 \\ & & & 1.000 & 0.994 & 1.069 & 1.329 \\ & & & & 1.000 & 1.394 & 0.867 \\ & & & & & 1.000 & 0.772 \\ & & & & & & 1.000 \end{bmatrix} \quad (16)$$

The weight of seven criteria in the global green manufacturing risk factor layer is  $(0.173, 0.149, 0.162, 0.145, 0.127, 0.119, 0.125)^T$ . A consistency test was carried out, and there were  $CI = 0.048$ ,  $RI = 1.320$ , and  $CR = 0.036 < 0.1000$ . At this time, the judgment matrix met the consistency requirement. Similarly, the discriminant matrix of the criterion of the element layer was obtained, as shown below.

$$W_{C_3} = \begin{bmatrix} 1.000 & 1.136 & 1.063 & 0.987 & 1.238 & 1.493 & 0.983 \\ & 1.000 & 1.261 & 1.037 & 1.069 & 1.364 & 0.861 \\ & & 1.000 & 1.068 & 1.392 & 0.867 & 1.033 \\ & & & 1.000 & 1.081 & 0.976 & 1.284 \\ & & & & 1.000 & 1.266 & 0.862 \\ & & & & & 1.000 & 0.871 \\ & & & & & & 1.000 \end{bmatrix} \quad (17)$$

The weight of seven criteria in the global green marketing risk factor layer is  $(0.159, 0.150, 0.142, 0.147, 0.131, 0.125, 0.146)^T$ . A consistency test was carried out, and there were  $CI = 0.010$ ,  $RI = 1.320$ , and  $CR = 0.008 < 0.1000$ . At this time, the judgment matrix met the consistency requirement. Similarly, the discriminant matrix of the criterion of the element layer was obtained, as shown below.

$$W_{C_4} = \begin{bmatrix} 1.000 & 1.134 & 1.196 & 1.213 & 1.284 \\ & 1.000 & 1.157 & 1.095 & 1.186 \\ & & 1.000 & 1.207 & 0.834 \\ & & & 1.000 & 0.715 \\ & & & & 1.000 \end{bmatrix} \quad (18)$$

The weight of five criteria in the global green service risk factor layer is  $(0.231, 0.210, 0.187, 0.169, 0.203)^T$ . A consistency test was carried out, and there were  $CI = 0.005$ ,  $RI = 1.120$ , and  $CR = 0.004 < 0.1000$ . At this time, the judgment matrix met the consistency requirement.



According to the weights of the criteria layer to the target layer, the criteria layer of green innovation risk identification was divided under the GVC. The combination weight of the criterion of the element layer to the target layer was obtained, as shown in Table 4.

**Table 4.** The hierarchy weights and combined weights.

$W_{C_1} = 0.310$	$C_{11}$	$C_{12}$	$C_{13}$	$C_{14}$	$C_{15}$	$C_{16}$	
Hierarchy weights	0.210	0.189	0.164	0.136	0.152	0.149	
Combination weights	0.065	0.059	0.051	0.042	0.047	0.046	
$W_{C_2} = 0.265$	$C_{21}$	$C_{22}$	$C_{23}$	$C_{24}$	$C_{25}$	$C_{26}$	$C_{27}$
Hierarchy weights	0.173	0.149	0.162	0.145	0.127	0.119	0.125
Combination weights	0.046	0.039	0.043	0.038	0.034	0.032	0.033
$W_{C_3} = 0.234$	$C_{31}$	$C_{32}$	$C_{33}$	$C_{34}$	$C_{35}$	$C_{36}$	$C_{37}$
Hierarchy weights	0.159	0.150	0.142	0.147	0.131	0.125	0.146
Combination weights	0.037	0.035	0.033	0.034	0.031	0.029	0.034
$W_{C_4} = 0.191$	$C_{41}$	$C_{42}$	$C_{43}$	$C_{44}$	$C_{45}$		
Hierarchy weights	0.231	0.210	0.187	0.169	0.203		
Combination weights	0.044	0.040	0.036	0.032	0.039		

### 5.2. Determination Value of Identification Criteria

The first level criterion set is  $C = \{C_1, C_2, C_3, C_4\}$  derived from the established criteria system of green innovation risk identification of the manufacturing industry under the GVC. The second level criterion set is  $C_1 = \{C_{11}, C_{12}, \dots, C_{16}\}$ ,  $C_2 = \{C_{21}, C_{22}, \dots, C_{27}\}$ ,  $C_3 = \{C_{31}, C_{32}, \dots, C_{37}\}$ , and  $C_4 = \{C_{41}, C_{42}, \dots, C_{45}\}$ . Level 7 resume comment set, namely {Very low risk, Low risk, Medium low risk, Medium risk, Medium high risk, High risk, Very high risk}, was selected as a fuzzy language set in this study.

(i). Data acquisition of qualitative criteria. Fifteen experts were invited to identify green innovation risk identification based on the criteria system. In order to effectively and fully obtain the data of the green innovation risk in the manufacturing industry, experts were invited from manufacturing enterprises, industry associations, and relevant government departments. A total of 15 experts formed a risk assessment team to further investigate the risks of green innovation. The enterprise experts are from the green product R&D department, the green product manufacturing department, the green product marketing department, the green product service department, and the green product management department. Industry alliance experts come from different sub-industry alliance managers, and government experts come from green government and green management departments. The language variable of these experts was converted into the corresponding TFN. In the green innovation risk identification system, the relationship between TFN and expert language was established.

(ii). Data acquisition of quantitative criteria. Quantitative data are from the 2016–2018 China industrial economic statistical yearbook, China statistical yearbook, China environment statistical yearbook, China energy statistical yearbook, China industrial economic statistical yearbook, China statistical yearbook of science and technology, industrial enterprise science and technology activity statistics/yearbook, China economic census yearbook, human resources and social security development statistical bulletin and related database website, such as the national bureau of statistics and the state intellectual property office.

### 5.3. Process of Risk Identification

In order to effectively obtain the identification value, quantitative criteria and qualitative criteria are combined in this paper. The acquisition of criterion data combined with the overall risk of green innovation in the manufacturing industry in China, and a panel of 15 experts from green product R&D departments of the manufacturing industry and green management departments of the government carried out qualitative evaluation activities. Then, the data after standardized processing

were determined through a comprehensive evaluation of fuzzy processing based on the attribute recognition theory.

(i). The fuzzy identification matrix of green R&D risk, green manufacturing risk, green marketing risk, and green service risk in global manufacturing green innovation risk from 2015 to 2017 was converted into a real number identification matrix.

(ii). The comprehensive evaluation value of green R&D risk, green manufacturing risk, green marketing risk, and green service risk in global manufacturing green innovation risk from 2015 to 2017 was calculated, and the result of this calculation is shown in Supplementary Material 3.

(iii). The time weights of green R&D risk, green manufacturing risk, green marketing risk, and green service risk in global manufacturing green innovation risk from 2015 to 2017 were calculated. Time degree is set to be 0.3, and the subjective and objective time weight is set to be 0.6. Lingo software was used to solve the nonlinear programming model to obtain the combined time weight. The calculated time weight result is as follows:

$$w_t = (0.18315, 0.23370, 0.58315).$$

(iv). The risk identification values of green R&D risk, green manufacturing risk, green marketing risk, and green service risk in global manufacturing green innovation risk from 2015 to 2017 were calculated. The weight calculated by the spread maximization method is  $w_{tjC_j} (t = 1, 2, 3; j = 1, 2, \dots, 15)$ , and the risk identification values of green R&D risk, green manufacturing risk, green marketing risk, and green service risk from 2015 to 2017 are as follows:

$$\begin{aligned} \overline{V}_{11} &= w_{1jC_1} \otimes V_{11} = \left[ 0.6167, 0.5211, 0.5522, 0.5200, 0.5000, 0.5722 \right]^T \\ \overline{V}_{12} &= w_{2jC_1} \otimes V_{12} = \left[ 0.6111, 0.6167, 0.5978, 0.4922, 0.3978, 0.6444 \right]^T \\ \overline{V}_{13} &= w_{3jC_1} \otimes V_{13} = \left[ 0.6233, 0.5711, 0.4811, 0.6167, 0.4434, 0.7355 \right]^T \\ \overline{V}_{21} &= w_{1jC_2} \otimes V_{21} = \left[ 0.4878, 0.4822, 0.6422, 0.6467, 0.5200, 0.5067, 0.5722 \right]^T \\ \overline{V}_{22} &= w_{2jC_2} \otimes V_{22} = \left[ 0.5844, 0.6733, 0.6100, 0.4922, 0.5967, 0.4944, 0.6444 \right]^T \\ \overline{V}_{23} &= w_{3jC_2} \otimes V_{23} = \left[ 0.5856, 0.6089, 0.4989, 0.5578, 0.4944, 0.7089, 0.6033 \right]^T \\ \overline{V}_{31} &= w_{1jC_3} \otimes V_{31} = \left[ 0.5656, 0.6544, 0.7889, 0.6678, 0.5333, 0.5067, 0.6689 \right]^T \\ \overline{V}_{32} &= w_{2jC_3} \otimes V_{32} = \left[ 0.5322, 0.6989, 0.7400, 0.6600, 0.5767, 0.5911, 0.7333 \right]^T \\ \overline{V}_{33} &= w_{3jC_3} \otimes V_{33} = \left[ 0.6111, 0.6355, 0.6289, 0.6422, 0.5589, 0.7155, 0.7255 \right]^T \\ \overline{V}_{41} &= w_{1jC_4} \otimes V_{41} = \left[ 0.6044, 0.6689, 0.6933, 0.6355, 0.5833 \right]^T \\ \overline{V}_{42} &= w_{2jC_4} \otimes V_{42} = \left[ 0.6433, 0.6933, 0.5989, 0.6344, 0.5522 \right]^T \\ \overline{V}_{43} &= w_{3jC_4} \otimes V_{43} = \left[ 0.6355, 0.6989, 0.6333, 0.6678, 0.5656 \right]^T \end{aligned}$$

The subjective and objective time weighting method is used to calculate the comprehensive identification values of green R&D risk, green manufacturing risk, green marketing risk, and green service risk from 2015 to 2017, as shown in Table 5.

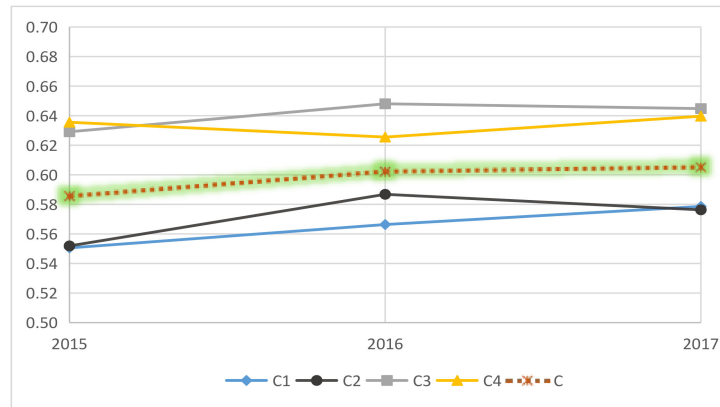
**Table 5.** The overall level of green innovation risk from 2015 to 2017.

	C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	C <sub>4</sub>	C
V <sub>T1</sub>	0.5505	0.5519	0.6291	0.6356	0.5855
V <sub>T2</sub>	0.5664	0.5868	0.6480	0.6255	0.6022
V <sub>T3</sub>	0.5786	0.5763	0.6448	0.6397	0.6051
CV	0.5706	0.5743	0.6427	0.6356	0.6009
W <sub>Ci</sub>	0.3100	0.2650	0.2340	0.1910	1.0000

## 6. Results and Discussion

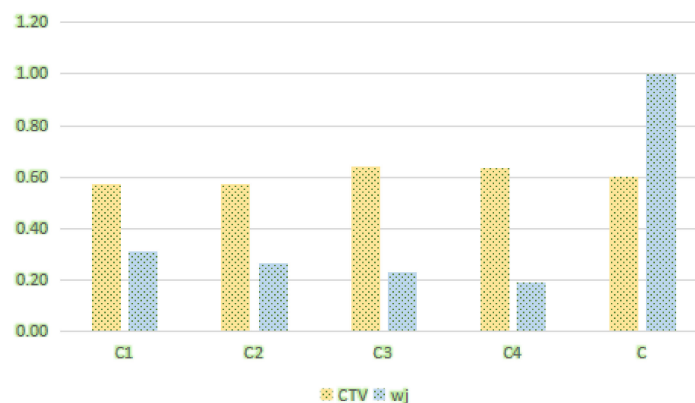
### 6.1. Analysis of Green Innovation Risk

According to the empirical study in Section 5, the dynamic changes of green innovation risk in the manufacturing industry from 2015 to 2017 can be expressed as shown in Figure 2.



**Figure 2.** The dynamic changes of green innovation risk in the manufacturing industry from 2015 to 2017.

Figure 2 shows the dynamic change process of green R&D risk, green manufacturing risk, green marketing risk, and green service risk in the manufacturing industry from 2015 to 2017. From 2015 to 2017, green R&D risk and green service risk showed a rising trend. The difference in the green R&D risk was higher than the 0.2 level, and the risk level of green R&D in 2017 was 0.5786. The difference in green service risk is close to 0. The risk level of green service in 2017 was 0.6397. The green manufacturing risk and green marketing risk first increased and then decreased. The difference in green manufacturing risk was higher than the 0.2 level, and the green manufacturing risk level in 2016 was 0.5868. The difference in green marketing risk was close to 0.2, and the risk level of green R&D in 2017 was 0.6448. Therefore, it can be seen from Figure 3 that the risk levels of green R&D and green manufacturing in the past three years were equal. The green marketing risk level was high, and the green manufacturing risk level was low. In addition, among the four stages of green innovation, green marketing was the highest risk, followed by green service risk, and green R&D and green manufacturing was the lowest risk. From 2015 to 2017, green innovation risk in the manufacturing industry showed a rising trend. In 2017, the green innovation risk was higher than 0.6, which was on the high side.



**Figure 3.** The comprehensive level of green innovation risk in the manufacturing industry in three years.

According to the empirical study in Section 5, the comprehensive identification values of green R&D risk, green manufacturing risk, green marketing risk, and green service risk in global manufacturing green innovation risk from 2015 to 2017 can be expressed as shown in Figure 3.

Figure 3 shows the comprehensive level of green R&D risk, green manufacturing risk, green marketing risk, and green service risk. The yellow graph shows the level of green risk, and the blue graph shows the level of criteria weight. The weights of green R&D risk, green manufacturing risk, green marketing risk, and green service risk were 0.3100, 0.2650, 0.2340, and 0.1910, respectively, which showed a state of decline. By comparing the weights, it is found that the weights in the target layer decreased successively. In the process of green innovation, the more information manufacturing enterprises know, the uncertainty of green innovation will gradually decrease. The overall level of green marketing risk and green service risk was higher than 0.6, and the green R&D risk and green manufacturing risk were higher than 0.5. Green R&D risk is the key to green innovation risk in the manufacturing industry, which has an important impact on the risk level of three successive stages.

### 6.2. Analysis of Green R&D Risk

According to the empirical study in Section 5, the dynamic change value and comprehensive level of green R&D risk in global manufacturing green innovation risk from 2015 to 2017 can be expressed as shown in Figures 4 and 5, respectively.

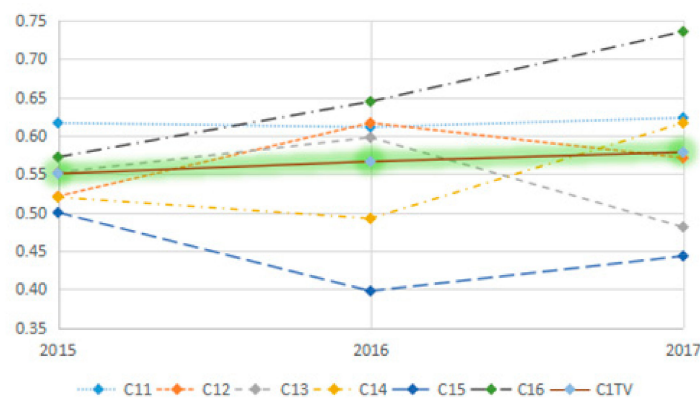


Figure 4. The dynamic changes of green R&D risk in the manufacturing industry from 2015 to 2017.

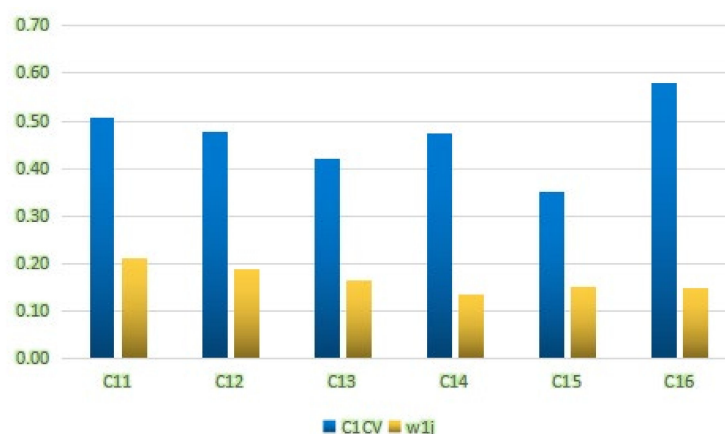


Figure 5. The comprehensive level of green R&D risk in the manufacturing industry in three years.

Figure 4 shows the dynamic change process of green R&D risk in the manufacturing industry from 2015 to 2017. From 2015 to 2017, global green R&D personnel investment, global green R&D capital investment, stability of green technology application, and international protection of green technology patents showed a rising trend. The difference in international protection intensity of green

technology patents was higher than 0.15, and the risk level was 0.7355. The proportion of green R&D personnel and the stability risk level of green technology applications in the manufacturing industry were both higher than 0.6. The stability of global green R&D and the ease of international transfer of green technology showed a trend of first increasing and then decreasing. These two risks were below the 0.5 level. Therefore, as can be seen from Figure 4, the risk level of green R&D in the past three years was slowly rising. However, the overall level of green R&D was lower than 0.6, which was at the medium and high end. Figure 5 shows the comprehensive level of green R&D risk in three years. The weight of green R&D risk criteria generally showed a decreasing state. In the process of green R&D, the investment proportion of green R&D personnel in the manufacturing industry played a key role, which exceeded the 0.2 level. In addition, the proportion of green R&D capital invested and the stability of green technology R&D played a secondary role, with both risk criteria higher than 0.15. The stability of global green technology applications, the ease of international transfer of green technology, and the international protection of green technology patents in the manufacturing industry were at a low level.

The personnel and funds played a fundamental role in guaranteeing green innovation activities of the manufacturing industry. The uncertainty of green technology and the risk level of international protection of green patents reflected the lack of R&D power of the manufacturing industry. Although some international conventions have provided legal protection for intellectual property rights, there are still some laws in the international market that do not restrict the infringement of intellectual property rights sufficiently. The life cycle uncertainty of global green R&D and the difficulty of international transfer of green technology were moderately low, while the possibility of global green R&D was very low. Green technology is still an emerging technology with low substitutability, and green technology transfer has not yet formed a scale.

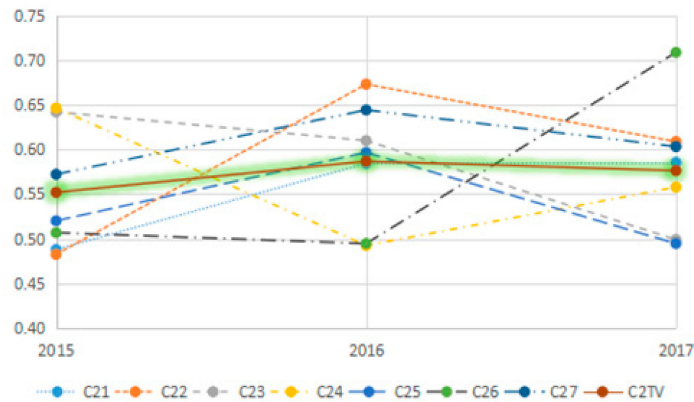
### 6.3. Analysis of Green Manufacturing Risk

According to the empirical study in Section 5, the dynamic change value and comprehensive level of green manufacturing risk in global manufacturing green innovation risk from 2015 to 2017 can be expressed as shown in Figures 6 and 7, respectively.

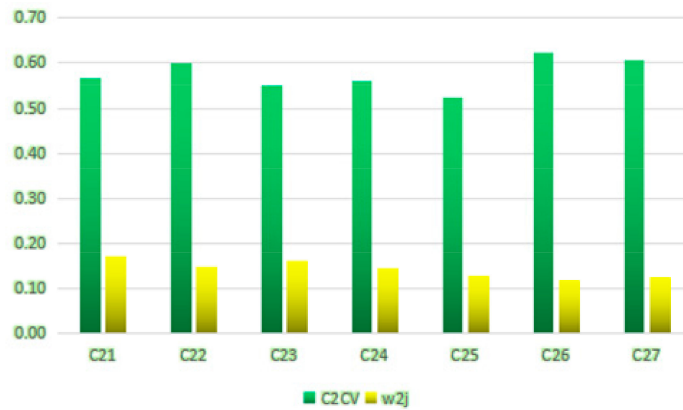
Figure 6 shows the dynamic change process of green manufacturing risk in the manufacturing industry from 2015 to 2017. From 2015 to 2017, the proportion of green manufacturing personnel input, capital input, technical transformation degree, and cost increase showed a rising trend. The difference in global green manufacturing technology transformation degree was higher than the 0.2 level, and the risk level was 0.7089. The global green manufacturing capital investment and cost increase were both higher than 0.6. The global quality and performance level of green manufacturing products was lower than 0.6. The global production scale and the global outsourcing scale of green manufacturing products showed a trend of first increasing and then decreasing. These two risks were below the 0.5 level. Therefore, it can be seen from Figure 6 that the risk level of green manufacturing in the recent three years increased first and then declined slowly. However, the overall level of green manufacturing was lower than 0.6. Figure 7 shows the overall level of green manufacturing risk in the past three years. The weight of the green manufacturing risk criteria was generally decreasing. The proportion of green manufacturing personnel played a key role, which exceeded the 0.15 level. In addition, global green manufacturing capital investment and product production scale played a secondary role, which was at the level of 0.15. The performance level of green manufacturing products, the scale of global outsourcing, the degree of technological transformation, and the increase in costs were at a low level.

Global green manufacturing risk was relatively low. The investment of personnel and capital still occupied a key position in both weight and grade, which was a key factor affecting green manufacturing. The production of green products requires higher requirements on the original equipment and raw materials to adapt to the production of green new products. The production scale of green products, the degree of technical performance requirements for raw materials, global outsourcing, and international OEM scale risk levels were below medium. Green technology, as an

emerging technology, is still in the development stage and not mature enough. Therefore, if a higher production scale cannot be achieved, the risk will be smaller.



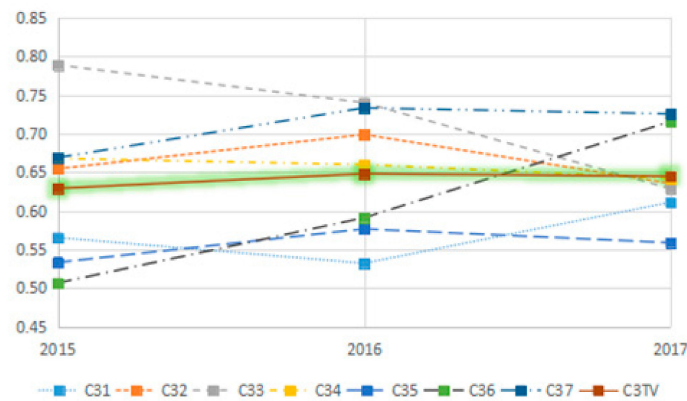
**Figure 6.** The dynamic changes of green manufacturing risk in the manufacturing industry from 2015 to 2017.



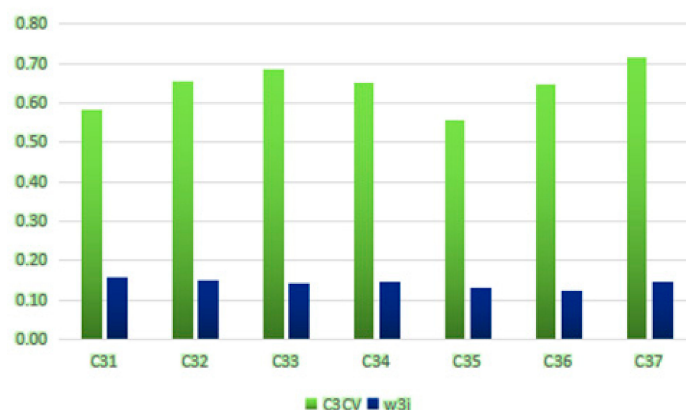
**Figure 7.** The comprehensive level of green manufacturing risk in the manufacturing industry in three years.

6.4. Analysis of Green Marketing Risk

According to the empirical study in Section 5, the dynamic change value and comprehensive level of green marketing risk in global manufacturing green innovation risk from 2015 to 2017 can be expressed as shown in Figures 8 and 9, respectively.



**Figure 8.** The dynamic changes of green marketing risk in the manufacturing industry from 2015 to 2017.



**Figure 9.** The comprehensive level of green marketing risk in the manufacturing industry in three years.

Figure 8 shows the dynamic change process of green marketing risk in the manufacturing industry from 2015 to 2017. From 2015 to 2017, the proportion of green marketing personnel, the share of international marketing channels, the level of commercialization and internationalization, and the intensity of green technical barriers to trade in the international community showed a rising trend. The difference between the commercialization level and internationalization level in the manufacturing industry was higher than the 0.2 level, and the risk level was 0.7155. The proportion of green marketing personnel and the intensity of green technical barriers to trade were both higher than 0.6. The share of international marketing channels for green products was lower than 0.6. The proportion of green marketing funds, the level of international demand, and the intensity of international competition showed a trend of first increasing and then decreasing. Both of these risks were higher than 0.6. Therefore, it can be seen from Figure 8 that the risk level of green marketing in the recent three years increased first and then declined slowly. However, the overall level was higher than 0.6. Figure 9 shows the comprehensive levels of green marketing risk over three years. The weight of the green marketing risk criterion is generally decreasing. The proportion of green marketing personnel and capital investment played a key role, which exceeded the 0.15 level. In addition, the risk level of international demand, the intensity of international competition, and the intensity of green technical barriers were between 0.14 and 0.15.

Marketing risks were second only to R&D risk. The scale of personnel and financial input, the degree of international market competition, and the risk of green technical barriers to trade were at a high side. The green product market is an emerging market, which poses a great threat to the sales of green products. Green product recognition, international market share, and green technology commercialization, internationalization level risk levels were general. The international marketing channel occupancy risk was medium to lower, and the green product demand level risk was very low.

### 6.5. Analysis of Green Service Risk

According to the empirical study in Section 5, the dynamic change value and comprehensive level of green service risk in global manufacturing green innovation risk from 2015 to 2017 can be expressed as shown in Figures 10 and 11, respectively.

Figure 10 shows the dynamic change process of green marketing risk in the manufacturing industry from 2015 to 2017. From 2015 to 2017, the proportion of green service personnel and service capital invested, as well as the globalization level of the green supply chain, showed a rising trend. The risk level difference in the above three aspects was at 0.03 levels, and the risk level was higher than 0.6355. Global green service network coverage and global after-sales technical service capacity showed a trend of first increasing and then decreasing. The global green service network coverage was higher than 0.6. The global after-sales technical service capacity of green products was lower than 0.6. Therefore, it can be seen from Figure 10 that the risk level of green service in the recent three years decreased first and then slowly increased. However, the overall level was higher than 0.6. Figure 11

shows the comprehensive level of green service risk in three years. The weight of the green service risk criterion is generally decreasing. The proportion of green service personnel in the manufacturing industry played a key role, which exceeded 0.23. In addition, the proportion of the global green service capital invested and the global after-sales technical service capacity played a secondary role. These risk indicators were above the 0.2 level. The global green service network coverage of the manufacturing industry and the globalization of the supply chain were at a low level.

The green service risk was only higher than the green manufacturing risk. The key to maintain and expand market shares is that service personnel can bring value extension of products to consumers and affect consumer satisfaction. Adequate service funds not only provide strong support for green product services but also improve service quality and efficiency. Under the premise of homogeneous products, consumers prefer green products that can provide high-quality services.

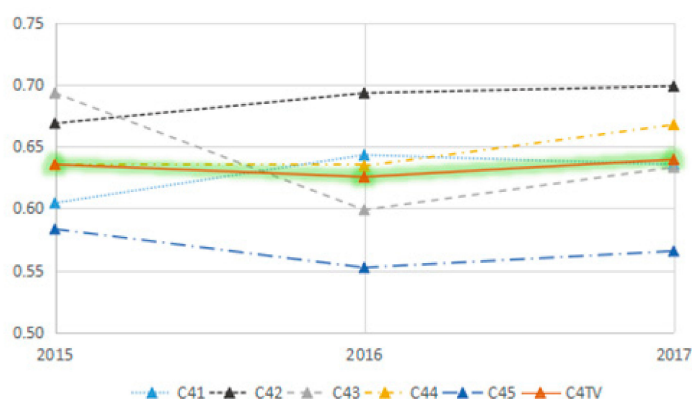


Figure 10. The dynamic changes of green service risk in the manufacturing industry from 2015 to 2017.

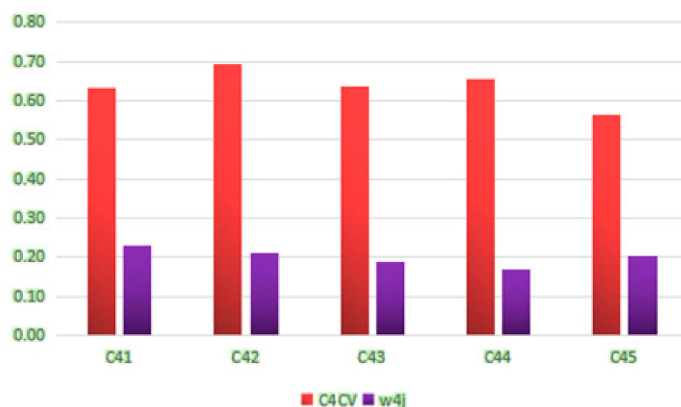


Figure 11. The comprehensive level of green service risk in the manufacturing industry over three years.

### 7. Response to Green Innovation Risk

The response to green innovation risk in the manufacturing industry is a circular and progressive process in which measures to change risk are selected based on risk identification. According to the risk management framework given by COSO [73], risk aversion, risk reduction, risk diversification, and risk acceptance were used in this study to analyze responses to green innovation risks in the manufacturing industry.

#### 7.1. Response Way to Green Innovation Risk

**Risk aversion** is a method to completely avoid losses by stopping or withdrawing from activities that lead to green innovation risk. In the process of green innovation, if a risk factor is very likely to occur, the risk can be avoided by actively abandoning or stopping the activity [54]. For example, consumers in a given country have low demand and awareness of green products, and this means



that the green products produced will be slow to sell and have high risk, which can be avoided by refusing to expand into the local market [54–56]. Risk aversion completely reduces the possibility of loss to 0 before the occurrence of a risk event. However, it should be pointed out that risk aversion is a relatively negative coping method.

**Risk transfer** is a method to transfer risk to others through insurance or legal subcontracting to reduce the consequences of losses [61]. Generally, it is applicable for risk factors with relatively serious loss and low occurrence probability. Under the GVC, green innovation risk transfer generally includes three ways [55–61]. (i). Contract transfer. By contracting with others, innovation activities that may have serious loss consequences are transferred to a third party. Typically, contracts for creative development, manufacturing, or marketing services are concluded. (ii). Joint investment. Joint investment is an important channel to obtain the capital of innovative projects and can increase the risk allocation subject caused by the increase of huge capital investment. (iii). Insurance transfer. Through insurance transfer, the insurance company is regarded as the sharing subject of innovation risk, and the risk cost is minimized on the premise of guaranteeing innovation benefits. However, while risk can be shared by the third party, the third party should also share the benefits with the manufacturing industry.

**Risk reduction** means that the loss consequence or probability of green innovation under the GVC can be reduced by taking effective measures [63]. Diversification of investment subjects is the most important form to minimize risk and is under the dual background of the vigorous development of the Internet. Global green innovation subjects can achieve diversification of capital investment subjects by absorbing social capital [59]. In this way, the risk of green innovation can not only be transferred to the majority of investors, but also the anti-risk ability of green innovation subjects can be improved by relying on social capital as far as possible. In order to strengthen the overall anti-risk ability, the purpose of reducing green innovation risk is achieved through the business philosophy of “not putting all eggs in one basket” [70].

**Risk acceptance** is a kind of active response or just monitoring risk to the possible loss consequences, including active acceptance and passive acceptance [54–57]. If steps are taken to minimize or eliminate risk, this is positive acceptance at an early stage of development. However, it is passive to take measures after the risk event has been formed. If the result of loss is within the scope that the innovation subject can bear, it will be included in the operating cost of the enterprise [56]. Risk acceptance is also a way to deal with residual risk after green innovation risk response. If a certain risk cannot be transferred to a third party, and the cost of taking such measures is higher than the actual loss caused by the occurrence of the risk, then only the way of risk acceptance can be adopted.

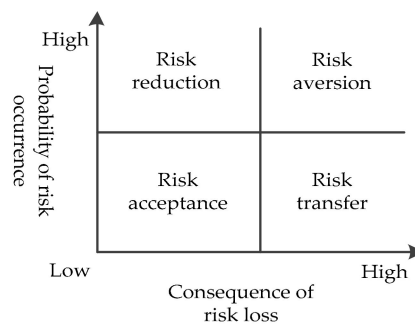
## 7.2. Response Procedure to Green Innovation Risk

The response procedure to green innovation risk is the process of choosing a risk response mode, which is usually considered from three aspects of response cost, risk possibility, and impact effect. Based on the above three factors, this paper designed the risk response program to obtain the optimal risk response strategies. The purpose of green innovation risk management is to reduce the adverse impact of risk on maximized profits [56–59]. If the cost of risk reduction is higher than the benefit of risk reduction, the innovative enterprise will lose more than it gains. Therefore, the response measures to green innovation risk should balance the costs and benefits, which can be calculated by the following formula.

$$\xi = \frac{\text{Cost of risk response}}{\text{Benefits of risk response}} \quad (19)$$

where  $\xi$  is the cost imbalance factor, which is used to measure whether the costs and benefits are out of balance. When  $\xi < 1$ , it means that the benefit of changing risk strategy is higher than the cost, and it is reasonable to apply risk countermeasures. When  $\xi \geq 1$ , it means that the benefit of changing the risk strategy is lower than the cost, and taking risk countermeasures are not worth the loss, so countermeasures should not be chosen. The purpose of risk response is to reduce the probability of

green innovation risk occurrence or influence degree, or both. According to the position of risk in the matrix, appropriate strategies can be determined from the four risk responses, as shown in Figure 12.



**Figure 12.** The risk response mode selection matrix.

According to the PC two-dimensional matrix, the risk response cost level and risk level are comprehensively considered, and the risk response program is given, as shown in Figure 13. The selection process of risk response mode is as follows: The probability and severity are judged according to the specific situation of the current risk. If the probability is high and the impact is large, then risk aversion is more appropriate. In addition, considering the cost of risk aversion, it is appropriate to choose risk aversion when the cost of avoidance is lower than the cost of acceptance. Otherwise, proceed to the next step and choose the remaining way to deal with green innovation risk. The probability of risk occurrence is small, but the impact is serious, and the acceptance cost is higher than the dispersed cost. The way of risk dispersion is applicable in this case, such as transferring risk to third parties through cooperation. If the risk occurrence probability is high, but the impact is not deep. And if the acceptance cost is higher than the reduction, then it is suitable for the risk reduction response. The probability of risk occurrence is small, and the influence is not deep. It is also possible that there is no other way to change the existing risk. The way to accept risk is applicable in this case, and the enterprise is fully capable of reducing risk by its own strength. The result of risk management is not to eliminate risk completely. In addition, risk management does not respond to risk in a single way. The manufacturing industry should make a timely assessment of the new risk arising from green innovation activities and choose the risk response mode. At the same time, appropriate measures should be taken to control risk within the limits of the manufacturing industry.

The selection process of green innovation risk response is explained as follows: (i). If the possibility of risk occurrence is high and the consequences are serious, the method of avoidance should be given priority, and the cost of risk avoidance should be considered at the same time. If the cost of risk aversion is lower than the cost of risk acceptance, the method of risk aversion is adopted directly. If it is unable to avoid or the cost of avoiding is high, then it will move to the next step and deal with it by means of risk sharing, reduction, or acceptance. (ii). For the risk with serious consequences, less likely to occur, and the risk sharing cost is less than the risk acceptance cost, the power of the "third party" should be used. By way of risk sharing, the risk is transferred to other subjects. (iii). If the possibility of risk occurrence is high and the consequences are not serious, and the cost of taking measures to reduce the risk is less than the cost of risk acceptance, then one can use its own ability to reduce the risk. (iv). For risk factors that are less likely to occur, have less serious consequences, or cannot be dealt with in other ways, risk acceptance is adopted. (v). After adopting a certain risk response, there will be residual green innovation risk. At the same time, in the process of risk response, there may be new green innovation risks. This requires reassessing the likelihood and severity of the consequences of each risk factor and repeating the process until the risk of green innovation is reduced to an acceptable level for the innovation body.

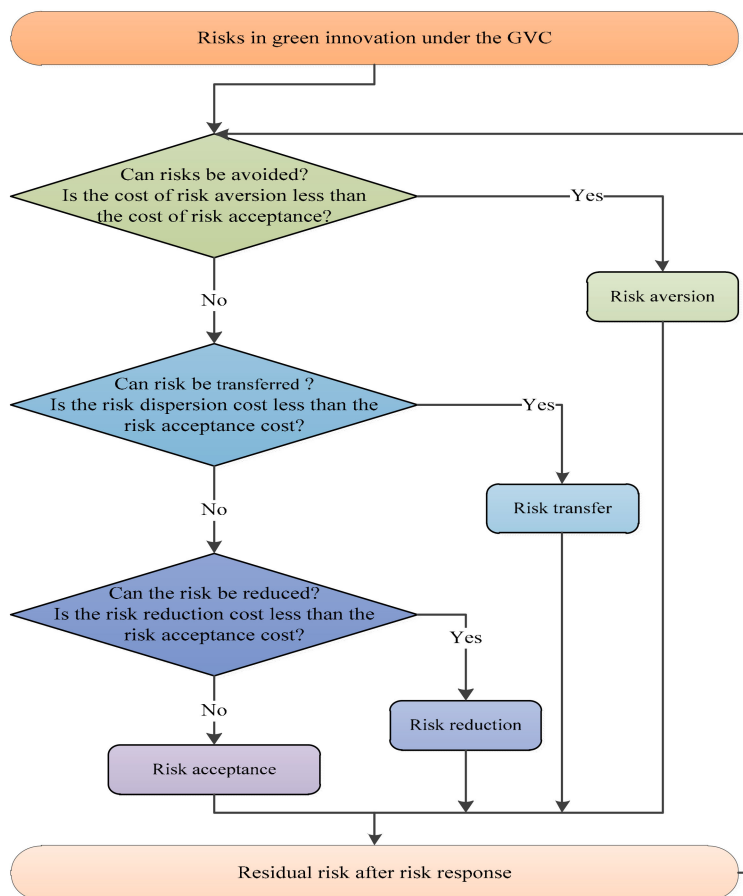


Figure 13. The risk response process of green innovation in the manufacturing industry under the GVC.

### 7.3. Response Strategy to Green Innovation Risk

In the process of green innovation, different risks have different severity of consequences, and the cost of reducing the risk or the benefit gained from risk is also different. In practice, decision makers often choose a certain response mode or combine several ways to deal with risk in the process of green innovation according to the actual situation, including the possibility of risk occurrence, severity of consequences, risk tolerance, and risk preference. As the main body of green innovation, the manufacturing industry directly bears the risk of green innovation [82]. As the risk faced by different manufacturing industries are different, and the risk tolerance and risk preference of the manufacturing industry are different. This makes it difficult to formulate risk response strategies applicable to all enterprises in the whole industry, and it is also difficult to accurately describe the best risk response methods. Therefore, this paper formulated directional risk response strategies for the risk factors of the manufacturing industry in China under the GVC for reference based on the multi-causality theory. In practice, manufacturing enterprises should make adjustments according to their actual conditions and choose the most suitable way to deal with the risk of green innovation under the GVC. Based on the identification results of each risk factor and the PC matrix for the response mode, the selection scheme of green innovation risk response strategies for the manufacturing industry in China under the GVC was developed, as shown in Table 6.

**Table 6.** Response strategy to green innovation risk in the manufacturing industry under the GVC.

Risk Categories	Risk Factors	Response Strategy to Green Innovation Risk			
		Risk Aversion	Risk Transfer	Risk Reduction	Risk Acceptance
Global green R&D risk	Green R&D personnel factor		○	○	
	Green R&D funding factor		○		
	Green technology R&D factor	○	○	○	
	Green technology application factor			○	
	International transfer of green technology factor		○		
	International protection factors for green technology patents factor	○		○	
Global green manufacturing risk	Green manufacturing personnel factor		○		
	Green manufacturing capital factor		○		
	Green manufacturing product production factor		○		
	Green manufacturing product quality factor		○	○	
	Global outsourcing of green products factor			○	
	Green manufacturing technology transformation factor		○		
Global green marketing risk	Green manufacturing cost factor	○		○	○
	The green marketer factor		○		
	Green marketing funding factor		○		
	International demand for green products factor	○		○	
	Green product international competition factor			○	
	Green product international marketing channel factor		○	○	
	The commercialization and internationalization of green technology factor		○		
Global green service risk	International community green technical trade factor	○	○		
	Green service personnel factor		○		
	Green service funding factor		○		
	Green service point factor		○	○	
	Globalization of green product supply chain factor		○	○	
	Green product global after-sales service factor			○	

Note: “○” means the corresponding measures for green innovation risk factors under the GVC.

## 8. Conclusions and Future Research

For a long time, climate change has attracted the attention of the world, and its severity has put great pressure on the survival and economic activities of all mankind. Countries around the world are taking measures to reduce carbon emissions and combat global warming. The use of innovative green products has become one of the important ways and has been widely concerned. GVC is a key opportunity for green development of the manufacturing industry. The manufacturing industry in China can only fix the bottom end of the GVC and is passively dominated by developed countries due to the development mode of low value-added and high pollution. The overall low level of green technology in the manufacturing industry restricts the creation of value. Only by implementing green innovation can the green value added under the GVC be enhanced. However, the high uncertainty of green innovation makes it a risky activity. Effective risk management can not only reduce the green innovation risk in the manufacturing industry but also ensure the progress of green innovation.

Scientific and systematic management of green innovation risks is the focus of this paper, which has the following achievements: (1) From the perspective of process, combining the green innovation process and the product innovation risk process, the four risks of this paper are divided into global green R&D risk, global green manufacturing risk, global green marketing risk, and global green service risk. Through the comparative analysis of the risk process of several authoritative institutions, the risk management process, risk identification, risk evaluation, and risk response are obtained. Finally, a conceptual model is designed based on the above contents. (2) A literature review method was used to sort out and summarize the literature on the risk of process-based product innovation. Combined

with the research background of the global value chain and the object of green innovation, the risks of this paper were identified. (3) According to the principle of scientific, systematic, maneuverability, and globalization, the risk index evaluation system of this paper is designed on the basis of risk identification. The system contains four primary variables and 25 secondary variables. Then the risk assessment model based on F-AHP is used to calculate the risk level. That is, the risk of green innovation in manufacturing enterprises under the global value chain is above the medium level. In the specific link, the R&D risk, marketing risk, and service risk decrease successively and are in the middle and high risk, while the manufacturing risk is in the middle and low position.

Green innovation risk management in the manufacturing industry has important theoretical and practical significance. In the theoretical sense, although Chinese scholars have long studied global value chains, innovation, and risk management, these theories originated from abroad, and few studies have integrated these theories. The study of green innovation risks in manufacturing enterprises affected by global value chains (GVCS) can provide a new perspective for GVCS, innovation, and risk management theories. At the same time, it is helpful to expand the theoretical scope and lay a foundation for future research. In the practical sense, this study focuses on the global value chain and studies the risk management of green innovation in manufacturing enterprises. Through the analysis of the risk environment, this study identified the risk factors of green product creation in manufacturing enterprises. Furthermore, the risk index system is evaluated to get the risk level. Finally, the coping and control methods are given. This is conducive to the green innovation of the manufacturing industry in China in a timely and comprehensive understanding of the risks faced, and fully grasping the risk situation for the future handling of green innovation risk provides a reference.

Although this paper attempted to carry out innovative research in the field of the green innovation risk management manufacturing industry in China under the GVC, there are still many areas for future research. For example, an organizational system will be further studied to reveal green innovation risk monitoring in the manufacturing industry in China under the GVC, and the operation mode of the risk monitoring system should also be explored in the future. In addition, an artificial intelligence network analysis method can be applied to the research and practice of green innovation risk early warning and prevention.

**Supplementary Materials:** The following are available online at <http://www.mdpi.com/2071-1050/12/2/545/s1>, Supplementary Material 1: Analytic hierarchy process method, Table S1: Saaty's contrast ruler, Table S2. RI values, Supplementary Material 2, Table S3. Notation definition, Supplementary Material 3.

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