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How to Improve the Quality and Speed of Green New Product Development?

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Received: 20 May 2019; Accepted: 10 July 2019; Published: 12 July 2019



Abstract: With the deep integration of supply chain with Internet and Internet of things, it is an important way for enterprises to win market competition and seek sustainable development to develop green new products through external green supply chain integration (GSCI). This study established a unified research framework of external GSCI, knowledge spiral (KS), green new product development (NPD), and top management's environmental awareness (TMEA). Structural equation modeling and analytic hierarchy process are used to explore the mechanism of the established research framework. The research results of this paper are as follows: (i) Green supplier integration (SI) and green consumer integration (CI) have significant positive effects on green NPD speed (GS), green NPD quality (GQ), and KS, and KS has a significant positive effect on GS and GS, respectively. Compared with green CI, green SI has a greater impact on KS, GS, and GQ. In addition, compared with GS, KS has a greater impact on GQ; (ii) KS has a significant partial mediating effect in the relationship between green CI, GS, and GQ. Compared with GS, KS has stronger mediating effect between green CI and GQ. Compared with green SI, the equivalent KS capability is more significant in integrating green customer information; (iii) TMEA has a significant moderating effect on the relationship between KS, and GQ and has no significant moderating effect on the relationship between KS and GS. Future research will analyze the mediating effect of the four dimensions of KS in the relationship between external GSCM and the green NPD speed and green NPD quality.

Keywords: knowledge spiral; green NPD speed; green NPD quality; top management's environmental awareness; green supply chain integration

1. Introduction

The economic activities of human society have caused serious damage to the environment, and environmental problems keep emerging, such as global warming, Antarctic ozone hole, serious land degradation, biodiversity reduction, and so on. It was reported that about 37 million people die each year as a result of environmental degradation [1]. The extensive development mode has not only polluted and damaged the ecological environment, but also restricted the sustainable development of the manufacturing industry [2]. The important problem facing the manufacturing industry at present is how to reduce the consumption of resources and environmental pollution to the greatest extent in the development of the manufacturing industry [2]. The concept of green manufacturing is considered as the inevitable choice for the manufacturing industry to solve the current development dilemma. Green manufacturing is a modern manufacturing model that systematically considers environmental impact and resource efficiency, and its goal is to realize resource optimization and environmental protection [3]. In order to better cope with the change of market environment, the manufacturing industry should rely on the green manufacturing ability to obtain long-term competitive advantage. To fully promote green manufacturing, enterprise must build a green manufacturing system, including the development of green products, green factories, green parks, green supply chains, and green

supervision [4]. There must be systematic green technology innovation in green manufacturing, and one of the key problems to be solved first is how to achieve green innovation.

Green innovation is a booster to promote economic growth and environmental protection. It has played an important role in adjusting the industrial structure and solving prominent environmental problems [5]. Green innovation is the innovation of hardware or software related to green products or green processes, including technological innovation related to energy conservation, pollution prevention, pollution recovery, green product design, and environmental management. Enterprises can create or significantly improve their products quality, marketing methods, organizational structures and institutional arrangements, so as to improve their environment better than their counterparts. Green new product development (NPD) is one of the key links of green innovation [6]. Green NPD is a complex technical and market process, which should strengthen the top-level design and system layout. With the enhancement of citizens' awareness of environmental protection, green products are more and more valued by consumers. On the one hand, under the tide of energy saving and environmental protection, consumers have higher and higher requirements on the performance of energy saving and environmental protection of products. On the other hand, the research and development (R&D) of personalized and diversified green new products has become a challenge for supply chain enterprises [7]. Green NPD can not only bring internal benefits such as technology, cost, and reputation to enterprises, but also improve the ecological environment and create a good living space for the society, thus generating external environmental and social benefits. External cooperation helps manufacturing enterprises reduce the cost and risk of innovation by integrating internal and external technical resources and achieve technological breakthroughs and strategic goals [8]. By cooperating with green suppliers and customers, enterprises can improve the green NPD speed and green NPD quality and the personalized and diversified features of green NPD [9]. With the deep integration of supply chain with Internet and Internet of things, it is an important way for enterprises to comply with the green wave and win market competition to develop green new products through external green supply chain integration (GSCI) [10].

At present, the urgent problem that enterprises need to solve is how to effectively enhance NPD speed and quality through external GSCI. Many scholars acquiesce to the positive role of GSCI in green NPD [11–19]. Many existing studies mainly discussed the influencing factors of green NPD from the following two perspectives. Firstly, many studies on the external environment mainly analyzed the influencing factors of green NPD based on stakeholder theory and institutional theory. Driessen and Hillebrand believed that employees, shareholders, economic institutions and other stakeholders play a major role in the process of green NPD [11]. De Medeiros et al. highlighted that enterprises will actively carry out green NPD activities if they have strong stakeholder integration ability [12]. Weng et al. found that environmental regulations and different stakeholders such as customers, suppliers, and competitors have differentiated impacts on enterprises' green innovation activities [13]. Hence, the pressure from environmental regulation and stakeholders is the main source of external pressure. Secondly, many studies on internal conditions mainly explored the driving mechanism of green innovation activities based on natural resource-based theory. Liao and Cheng proved that enterprise background characteristics such as size, age and industry can affect enterprise environmental innovation [14]. Albort-morant et al. studied from the perspective of internal enterprise and found that internal absorption capacity plays an important driving role in sustainable innovation [15]. Focusing on internal knowledge resources and capabilities, Lin and Chen found that green knowledge sharing can improve green dynamic capabilities, thus promoting enterprises to implement green innovation and gain green competitive advantages [16]. Song et al. believed that internal sources such as environmental leadership, culture, and environmental competence can promote green NPD [17]. Shu et al. highlighted that green management is more likely to lead to fundamental product innovation than incremental product innovation [18]. Tang et al. found that the positive impact of green product development on enterprise performance is compound without considering environmental management concerns [19]. Hence, enterprise background characteristics, resources, capabilities, managers' attention and so on are

the main internal driving forces. Although the above studies have achieved a series of valuable results, many studies on the driving factors of green NPD still have the following shortcomings. First, previous studies focused on examining the direct impact of independent explanatory variables on green NPD and did not consider the comprehensive mechanism of internal and external levels. The formulation of green NPD decisions is influenced by external environmental factors, especially the macro environment and green supply chain environment in which the enterprise is located. This formulation is also constrained by internal resources and green capabilities. The overall analysis of internal and external environmental factors is conducive to the comprehensive understanding of green NPD mechanisms. Second, previous studies only considered managerial attention as an internal factor of organization and ignored the influence of executive awareness on green NPD through its internal driving force. Third, previous studies have mostly used Western developed countries as a sample and lacked research on the driving factors for green NPD for Chinese companies. GSCM is an effective way to solve the conflict between manufacturing and environment from the perspective of system and integration [11]. Accessing knowledge from outside and sharing internal knowledge are processes of knowledge creation that drive product innovation. Green NPD is not only to open up new market share, but also a huge driving force to break the green barriers of market trade [16]. In order to enter a certain market, enterprises must bypass green barriers and develop green new products. Top managers are important personnel, responsible for operation and management and mastering important information, and are the key players in the enterprise's innovation decision-making [18]. From this point of view, some questions need to be further explored. How to improve the performance of green NPD through GSCI? What is the specific path and mechanism of the effects of external GSCI and knowledge spiral (KS) on the speed and quality of green NPD? Whether top management's environmental awareness (TMEA) has a moderation role? How to improve the quality and speed of green NPD?

To compensate for the shortcomings, this study established a unified research framework of external GSCI, KS, green NPD, and TMEA. Structural equation modeling and analytic hierarchy process are used to explore the impact of external GSCI on green NPD and reveal the specific path and mechanism for improving the green NPD speed and green NPD quality. This paper not only explores the mechanism of green supplier integration (SI) and green customer integration (CI) on KS and the mechanism of their impact on the green NPD speed and green NPD quality, but also reveals the mediation role of KS in the relationship between external GSCI and green NPD. Moreover, this paper studies the moderation role of TMEA on the relationship between KS and green NPD.

The rest of this paper is structured as follows. The literature review is presented in Section 2. In Section 3, Method, which includes variable measurements, data collection, and deviation tests, is introduced. Structural equation modeling and analytic hierarchy process are used to analyze the data in Section 4. In Section 5, the analysis of main effect, mediation effect and moderation effect are presented. Finally, conclusions and future research are presented in Section 6.

2. Literature Review

2.1. Theoretical Basis

2.1.1. External Green Supply Chain Integration (GSCI)

Green supply chain management (GSCM) is an effective way to solve the conflict between manufacturing and environment from the perspective of system and integration [20]. Implementing GSCM not only integrates environmental concepts into the whole supply chain management process, but also minimizes the resource consumption and environmental impact of the whole supply chain to achieve sustainable development [21]. With the deep integration of supply chain with Internet and Internet of things, it is an important way for enterprises to comply with the green wave and win market competition to develop green new products through external GSCI [10]. As an important part of GSCM, external GSCI is a modern manufacturing model based on green manufacturing theory and the application of environmental management and integration ideas to external GSCM [18]. Gold et al.

highlighted that inter-organizational environmental management is an important part of GSCM [22]. Büyüközkan and Çifçi evaluated the level of GSCM in terms of cooperation with green suppliers, green product design and product lifecycle management [23]. Wang et al. believed that GSCM includes four subsystems: production system, consumption system, social system and environmental system [24]. By cooperating with green suppliers and customers, enterprises can improve the green NPD speed and green NPD quality and the personalized and diversified features of green NPD [9]. External GSCM is a complex system engineering, and it is necessary to study the system characteristics of external green supply chain, especially integration characteristics [25].

External GSCM includes benefit integration, information integration, process integration and target integration [20–29]. Benefit integration is mainly reflected the following two aspects [26]. (i) Enterprises can maximize resource utilization and reduce resource consumption, thereby reducing or avoiding fines caused by environmental problems; (ii) Enterprises can improve the health of employees and improve work safety, which helps to improve the employee's subjective initiative and work efficiency. Information integration not only involves all the information of general external supply chain management, but also emphasizes that the information related to resource consumption information and environmental impact information should be integrated. Moreover, the information flow, logistics, and energy flow should be integrated organically [27]. Process integration includes not only the entire time from design, manufacture, packaging, transportation, and use to end-of-life, but also the time it takes for components to be reused in multiple generations of product cycles after they are scrapped [28]. Target integration can not only embody the objectives of traditional supply chain management (time, quality, cost, service), but also be as important as the environmental and resource objectives [29]. The targets of external GSCI should include time, quality, cost, service, environment, and resources. These factors are interrelated and constitute an integrated system of external GSCI.

2.1.2. Knowledge Spiral (KS)

From the perspective of knowledge management, an enterprise is actually an organization that acquires, shares, and creates knowledge. Accessing knowledge from outside and sharing internal knowledge are processes of knowledge creation that drive product innovation [30]. In the era of knowledge economy, the essence of product innovation is knowledge innovation characterized by knowledge transformation and KS [31]. Tacit knowledge is unrepresentable and high-value and is an indispensable factor in organizational innovation. The transformation and spiraling between explicit knowledge and tacit knowledge create the uniqueness of product innovation. Nonaka and Takeuchi proposed the SECI model of knowledge innovation, and the concept of KS, namely the knowledge innovation model, was expounded based on the SECI model [32]. KS is divided into four modes [23,24]. Socialization is the process of creating tacit knowledge such as shared mental models and skills, and externalization is the process of creating concepts. Combination is the sum of various concepts, and for the process of knowledge system, knowledge can be further innovated, shared and disseminated. Finally, internalization is the process of internalizing explicit knowledge into individual tacit knowledge base. Through these four processes, KS presents a step-by-step cyclical progression and spiraling of the subordinate subject, which completes the process of knowledge transfer and creation. This process can effectively expand the scope of knowledge of individuals and organizations, thereby slowing down knowledge gaps and using existing knowledge to achieve target knowledge [33].

2.1.3. Green New Product Development (NPD)

Green NPD that is different from traditional end-of-pipe control solves environmental problems through product design and innovation, and has been increasingly valued by consumers, businesses and governments. Green new products have the following three important characteristics: environmental protection, energy conservation, and efficient use of resources [14,15]. In order to manage the green NPD process, we must first understand the driving force of green NPD. The driving force

for green NPD includes not only the driving factors (technology and market) of traditional NPD, but also government, consumers, and society [34]. Due to technological advancement, manufacturing technology is improving in the direction of green energy conservation and environmental protection. The continuous innovation of these green technologies can promote green NPD to cater to the trend of green consumption and seize market opportunities [3,4]. Green NPD is not only to open up new market share, but also a huge driving force to break the green barriers of market trade. In order to enter a certain market, enterprises must bypass green barriers and develop green new products [6–8]. Governments are advocates of sustainable development and supervisors of environmental destruction. The rising green consumption has created more and more market demand for green products, which has become a direct driving force for green technology innovation and green NPD [8].

There are many standards for measuring successful NPD. Griffin and Page divided it into four aspects, namely customer acceptance, business performance, product-level characteristics and enterprise-level characteristics [35]. Product-level features include the speed at which products are marketed, product quality, innovation, and technology content. Garcia et al. believed that the performance of NPD includes four aspects, namely marketing, cost target, time management and product advantages [36]. In addition, Sheng et al. summarized that the dimensions of successful NPD are NPD speed and the innovation of new products [37]. The NPD cycle, speed of promotion and product characteristics are critical to the success of NPD. Syed et al. thought NPD speed is becoming an important way for companies to gain market share and meet rapidly changing consumer preferences [38]. Wu et al. studied a theoretical account of bricolage effects on NPD speed, and bricolage has a positive correlation with NPD speed under high technology fluctuation [39]. The rapid development of new products can give enterprises a market-leading advantage, and the high-quality development can bring good reputation and core competitive advantages [35–39].

Based on the above analysis, this study divides the dimensions of green NPD into green NPD speed and green NPD quality. The shortening of green NPD cycle mainly includes the shortening of R&D cycle and production cycle. The improvement of the green NPD quality is reflected by the improvement of the intrinsic quality of new products, the improvement of market adaptability and the enhancement of market competitiveness. The innovation process has a positive impact on the performance of new products [40]. The rapid development of green new products helps enterprises extend the life cycle of green products and reduce the cost of R&D [41]. Zhu et al., thought open innovation has a positive impact on NPD speed [42]. The high-quality development of green new products pays attention to the excavation of the value of green products [43].

2.1.4. Top Management's Environmental Awareness (TMEA)

Top managers are important personnel and the key players in the enterprise's innovation decision-making [44–46]. Enterprises with the same political and economic background are influenced by the characteristics and values of top managers when carrying out different innovation activities [45]. In the case of limited resources, the investment income ratio is the primary factor for enterprises to consider project investment. Green innovation has the characteristics of high input resources, high market risk and uncertain R&D, which makes it difficult for enterprises to obtain economic benefits in a short period of time [46]. Top managers can only incorporate innovation resources into green NPD if it incorporates green innovation into its corporate management. Top managers with high environmental awareness are not only open and supportive of green innovation, but also good at coding the acquired information and integrating it with corporate resources. In addition, managers are able to absorb internal and external knowledge and apply it to green innovation [44].

The stronger the environmental awareness of top managers, the more likely they are to identify potential benefits and market opportunities for green innovation [47]. On the one hand, top managers with high environmental awareness are more likely to perceive the potential benefits of government-regulated incentives. Enterprises no longer meet the minimum requirements for environmental regulation, but actively integrate internal and external green knowledge to promote

green NPD, and then obtain government subsidies. On the other hand, top managers with high environmental awareness regard consumers and suppliers' attention to green NPD as a market opportunity, so as to integrate internal and external green knowledge and develop green new products required by consumers to form a competitive advantage. Top managers management of green knowledge affects green NPD strategy.

2.2. Research Hypotheses

2.2.1. Positive Effect of External GSCI on KS and Green NPD

The essence of green NPD is the innovation of green knowledge, which comes from the re-integration and creation of knowledge resources by enterprises [30]. Enterprises should not only rely on their own scarce knowledge resources, but also actively acquire new knowledge from the outside. External green knowledge integration brings diversified knowledge to enterprises and increases the possibility of knowledge recombination [48]. In the competitive environment, it is also necessary for enterprises to integrate external green knowledge faster and more effectively so as to carry out green innovation activities [49]. Compared with customers' understanding of the market demand, green suppliers can master the technical knowledge required for the upper design which is more related to green innovation. Enterprises can promote the development of green new products by acquiring the knowledge of green suppliers. Green suppliers can provide functional and technical green knowledge to help enterprises solve green problems in the process of green NPD [50]. Suppliers participate in the front-end design of green new products with their new technologies to control possible problems. In the subsequent production process of new products, suppliers' green knowledge can also help enterprises improve the production process and quickly solve green problems [47,48]. Therefore, it is very important to integrate the green knowledge of green suppliers for both the speed and the green NPD quality. Relationship theory holds that the contract between green suppliers and enterprises establishes a convenient knowledge communication channel, which is conducive to promoting the sharing and integration of tacit knowledge and explicit knowledge [51]. In addition, the contract between green suppliers and enterprises can ensure the smooth progress.

In the initial stage of NPD, the integration with green suppliers is particularly necessary [20–29]. The integration of enterprises and green suppliers helps enterprises to enhance the coordination degree of green product design and process design and accelerate the process of green technology innovation [52]. The participation of green supplier is a form of strategic cooperation between enterprises and green suppliers [53]. The participation of green suppliers in green NPD means that enterprises design a cooperation mechanism to enable green suppliers to fully provide their technology, experience, innovation ability and assume corresponding responsibilities to improve the performance of green NPD [51]. The participation not only includes the participation in all links, but also involves the redesign of the original products [48]. In particular, the participation includes the generation of green product concepts, the testing of green new product prototypes and the marketing strategy of green products. The integration with green suppliers can not only help enterprises shorten the time for green NPD, but also acquire the technical skills of green suppliers through mutual communication [28]. In addition, on the one hand, the integration can help enterprises integrate advanced green information and technology, and solve the problems existing in green NPD quickly [27]. On the other hand, it also reduces the cost of communicating with green suppliers, and help enterprises reduce the complexity and risk of internal green NPD process [29]. Therefore, we propose the following hypotheses:

Hypothesis H1a. *Green SI positively affects the green NPD speed.*

Hypothesis H1b. *Green SI positively affects the green NPD quality.*

Hypothesis H1c. *Green SI positively affects KS.*

The joint cooperation between enterprises and green consumers is extremely beneficial to the improvement of green NPD performance. Green consumers are not only willing to participate in various green innovation activities, but also able to provide enterprises with timely information on ideas, technologies, and services [54]. This can lead to an open and creative exchange of green information that drives green new products to market faster. Specific procedures for green customers to participate in green innovation can not only enhance the level of interaction between green customers and enterprises, but also drive the innovation degree, market share and profit performance of green new products [55]. In addition, the participation of green customers also includes the dimension of customer innovation, which means that green customers carry out green innovation by themselves to guide green NPD for enterprises [56]. Chang and Fong pointed out that green customers participation can positively and directly affect the quality and speed of green innovation [57]. In addition, some scholars explored the implementation mechanism of customers participation to drive NPD [50]. The interaction and collaboration between enterprises and stakeholders, including customers, can promote the spillover of green product innovation. Customer information is an important source of information for green NPD activities. Nieto and Santamara believed that customers collaborative innovation can increase the innovation frequency and improve the operation efficiency, thereby improving NPD performance [58].

The collaborative product innovation between customers and enterprises has formed an innovative atmosphere of mutual trust, respect, and synchronous action. At this time, multiple interactive behaviors can not only accumulate their reputation and examine the credibility of each other, but also strengthen the maintenance of existing knowledge [26,53]. Mahr et al. pointed out that customers collaboration has a positive impact on the common learning and knowledge transformation of green innovation [59]. Green customers collaboration can facilitate continuous access to scarce resources such as information and technology in a competitive environment, and this is conducive to integrating fragmented green knowledge into specific learning activities and further promoting green NPD activities [27–29]. A dynamic coordination mechanism is formed by establishing various work systems of customer-centered decision-making participation. It is very effective in strengthening the absorptive capacity and activating the knowledge stock. Green customers provide external green knowledge to enterprises to carry out learning activities that are characterized by knowledge transformation. These activities can not only maintain the inherent nature of green knowledge, but also carry out in-depth development of the knowledge according to practical demands. Therefore, green customers in the market and their participation in green innovation are important influencing factors for enterprises to maintain newly acquired green knowledge [53]. According to the core idea of organizational learning behavior, the original green knowledge of customers and enterprises should be maintained timely to ensure the success of green NPD [60]. Therefore, we propose the following hypotheses:

Hypothesis H2a. *Green CI positively affects the green NPD speed.*

Hypothesis H2b. *Green CI positively affects the green NPD quality.*

Hypothesis H2c. *Green CI positively affects KS.*

2.2.2. Positive Effect of KS on Green NPD, and its Mediating Effect

NPD process is an essential flow of knowledge innovation, and knowledge creation is the source of NPD [30,48]. The essence of green NPD is the process of integrating and creating green knowledge through acquisition, sharing and utilization. With the increasing integration of explicit knowledge and implicit knowledge, new ideas of green NPD emerge, and green NPD is the result of the interaction between explicit knowledge and implicit knowledge [61].

The socialization of KS can promote tacit knowledge interaction between individuals and departments, thus improving R&D and marketing skills [62]. Socialization can enable green ideas to be viewed from a more professional perspective and promote the learning and communication

of green NPD skills. The externalization of KS can make tacit knowledge explicit so as to provide individuals with explicit and visible knowledge guidance [63]. Externalization can provide a reliable standard of compliance for the screening of green ideas and a normative process for green NPD. The combination of KS can provide conditions for knowledge integration between departments, so as to improve product innovation and make it closer to market demand [64]. Combination can enable green ideas to be evaluated more comprehensively at the enterprise level and provide a knowledge base for green NPD. The internalization of KS can promote a deeper understanding of market trends and technical attributes through practice, so as to improve the pertinence and novelty of products [63], and it can promote the efficiency of green NPD. The process of green NPD is a process in which green ideas formed by KS are further tested by the market [60–63]. Knowledge exchange and sharing among organizations can help enterprises seize market opportunities and analyze technological development trends, so as to successfully introduce green new products to the market. Sufficient and effective green knowledge integration can not only promote the generation of new ideas, but also improve the utilization rate of specialized labor division model, and these measures can shorten the launch time and actively promote green NPD [65]. Therefore, we propose the following hypotheses:

Hypothesis H3a. *KS positively affects the green NPD speed.*

Hypothesis H3b. *KS positively affects the green NPD quality.*

The combination of design tools and green knowledge is an important guarantee for green innovation. Enterprises can fully utilize the complementary effects of green innovation, green skills application and green knowledge composition to develop green new products with market prospects through collaborative efforts and mutual learning with green suppliers and customers [26,30,53]. Esper and Ellinger pointed out that supply chain integration can enable enterprises to more rationally and effectively link resources, R&D and production to market demand through knowledge transfer [66]. Enterprises can speed up green NPD by making special relationship investment in green integrated supply chain and taking measures such as bilateral locking and interdependent results. The sharing and integration of green knowledge are the purpose of mutual learning between enterprises and green integrated supply chain and have a positive impact on green NPD [50,51]. The key to supply chain collaborative green NPD driving R&D performance lies in the knowledge transformation between enterprises and green integrated supply chain, and the importance of KS is self-evident [60–63]. When green integrated supply chain collaborates with green NPD, the joint team composed of green integrated supply chain and enterprise developers inevitably carry out KS activities with knowledge maintenance and activation as the main performance characteristics, so as to improve the performance of green NPD. KS is in the external GSCI center and is closely related to the green integrated supply chain and the green NPD speed and green NPD quality [67]. Hence, there is a complex relationship between external GSCI, KS and the green NPD speed and green NPD quality. The KS in this study is a mechanism to explain how the external GSCI affects the performance of green NPD in GSCI. Through the important role of KS, enterprises can not only respond to the rise, growth, and disappearance of the green market at any time, but also obtain the green knowledge from green suppliers and consumers at the most appropriate time. Furthermore, this green knowledge is integrated into the green NPD so that the green NPD speed and green NPD quality can be significantly improved. Therefore, we propose the following hypotheses:

Hypothesis H3c. *KS has a mediating effect in the relationship between green SI and the green NPD speed.*

Hypothesis H3d. *KS has a mediating effect in the relationship between green SI and the green NPD quality.*

Hypothesis H3e. *KS has a mediating effect in the relationship between green CI and the green NPD speed.*

Hypothesis H3f. *KS has a mediating effect in the relationship between green CI and the green NPD quality.*

2.2.3. Mediation Effect

The stronger the TMEA, the more enterprises can perceive the pressure of environmental risks transmitted by green suppliers and consumers, and the more likely they are to adopt green NPD activities [43–45]. Most green NPD activities requires enterprises to invest more resources, and the risk of green NPD failure is very high. It is difficult to obtain economic benefits in a short period of time [68]. Only when top managers are fully aware of the importance of green NPD will green be included in sustainable development goals and invest resources to develop green NPD activities [69]. The stronger the TMEA, the more they tend to identify the potential benefits and market opportunities of green innovation, and then develop green new products [46]. On the one hand, top managers with high environmental awareness are more likely to perceive the potential benefits of government-regulated incentives. Enterprises no longer meet the minimum requirements for environmental regulation, but actively integrate internal and external green knowledge to promote green NPD, and then obtain government subsidies. On the other hand, top managers with high environmental awareness regard consumers and suppliers' attention to green NPD as a market opportunity, so as to integrate internal and external green knowledge and develop green new products required by consumers to form a competitive advantage.

Top managers' interpretation of external pressures and opportunities can affect knowledge management, which can promote green NPD. The stronger the TMEA, the more likely the enterprises are to identify the green resources brought by green suppliers and customers, and the effective integration of knowledge resources can promote green NPD [70]. Strong environmental awareness can promote enterprises to identify information resources from green suppliers and consumers and helps enterprises to rationally allocate these resources and internal resources, and integrate the integrated knowledge into green NPD [71]. In addition, top managers' attitudes and commitments to the environment can affect green NPD, and good attitudes and commitments are conducive to establishing a favorable green NPD environment [72]. Therefore, we propose the following hypotheses:

Hypothesis H4a. *TMEA positively mediates the relationship between KS and the green NPD speed.*

Hypothesis H4b. *TMEA positively mediates the relationship between KS and the green NPD quality.*

Based on the above theoretical basis and research hypotheses, the structural model of this study was proposed, as shown in Figure 1.

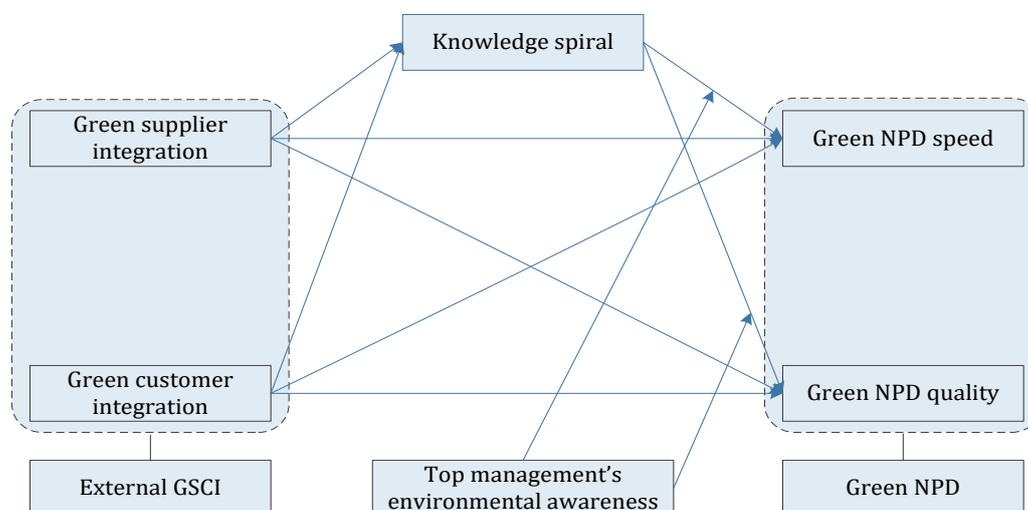


Figure 1. Research model.

3. Method

3.1. Variable Measurements

In order to ensure the reliability, the scale in this study adopts mature scale, and then we make appropriate modifications. The research scales are all in the form of Likert 7 scale, “1” means “completely inconsistent” and “7” means “completely consistent”. The measurements of green SI and green CI mainly adopt the mature scale used by Yu et al. [8] and Maditati et al. [73]. The measurement scale of KS mainly uses the scale developed by Becerra-Fernandez and Sabherwal [74] and Lee and Choi [75]. the green NPD speed and green NPD quality are mainly measured by the maturity scale designed by Shen et al. [37] and Chang et al. [76]. In order to further ensure the data quality from the source, we had adopted the measurement indexes designed in many relevant research to develop the pre-survey questionnaire before the formal survey. 70 questionnaires had been distributed in high-end manufacturing enterprises managed by MBA and EMBA students of Harbin engineering university. The respondents are product managers, department managers and product designers of green NPD in high-end manufacturing enterprises, and 58 copies had been recovered. In order to reduce the subjective degree of respondents, the questionnaire also does not contain questions about capability hypothesis and innovation performance. At the same time, we invited experts in the field of green innovation and organizational behavior and top managers to modify the questionnaire according to the test results. Finally, we developed a formal questionnaire, which is shown in Appendix A.

3.2. Data Collection

High-end manufacturing enterprises are not only the mainstay of national strategic economy, but also the subject of high resource, high energy consumption, and high pollution. They are facing increasingly severe environmental regulations. In order to obtain effective research data, enterprises surveyed in the questionnaire are all enterprises in the green supply chain, including large aircraft manufacturing industry, aviation engine and gas turbine industry, civil aerospace industry, high-tech shipping industry, Marine engineering equipment industry, energy saving and new energy automobile industry and other high-end manufacturing industries. There are the following requirements. First, enterprises are high-end manufacturing enterprises with innovative development, and in the past five years, they have implemented or are carrying out green NPD projects with green supply chain strategic alliance partners. Second, in the past five years, enterprises have organized at least 5 communication activities related to green NPD between enterprises and green suppliers and customers. In the questionnaire survey, the respondents are limited to the product managers, department managers and product designers of green NPD in high-end manufacturing enterprises. The data of this questionnaire are mainly obtained through network survey. In the formal questionnaire distribution from July to October, 2018, we contacted the target enterprise through social relations such as friends and alumni, and sent the link of the questionnaire to the corresponding respondents by email. A total of 400 electronic questionnaires were distributed, and 317 were recovered, with a recovery rate of 79.25%. After screened, 225 valid questionnaires were obtained, with an effective recovery rate of 70.97%. The demographic characteristics of the sample are shown in Table 1. Nature of firm included state-owned enterprises (12.89), private enterprise (64.44) and Joint venture (22.67). Size of firm mainly concentrated in 300–500, accounting for 56.44%. And high-polluting industry accounts for 54.22%. The results of the industry survey are as follows: large aircraft 12.44%, aviation engine and gas turbine 11.11%, civil aerospace 12.00%, high-tech shipping 18.67%, Marine engineering equipment 14.67%, energy saving and new energy automobile 20.89% and other high-end manufacturing 10.22%. In addition, the industry the enterprise belongs to is measured according to whether it belongs to the high-pollution industry.

Table 1. Demographic characteristics of the sample.

Title Characteristic	Category	Numbers	Percent (%)
Nature of Firm	State-owned enterprises	29	12.89
	Private enterprise	145	64.44
	Joint venture	51	22.67
Size of Firm	<300	22	9.78
	300–500	127	56.44
	>500	76	33.78
Years after establishment	<5	56	24.89
	10–20	109	48.44
	>20	60	26.67
Highly polluting	Yes	122	54.22
	No	103	45.78
Industry	Large aircraft manufacturing industry	28	12.44
	Aviation engine and gas turbine industry	25	11.11
	Civil aerospace industry	27	12.00
	High-tech shipping industry	42	18.67
	Marine engineering equipment industry	33	14.67
	Energy saving and new energy automobile industry	47	20.89
	Other high-end manufacturing industries	23	10.22

3.3. Deviation Tests

In order to avoid the deviation of the study samples, we tested the study data by homologous method deviation and unrespondent deviation. In terms of the homologous method deviation, Harman single factor analysis method was adopted in this paper, and we used the exploratory factor analysis (EFA) program provided by SPSS software (24.0, IBM, New York, State of New York, USA, 2016) to test the homologous method deviation. The results show that the load of the first principal component without rotation is only 29.06%. There is no single factor that can explain most of the variation, and homologous method deviation do not have a significant impact. In terms of the unrespondent deviation, we sorted the samples according to the return time of the questionnaire and selected the first 1/3 and the last 1/3 samples for t-test. The results show that there is no significant difference in more than 91% of the observed variables, and the deviation of the unresponders do not have a significant impact.

3.4. Reliability and Validity Tests

The reliability and validity of the samples in this study were tested as follows. First, Cronbach's alpha coefficient test was conducted for each variable to evaluate the internal consistency of the sample data. Second, mean variance extraction method was used to test the convergent validity of the sample data. Third, Kaiser–Meyer–Olkin (KMO) value and Barlett's Test of Sphericity method were used to test the construct validity of the sample data. Four, the research questionnaire was summarized and revised based on relevant research results. The content can effectively reflect the variable information, and the scale has a high content validity. SPSS software was used to test the reliability and validity of the questionnaire data, and the test results are shown in Tables 2 and 3.

As shown in Table 2, the Cronbach's alpha coefficient of all variables ranges from 0.822 to 0.891, which are higher than the generally recommended minimum standard 0.7. The results show that the internal consistency reliability of the sample data fulfills the research requirements. In terms of the convergent validity test, the factor load of all variables ranges from 0.633 to 0.891, and these values are all higher than the generally recommended 0.6. The mean variance of each variable is more than 50%, which indicate that the convergent validity of the variable measurement index fulfills the research requirements. As shown in Table 3, the KMO value of the questionnaire data is 0.844, which is higher than the generally recommended minimum standard 0.6. The result of Barlett's Test is significant and indicates that the sample data has appropriate construct validity.

Table 2. Reliability analysis for each scale.

Dimension	Constructs	Items	Factor Loading	Cronach's α	AVE (%)
External GSCI factors	Green supplier integration	SI1	0.741	0.838	60.46
		SI2	0.777		
		SI3	0.813		
	Green customer integration	CI1	0.727	0.822	53.00
		CI2	0.700		
		CI3	0.756		
Integration factor	Knowledge spiral	KS1	0.891	0.891	63.28
		KS2	0.730		
		KS3	0.718		
		KS4	0.830		
Green NPD factors	GNPD speed	GS1	0.696	0.872	55.63
		GS2	0.799		
		GS3	0.739		
	GNPD quality	GQ1	0.708	0.860	57.38
		GQ2	0.787		
		GQ3	0.775		
Top managers factor	TMEA	TA1	0.633	0.875	56.88
		TA2	0.809		
		TA3	0.807		

Table 3. Kaiiser–Meyer–Olkin (KMO) and Bartlett's Test.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy	0.844	
Bartlett's Test of Sphericity	Approx. Chi-Square	3404.176
	df	171
	Sig.	0.000

4. Data Analysis

4.1. Fitting Analysis of Mediation Model

Maximum likelihood method was used for the estimation of structural equation model, and it is generally believed that the number of samples should be at least 100–150. In this study, a total of 225 samples were used for structural equation model estimation. The sample size fulfills the research requirements. We established a structural equation model to analyze the impact of external GSCI on the green NPD speed and green NPD quality and the mediating effect of KS. The established structural equation model is shown in Figure 2.

AMOS software (24.0, IBM, New York, State of New York, USA, 2016) was used to conduct fitting analysis of the mediation model according to Figure 2, and the results of fitting analysis are shown in Table 4. Table 4 shows that χ^2/df is 1.743 which is less than the maximum of general recommendation 3. The RMSEA of the approximate error is 0.058, which is less than the recommended value 0.08. The range of incremental fit correlation index values is between 0.914 and 0.961, which is both larger than the generally recommended minimum value 0.9. Parsimony-adjusted comparative fit index is 0.633, which is larger than the commonly recommended minimum value 0.5. In conclusion, the fitting of mediation model fulfills the research requirements.

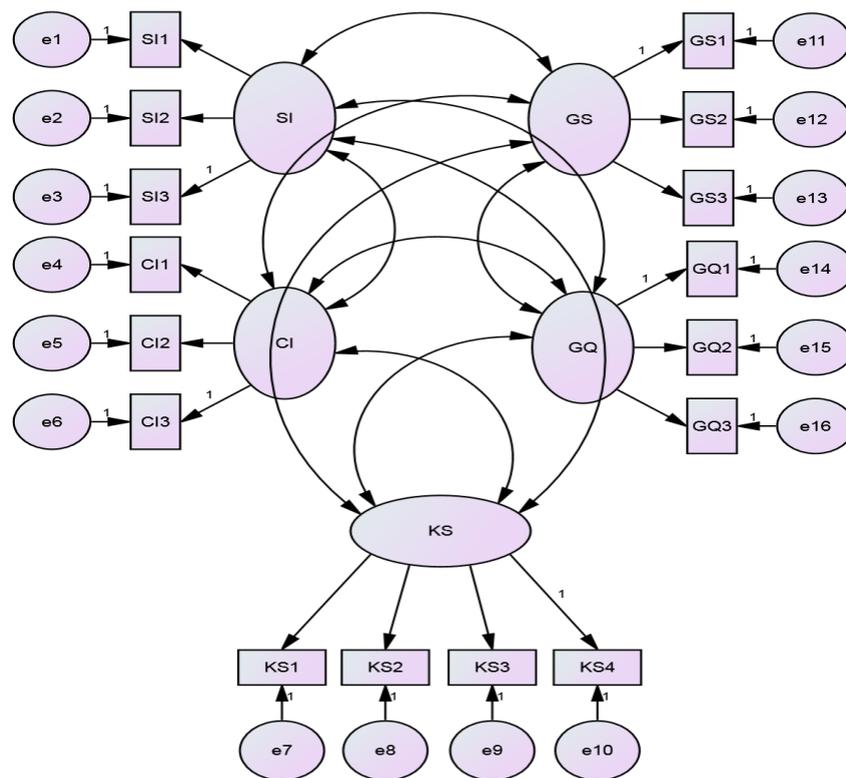


Figure 2. Confirmatory factor analysis (CFA) model.

Table 4. Goodness-of-fit measures of CFA model.

Goodness-of-Fit Measure	Index	Basic Level	Results	Model Fitting Judgment
Absolute fit	χ^2/df	<3	1.743	Accepted
	RMSEA	<0.08	0.058	Accepted
Incremental fit	CFI	>0.90	0.961	Accepted
	TLI	>0.90	0.950	Accepted
	IFI	>0.90	0.961	Accepted
	NFI	>0.90	0.914	Accepted
	GFI	>0.90	0.915	Accepted
Parsimony-adjusted comparative fit index	PGFI	>0.50	0.633	Accepted

4.2. Main Effect Test Results

The effect of green SI and green CI on the green NPD speed and green NPD quality are tested by using AMOS statistical software according to the questionnaire data. The test results of the structural equation model are shown in Figure 3, and the abbreviations are shown in Table 5. The standardized estimate values of all parameters are appropriate, and the C.R. test value is greater than 1.96 (see Table 6). The standard deviation of the parameter estimation is greater than 0, and the model is well fitted. Obviously, although the significance level of the path coefficient is different, the hypotheses from H1a to H3b are supported. In addition, the significant level of the path coefficient in Figure 3 shows that KS has a mediating effect in the relationship between green SI and green CI on the green NPD speed and green NPD quality. The mediating effect of KS is initially supported.

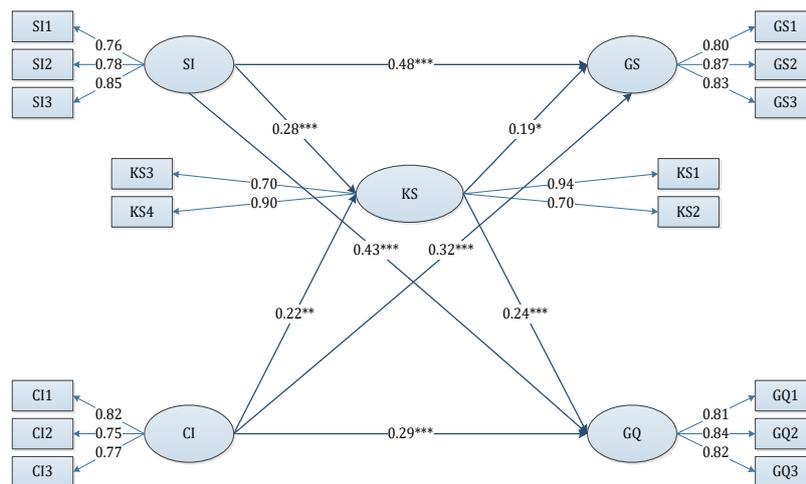


Figure 3. The structural equation model. (Note: *** *p*-value is less than 0.001; ** *p*-value is less than 0.01; * *p*-value is less than 0.05).

Table 5. Glossary of abbreviations.

Abbreviations	Constructs	Items
SI	Green supplier integration	SI1-SI3
CI	Green customer integration	CI1-CI3
KS	Knowledge spiral	KS1-KS4
GS	Green new product development speed	GS1-GS3
GQ	Green new product development quality	GQ1-GQ3

Table 6. Unstandardized regression weights.

			Estimate	S.E.	C.R.	P
KS	<←	SI	0.338	0.089	3.776	***
KS	<←	CI	0.307	0.107	2.875	0.004 **
GS	<←	SI	0.493	0.081	6.058	***
GS	<←	CI	0.377	0.095	3.991	***
GS	<←	KS	0.157	0.061	2.583	0.017 *
GQ	<←	SI	0.411	0.074	5.555	***
GQ	<←	CI	0.322	0.086	3.731	***
GQ	<←	KS	0.190	0.057	3.361	***
GS41	<←	GS	1.000			
GS42	<←	GS	1.066	0.079	13.491	***
GS43	<←	GS	0.980	0.075	13.103	***
GQ53	<←	GQ	1.000			
GQ52	<←	GQ	0.968	0.076	12.773	***
GQ51	<←	GQ	0.977	0.078	12.561	***
SI13	<←	SI	1.000			
SI12	<←	SI	0.864	0.072	11.996	***
SI11	<←	SI	0.871	0.074	11.702	***
CI23	<←	CI	1.000			
CI22	<←	CI	0.876	0.085	10.256	***
CI21	<←	CI	0.978	0.092	10.644	***
KS34	<←	KS	1.000			
KS33	<←	KS	0.732	0.058	12.693	***
KS32	<←	KS	0.710	0.056	12.674	***
KS31	<←	KS	1.107	0.054	20.406	***

Note: *** *p*-value is less than 0.001; ** *p*-value is less than 0.01; * *p*-value is less than 0.05.

4.3. Mediation Effect Test Results

In order to obtain accurate test results, we used the nonparametric percentile Bootstrap method with deviation correction to further test the mediating effect of KS. Amos software was set up as follows: 5000 repeat sampling and 95% deviation correction confidence interval. The mediating effect test includes the following four paths: SI→KS→GS, SI→KS→GQ, CI→KS→GS, and CI→KS→GQ. Table 7 shows the test results of the direct effects, indirect effects, total effects, *p* values, and confidence intervals. The results further support the hypotheses from H3c to H3f, and the mediating effect of KS is significant.

Table 7. Mediating effect of knowledge spiral.

Path	Direct Effects	P	BC95% Confidence Interval		Indirect Effects	P	BC95% Confidence Interval		Total Effects
			Lower Bounds	Upper Bounds			Lower Bounds	Upper Bounds	
SI→KS→GS	0.478	0.001	0.297	0.704	0.042	0.026	0.005	0.113	0.520
SI→KS→GQ	0.435	0.000	0.225	0.635	0.059	0.004	0.017	0.126	0.494
CI→KS→GS	0.316	0.000	0.163	0.622	0.048	0.004	0.014	0.138	0.364
CI→KS→GQ	0.293	0.002	0.102	0.588	0.060	0.002	0.020	0.142	0.353

4.4. Moderation Effect Test Results

In the test of the moderating effect of TMEA, three-step regression analysis method was used to test the moderation effect. The specific steps to test the mediating effect are as follows: (i) The regression of dependent variable to independent variable and moderating variable shows significant independent variable coefficient; (ii) The regression of mediating variable to independent variable and moderating variable shows significant independent variable coefficient; (iii) The regression of dependent variables to independent variables, moderating variables, moderating variables and mediating variables show significant interaction coefficient.

The results are shown in Table 8. Model1 and Model4 respectively tested the influence of control variables on the green NPD speed and green NPD quality. Model2 and Model5 respectively tested the influence of KS and TMEA on the green NPD speed and green NPD quality. Model3 tested the hypothesis that TMEA positively mediates the relationship between KS and the green NPD speed. Model6 tested the hypothesis that TMEA positively mediates the relationship between KS and the green NPD quality.

Table 8. Test results of moderating effect.

Variable		Green NPD Speed			Green NPD Quality		
		Model1	Model2	Model3	Model4	Model5	Model6
Control variables	H-polluting	0.009	0.013	0.016	0.007	0.008	0.018
	Nature	0.112 +	0.124 *	0.130 **	−0.058	−0.059	−0.040
	Size	0.122 +	0.103 +	0.102 +	0.138 **	0.116 +	0.113 +
	Year	0.261 ***	0.002	0.000	0.240 ***	0.119 +	0.111
Main effects	KS		0.143 **	0.303 +		0.236 ***	0.701 ***
	TA		0.556 ***	0.703 ***		0.211 **	0.642 **
Interaction effect	KS × TA			−0.251			0.731 *
	R ²	0.098	0.402	0.405	0.098	0.210	0.233
	ΔR ²		0.386 ***	0.386 ***	0.082 ***	0.188 ***	0.208 ***
	F	5.969 ***	24.436 ***	21.086 ***	5.979 ***	9.651 ***	9.421 ***

Note: *** *p*-value is less than 0.001; ** *p*-value is less than 0.01; * *p*-value is less than 0.05; + *p*-value is less than 0.1.

5. Results and Discussion

According to the test results of main effect, mediation effect and moderation effect in Section 4, the above results can be shown in Table 9.

Table 9. Results of H1a-H4b tests.

Structural Paths	Standardized Coefficient	Hypothesis Test
SI→GS (H1a)	0.480 ***	Supported
SI→GQ (H1b)	0.430 ***	Supported
SI→KS (H1c)	0.280 ***	Supported
CI→GS (H2a)	0.320 ***	Supported
CI→GQ (H2b)	0.290 ***	Supported
CI→KS (H2c)	0.220 **	Supported
KS→GS (H3a)	0.190 *	Supported
KS→GQ (H3b)	0.240 ***	Supported
SI→KS→GS (H3c)	0.520 **	Supported
SI→KS→GQ (H3d)	0.494 ***	Supported
CI→KS→GS (H3e)	0.364 ***	Supported
CI→KS→GQ (H3f)	0.353 **	Supported
TA×KS→GS (H4a)	−0.251	Not Supported
TA×KS→GQ (H4b)	0.731 *	Supported

Note: *** *p*-value is less than 0.001; ** *p*-value is less than 0.01; * *p*-value is less than 0.05.

As shown in Table 9, the hypotheses from H1a to H3f are supported. The mediating effect of KS is significant. The hypothesis H4a is not supported by test results. The moderating effect supports the hypothesis H4b that TMEA has a significant moderating effect on the relationship between KS and GQ.

5.1. Analysis of Main Effect

As shown in Figure 3 and Table 6, the standardized path coefficients of green SI and green CI on GS are 0.48 and 0.32, respectively, and are all significant at 1% level. The standardized path coefficients of green SI and green CI on GQ are 0.43 and 0.29, respectively, and are all significant at 1% level. The standardized path coefficients of green SI and green CI on KS are 0.28 and 0.22, respectively, and are significant at the level of 1% and 5%, respectively. The standardized path coefficient of KS on GS is 0.19 and is significant at 10%. The standardized path coefficient of KS on GQ is 0.24 and is significant at 1%. The above analysis shows that green SI and green CI have significant positive effects on GS, GQ, and KS, and KS has a significant positive effect on GS and GS, respectively. The hypotheses from H1a to H3b have been verified. In addition, compared with green CI, green SI has a greater impact on KS, GS and GQ. Furthermore, compared with GS, KS has a greater impact on GQ.

Based on the above analysis, enterprises should strengthen the construction of green NPD information system by integrating with external green supply chain and establishing long-term strategic partnership. The system can not only effectively realize information sharing and maximize the reduction cost of green new product and transaction, but also optimize the allocation of green NPD resources. In addition, the system can improve the competitive advantage of external GSCI and has a positive impact on the green NPD speed and green NPD quality. It should be emphasized that the KS effect generated by the integration of enterprises and external green supply chain cannot be ignored in this process. The purpose of KS is for enterprises to rely on the existing knowledge to integrate the knowledge of green suppliers and customers, and then create the target knowledge needed for green NPD. This is conducive to reducing the knowledge gap and improving the green NPD speed and green NPD quality. Therefore, enterprises should implement GSCI measures from the strategic level with green NPD as the object. Moreover, enterprises should efficiently integrate knowledge resources in green supply chain to realize the optimal allocation, advantage reciprocity and resource sharing of green NPD resources. In addition, enterprises should grasp the green trend of green suppliers and customers, and timely adjust green NPD strategy. In terms of knowledge interaction, enterprises should strengthen the management of knowledge related to green NPD based on external GSCI and create a knowledge sharing atmosphere for green NPD. On the one hand, enterprises should actively cultivate rational trust, emotional tacit understanding and common vision with green suppliers and customers and enhance the sense of security and willingness of knowledge sharing. On the other hand,

enterprises should set up appropriate incentive mechanism of reward and punishment and intellectual property protection measures to reduce the cost of knowledge sharing and the economic loss caused by knowledge spillover effect. These measures are conducive to mobilizing the enthusiasm of green suppliers and customers to share knowledge. The results show that KS can shorten the time to market of green new products and promote the dissemination of innovative results and improve the green NPD speed and green NPD quality. Enterprises should clarify the interaction and transformation process of tacit knowledge and explicit knowledge and the role of KS in promoting the green NPD speed and green NPD quality. The government should pay attention to the environmental demands of green consumers and supply chain partners.

5.2. Analysis of Mediation Effect

KS has a significant mediating effect in the relationship between green SI and green CI and the green NPD speed and green NPD quality, respectively. As shown in Table 7, the total effect of green SI on GS is 0.520; the direct effect is 0.478 and the indirect effect is 0.042. That is to say, 0.042 of the total effect of green SI on GS is achieved through KS mediating effect, and the mediating effect accounts for 0.081 of the total effect. The total effect of green SI on GQ is 0.494; the direct effect is 0.435 and the indirect effect is 0.059. It indicates that the mediating effect of KS between green SI and GQ is 0.059, and the mediating effect accounts for 0.119 of the total effect. In the above two mediation paths, the deviation correction bootstrap confidence interval with 95% confidence does not contain 0. The results show that KS play a significant part in the mediating role of green SI and the green NPD speed and green NPD quality. Compared with GS, KS has stronger mediating effect on green SI and GQ. The same analysis method was used to analyze the mediating effect of KS between CI and GS and GQ. Among the 0.364 total effect of CI on GS, 0.048 is achieved through the intermediary effect of KS, and the proportion of the intermediary effect in the total effect is 0.132. The mediating effect of KS between CI and GQ is 0.060, and the mediating effect accounts for 0.170 of the total effect. The deviation correction bootstrap confidence intervals for the above two mediation paths with 95% confidence do not contain 0. The results indicate that KS has a significant partial mediating effect in the relationship between green CI and GS and GQ. Compared with GS, KS has stronger mediating effect between green CI and GQ. The analysis results of the above four mediation paths show that KS has a stronger effect on improving GQ than GS. Compared with green SI, the equivalent KS capability is more significant in integrating green customers information.

The purpose of KS is to create the target knowledge needed for green NPD from the existing knowledge through socialization, externalization, combination, and internalization. This is conducive to reducing knowledge gap or cross-domain knowledge gap and improving the green NPD speed and green NPD quality. Socialization can provide help for the generation of green NPD ideas, and externalization can inspire green suppliers and customers to come up with ideas. Combination can help to integrate ideas from green suppliers and customers, and internalization can encourage enterprises to find problems and propose new ideas for green NPD. Therefore, enterprises should enhance the management awareness of knowledge related to green NPD and clarify the interaction and transformation process of tacit knowledge and explicit knowledge. Moreover, enterprises should establish a knowledge-based and learning-oriented cultural organization in green NPD team to promote knowledge sharing and integration. Furthermore, enterprises should try their best to make explicit the tacit knowledge from green suppliers and customers to promote the rise of KS. In terms of the personal ability of employees, enterprises should build a professional academic team to enhance the sensitivity, identification, and acceptance of new things and knowledge. In addition, enterprises should be good at seizing opportunities to bring valuable knowledge and technology related to green NPD back to enterprises for timely digestion, absorption, and R&D.

5.3. Analysis of Moderation Effect

The result of moderating effect supports the hypothesis H4b that TMEA has a significant moderating effect on the relationship between KS and GQ ($\beta = 0.731, p < 0.05$). This result shows that the stronger the TMEA is, the more enterprises attach importance to the social responsibility related to green NPD. Enterprises regard the emphasis on the green NPD quality from green consumers and suppliers as market opportunities and put green development factors into the interaction between explicit knowledge and implicit knowledge. This has a positive impact on improving the green NPD quality. The hypothesis H4a is not supported by test results, and TMEA has no significant moderating effect on the relationship between KS and GS. The result shows that the connection between KS and GS is close and significant, and whether the TMEA is strong or weak, the enterprise will pay attention to the product market situation. In this situation, enterprises tend to focus on the impact of KS on financial performance based on their own interests. At the same time, influenced by the mentality of “seeking quick success and quick profit”, the enterprise tends to utilize KS ability to occupy a wide range of market resources. We have noticed that the adjustment coefficient of TMEA on the relationship between KS and GS is a negative number. One possible explanation is that green NPD is divided into two stages: green product design and clean production. At present, most of China’s enterprises are in the primary stage of green NPD, and the higher the TMEA, the more likely the enterprise is to adopt cleaner production measures. From the design of green products to the transformation of green technology, the realization of clean production has the hysteresis of strategic timeliness. Therefore, it is likely that the adjustment coefficient between KS and GS is a negative number.

At the present stage of industrial transformation and consumption upgrading, China’s manufacturing industry has begun to shift from “quantity” to “quality”. The improvement of the green NPD quality reflects the competitiveness of sustainable growth of enterprises and becomes an effective means for enterprises to win long-term innovation benefits. The moderating effect of TMEA has the following implications. First, top managers should pay attention to the green NPD quality instead of rushing success. Second, enterprises should put the concept of green environmental protection into a strategic height, and truly integrate it into green NPD, thereby improving the green NPD quality. Third, the government should actively guide the establishment of social environmental awareness system, and create a good green concept and green atmosphere, thereby opening up new markets for green products. Fourth, policymakers should establish a relationship with top managers, and regularly deliver environmental protection information to top managers by organizing training courses for entrepreneurs and trade associations.

6. Conclusions

With the enhancement of environmental protection, green products have been attracted wide attention. As consumers consume more green products, supply chain enterprises are faced with diversified requirements of green consumers. Green NPD can meet the requirements of both green consumers and supply chain enterprises. With the integration of supply chain and Internet of things, the development of green new products through external GSCI is one of the important ways for enterprises to win the green market. To explore the mechanisms in this process, we used structural equation modeling and analytic hierarchy process to study the action mechanism of green SI and green CI on KS and its influence mechanism on the green NPD speed and green NPD quality, and reveal the mediating role of KS in the relationship between external GSCI and green NPD. In addition, the moderation effect of TMEA on the relationship between KS and green NPD was studied. The results of this study are as follows. (i) Green SI and green CI have significant positive effects on GS, GQ, and KS, and KS has a significant positive effect on GS and GS. Compared with green CI, green SI has greater impact on KS, GS and GQ. In addition, compared with GS, KS has a greater impact on GQ; (ii) KS has a significant partial mediating effect in the relationship between green CI, GS, and GQ. Compared with GS, KS has stronger mediating effect between green CI and GQ. Compared with green SI, the equivalent knowledge spiral capability is more significant in integrating green customer

information; (iii) TMEA has a significant moderating effect on the relationship between KS and GQ and has no significant moderating effect on the relationship between KS and GS.

This study not only further enrich the knowledge of institutional theory, knowledge management and green NPD, but also have important management implications for top managers and policymakers. For enterprises, first, enterprises should implement GSCI from the strategic level and take green NPD as the object to realize the optimal allocation of green NPD resources, advantage reciprocity and resource sharing. Second, enterprises should strengthen the knowledge management of green NPD, and create a knowledge sharing atmosphere of green NPD. At the same time, enterprises should enhance the interactive transformation process of tacit knowledge and explicit knowledge. Third, top managers should put the concept of green environmental protection at a strategic height and integrate it into green NPD to improve the quality of green NPD. For policymakers, first, policymakers should actively guide the establishment of social environmental protection awareness system and open up new markets for green products. Second, policymakers should establish a relationship with top managers, and regularly convey environmental protection information to top managers by organizing training courses for entrepreneurs and industry associations. Third, policymakers should pay attention to the environmental demands of green consumer groups and green supply chain partners.

In this study, there are still some deficiencies which also provide useful ideas for future study. First, due to the difficulty in data collection, the data used in this study is still not a large sample study in a strict sense. The data used in this study is only the cross-sectional data, and future study can attempt to use longitudinal data to further study. Second, KS as a variable to be considered ensures the integrity of green NPD, but it weakens the detailed analysis of each of its key steps. Future research can consider the mediating effect of the four dimensions of KS in the relationship between external GSCM and the green NPD speed and green NPD quality, so as to improve the comprehensiveness of research results.

Author Contributions: B.L. proposed the research framework and provided some comments. X.Z. contributed the analysis tools and participated in the data analysis. S.Y. analyzed the data and wrote the paper in English. M.Z. contributed the English language and structure.

Funding: This research was supported by the Fundamental Research Funds for the Central Universities (HEUCFW170901), the National Natural Science Foundation of China (71601087) and the Humanities and Social Sciences Planning Projects of Ministry of Education (15YJC630088).

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Questionnaire used in the survey.

Dimension	Constructs	Measurement Items	1	2	3	4	5	6	7
External GSCI factors	Green supplier integration	We actively interact with green suppliers to discuss the quality and design of green new product development. We have procedures and methods for obtaining green suppliers' operational information. We strive to build long-term relationships with green suppliers.							
	Green customer integration	We have formal practices and standard operating procedures to liaise with green customers to find green new products. We actively interact with green customers to promote green new product development. We strive to build long-term relationships with green customers.							

Table A1. Cont.

Dimension	Constructs	Measurement Items	1	2	3	4	5	6	7
Integration factor: Knowledge spiral		Employees are encouraged to use inductive and deductive methods to capture, learn and share information about green new product development.							
		The company has a wealth of information, learning courses and practical experience in the knowledge base of green new product development.							
		The company often carries out on-the-job training and face-to-face experience discussion activities for green new product development.							
		The company often carries out cross-departmental green new product development cooperation projects.							
Green NPD factors	GNPD speed	In the past three years, compared with the peers, the new green products developed by our company have been quickly introduced to the market.							
		In the past three years, compared with peers, the cycle of our company's green new product development is very short.							
Green NPD factors	GNPD quality	In the past three years, compared with peers, our company's green new product development speed is faster.							
		In the past three years, compared with peers, our company has done a very good job in the development of green new products.							
Top managers factor: Top management's environmental awareness		In the past three years, compared with peers, the green new products developed by our company have a good market prospect.							
		In the past three years, compared with peers, the quality of our green new products is higher.							
		Our top managers attach great importance to the impact of relevant environmental regulations on the company.							
Top managers factor: Top management's environmental awareness		Our top managers attach great importance to the adverse impact of production and business activities on the environment.							
		Our top managers attach great importance to the understanding and mastery of environmental protection measures.							

References

- World Health Organization. *Global Tuberculosis Report 2018*; World Health Organization: Geneva, Switzerland, 2018.
- Yang, C.H.; Tseng, Y.H.; Chen, C.P. Environmental regulations, induced R&D, and productivity: Evidence from Taiwan's manufacturing industries. *Res. Energy Econ.* **2012**, *34*, 514–532.
- Gandhi, N.S.; Thanki, S.J.; Thakkar, J.J. Ranking of drivers for integrated lean-green manufacturing for Indian manufacturing SMEs. *J. Clean. Prod.* **2018**, *171*, 675–689. [[CrossRef](#)]
- Dubey, R.; Bag, S. Antecedents of green manufacturing practices: A journey towards manufacturing sustainability. In *Operations and Service Management: Concepts 2018, Methodologies, Tools, and Applications*; IGI Global: Hershey, PA, USA, 2018.
- Feng, Z.J.; Chen, W. Environmental regulation, green innovation, and industrial green development: An empirical analysis based on the Spatial Durbin model. *Sustainability* **2018**, *10*, 223. [[CrossRef](#)]
- Dangelico, R.M.; Pujari, D. Mainstreaming green product innovation: Why and how companies integrate environmental sustainability. *J. Bus. Ethics* **2010**, *95*, 471–486. [[CrossRef](#)]
- Lin, R.J.; Tan, K.H.; Geng, Y. Market demand, green product innovation, and firm performance: Evidence from Vietnam motorcycle industry. *J. Clean. Prod.* **2013**, *40*, 101–107. [[CrossRef](#)]
- Yu, W.T.; Chavez, R.; Feng, M.Y.; Wiengarten, F. Integrated green supply chain management and operational performance. *Supply Chain Manag. Int. J.* **2014**, *19*, 683–696. [[CrossRef](#)]

9. Yan, Y.K.; Yazdanifard, R. The concept of green marketing and green product development on consumer buying approach. *Glob. J. Commer. Manag. Perspect.* **2014**, *3*, 33–38.
10. Li, L. Application of the internet of thing in green agricultural products supply chain management. In Proceedings of the 2011 Fourth International Conference on Intelligent Computation Technology and Automation, Shenzhen, China, 28–29 March 2011.
11. Driessen, P.H.; Hillebrand, B. Integrating multiple stakeholder issues in new product development: An exploration. *J. Prod. Innov. Manag.* **2013**, *30*, 364–379. [[CrossRef](#)]
12. De Medeiros, J.F.; Ribeiro, J.L.D.; Cortimiglia, M.N. Success factors for environmentally sustainable product innovation: A systematic literature review. *J. Clean. Prod.* **2014**, *65*, 76–86. [[CrossRef](#)]
13. Weng, H.H.; Chen, J.S.; Chen, P.C. Effects of green innovation on environmental and corporate performance: A stakeholder perspective. *Sustainability* **2015**, *7*, 4997–5026. [[CrossRef](#)]
14. Liao, Z.J.; Chen, H. The antecedents and outcomes of firm’s environmental innovation—from the perspective of environmental policy and firm’s background characteristics. *Stud. Sci. Sci.* **2014**, *32*, 792–800.
15. Albort-Morant, G.; Leal-Rodríguez, A.L.; De Marchi, V. Absorptive capacity and relationship learning mechanisms as complementary drivers of green innovation performance. *J. Knowl. Manag.* **2018**, *22*, 432–452. [[CrossRef](#)]
16. Lin, Y.H.; Chen, Y.S. Determinants of green competitive advantage: The roles of green knowledge sharing, green dynamic capabilities, and green service innovation. *Qual. Quant.* **2017**, *51*, 1663–1685. [[CrossRef](#)]
17. Song, W.H.; Ren, S.C.; Yu, J. Bridging the gap between corporate social responsibility and new green product success: The role of green organizational identity. *Bus. Strategy Environ.* **2019**, *28*, 88–97. [[CrossRef](#)]
18. Shu, C.L.; Zhou, K.Z.; Xiao, Y.Z.; Gao, S.X. How green management influences product innovation in China: The role of institutional benefits. *J. Bus. Ethics* **2016**, *133*, 471–485. [[CrossRef](#)]
19. Tang, M.F.; Walsh, G.; Lerner, D.; Fitz, M.A.; Li, Q.H. Green innovation, managerial concern and firm performance: An empirical study. *Bus. Strategy Environ.* **2018**, *27*, 39–51. [[CrossRef](#)]
20. Ahi, P.; Searcy, C. A comparative literature analysis of definitions for green and sustainable supply chain management. *J. Clean. Prod.* **2013**, *52*, 329–341. [[CrossRef](#)]
21. Ben-Daya, M.; Hassini, E.; Bahroun, Z. Internet of things and supply chain management: A literature review. *Int. J. Prod. Res.* **2017**, *11*, 1–24. [[CrossRef](#)]
22. Gold, S.; Seuring, S.; Beske, P. Sustainable supply chain management and inter-organizational resources: A literature review. *Corp. Soc. Responsib. Environ. Manag.* **2010**, *17*, 230–245. [[CrossRef](#)]
23. Büyüközkan, G.; Çifçi, G. Evaluation of the green supply chain management practices: A fuzzy ANP approach. *Prod. Plan. Control* **2012**, *23*, 405–418. [[CrossRef](#)]
24. Wang, Y.L.; Wang, N.M.; Sun, L.Y. The basic principles of green supply chain management. *Eng. Sci.* **2003**, *11*, 82–87.
25. Rauer, J.; Kaufmann, L. Mitigating external barriers to implementing green supply chain management: A grounded theory investigation of green-tech companies’ rare earth metals supply chains. *J. Supply Chain Manag.* **2015**, *51*, 65–88. [[CrossRef](#)]
26. Zhang, C.L.; Gunasekaran, A.; Wang, W.Y.C. A comprehensive model for supply chain integration. *Benchmarking* **2015**, *22*, 1141–1157. [[CrossRef](#)]
27. Wong, C.W.; Lai, K.H.; Bernroider, E.W. The performance of contingencies of supply chain information integration: The roles of product and market complexity. *Int. J. Prod. Econ.* **2015**, *165*, 1–11. [[CrossRef](#)]
28. Chen, H.; Daugherty, P.J.; Landry, T.D. Supply chain process integration: A theoretical framework. *J. Bus. Logist.* **2009**, *30*, 27–46. [[CrossRef](#)]
29. Ellram, L.M. Purchasing and supply management’s participation in the target costing process. *J. Supply Chain Manag.* **2000**, *36*, 39–51. [[CrossRef](#)]
30. Ozer, M.; Tang, J.W. Understanding the trade-off between familiarity and newness in product innovation. *Ind. Mark. Manag.* **2019**, *77*, 116–128. [[CrossRef](#)]
31. Trigo, A. Mechanisms of learning and innovation performance: The relevance of knowledge sharing and creativity for non-technological innovation. *Int. J. Innov. Technol. Manag.* **2013**, *10*, 1340028. [[CrossRef](#)]
32. Li, M.; Gao, F. Why Nonaka highlights tacit knowledge: A critical review. *J. Knowl. Manag.* **2003**, *7*, 6–14. [[CrossRef](#)]
33. Yousaf, M.J.; Ali, Q. Impact of knowledge management on innovation: Evidence from a South Asian country. *J. Inf. Knowl. Manag.* **2018**, *17*, 1850035. [[CrossRef](#)]

34. Dangelico, R.M. What drives green product development and how do different antecedents affect market performance? A survey of Italian companies with eco-labels. *Bus. Strategy Environ.* **2017**, *26*, 1144–1161. [[CrossRef](#)]
35. Griffin, A.; Page, A.L. An interim report on measuring product development success and failure. *J. Prod. Innov. Manag.* **1993**, *10*, 291–308. [[CrossRef](#)]
36. Garcia, N.; Sanzo, M.J.; Trespalacios, J.A. New product internal performance and market performance: Evidence from Spanish firms regarding the role of trust, interfunctional integration, and innovation type. *Technovation* **2008**, *28*, 713–725. [[CrossRef](#)]
37. Sheng, S.B.; Zhou, K.Z.; Lessassy, L. NPD speed vs. innovativeness: The contingent impact of institutional and market environments. *J. Bus. Res.* **2013**, *66*, 2355–2362. [[CrossRef](#)]
38. Syed, T.A.; Blome, C.; Papadopoulos, T. Impact of IT ambidexterity on new product development speed: Theory and empirical evidence. *Decis. Sci.* **2019**. [[CrossRef](#)]
39. Wu, L.; Liu, H.; Zhang, J. Bricolage effects on new-product development speed and creativity: The moderating role of technological turbulence. *J. Bus. Res.* **2017**, *70*, 127–135. [[CrossRef](#)]
40. Cheng, C.; Yang, M. Creative process engagement and new product performance: The role of new product development speed and leadership encouragement of creativity. *J. Bus. Res.* **2019**, *99*, 215–225. [[CrossRef](#)]
41. Redante, R.C.; de Medeiros, J.F.; Vidor, G.; Cruz, C.M.L.; Ribeiro, J.L.D. Creative approaches and green product development: Using design thinking to promote stakeholders' engagement. *Sustain. Prod. Consum.* **2019**, *19*, 247–256. [[CrossRef](#)]
42. Zhu, X.X.; Xiao, Z.X.; Dong, M.C.; Gu, J.B. The fit between firms' open innovation and business model for new product development speed: A contingent perspective. *Technovation* **2019**. [[CrossRef](#)]
43. Ng, C.Y. Green product design and development using life cycle assessment and ant colony optimization. *Int. J. Adv. Manuf. Technol.* **2018**, *95*, 3101–3109. [[CrossRef](#)]
44. Latan, H.; Jabbour, C.J.C.; de Sousa Jabbour, A.B.L.; Wamba, S.F.; Shahbaz, M. Effects of environmental strategy, environmental uncertainty and top management's commitment on corporate environmental performance: The role of environmental management accounting. *J. Clean. Prod.* **2018**, *180*, 297–306. [[CrossRef](#)]
45. Singh, S.K.; Gupta, S.; Busso, D.; Kamboj, S. Top management knowledge value, knowledge sharing practices, open innovation and organizational performance. *J. Bus. Res.* **2019**. [[CrossRef](#)]
46. Huang, X.X.; Hu, Z.P.; Liu, C.S.; Yu, D.J.; Yu, L.F. The relationships between regulatory and customer pressure, green organizational responses, and green innovation performance. *J. Clean. Prod.* **2016**, *112*, 3423–3433. [[CrossRef](#)]
47. Teixeira, A.A.; Jabbour, C.J.C.; de Sousa Jabbour, A.B.L. Relationship between green management and environmental training in companies located in Brazil: A theoretical framework and case studies. *Int. J. Prod. Econ.* **2012**, *140*, 318–329. [[CrossRef](#)]
48. Borrego, M.; Newswander, C.B.; McNair, L.D.; McGinnis, S.; Paretto, M.C. Using Concept Maps to Assess Interdisciplinary Integration of Green Engineering Knowledge. *Adv. Eng. Educ.* **2009**, *1*, n3.
49. Lee, K.H.; Kim, J.W. Integrating suppliers into green product innovation development: An empirical case study in the semiconductor industry. *Bus. Strategy Environ.* **2011**, *20*, 527–538. [[CrossRef](#)]
50. Cheng, J.H.; Yeh, C.H.; Tu, C.W. Trust and knowledge sharing in green supply chains. *Supply Chain Manag.* **2008**, *13*, 283–295. [[CrossRef](#)]
51. Hwang, B.G.; Ng, W.J. Project management knowledge and skills for green construction: Overcoming challenges. *Int. J. Proj. Manag.* **2013**, *31*, 272–284. [[CrossRef](#)]
52. Petersen, K.J.; Handfield, R.B.; Ragatz, G.L. Supplier integration into new product development: Coordinating product, process and supply chain design. *J. Oper. Manag.* **2005**, *23*, 371–388. [[CrossRef](#)]
53. Lo, S.M.; Zhang, S.S.; Wang, Z.Q.; Zhao, X.D. The impact of relationship quality and supplier development on green supply chain integration: A mediation and moderation analysis. *J. Clean. Prod.* **2018**, *202*, 524–535. [[CrossRef](#)]
54. Ottman, J.; Books, N.B. Green marketing: Opportunity for innovation. *J. Sustain. Prod. Des.* **1998**, *60*, 136–667.
55. Gan, C.; Wee, H.Y.; Ozanne, L.; Kao, T. Consumers' purchasing behavior towards green products in New Zealand. *Innov. Mark.* **2008**, *4*, 93–102.

56. Tsai, M.T.; Chuang, L.M.; Chao, S.T.; Chang, H.P. The effects assessment of firm environmental strategy and customer environmental conscious on green product development. *Environ. Monit. Assess.* **2012**, *184*, 4435–4447. [[CrossRef](#)] [[PubMed](#)]
57. Chang, N.J.; Fong, C.M. Green product quality, green corporate image, green customer satisfaction, and green customer loyalty. *Afr. J. Bus. Manag.* **2010**, *4*, 2836–2844.
58. Nieto, M.J.; Santamaría, L. The importance of diverse collaborative networks for the novelty of product innovation. *Technovation* **2007**, *27*, 367–377. [[CrossRef](#)]
59. Mahr, D.; Lievens, A.; Blazevic, V. The value of customer cocreated knowledge during the innovation process. *J. Prod. Innov. Manag.* **2014**, *31*, 599–615. [[CrossRef](#)]
60. Leal-Millán, A.; Roldán, J.L.; Leal-Rodríguez, A.L.; Ortega-Gutiérrez, J. IT and relationship learning in networks as drivers of green innovation and customer capital: Evidence from the automobile sector. *J. Knowl. Manag.* **2016**, *20*, 444–464. [[CrossRef](#)]
61. Sarin, S.; McDermott, C. The effect of team leader characteristics on learning, knowledge application, and performance of cross-functional new product development teams. *Decis. Sci.* **2003**, *34*, 707–739. [[CrossRef](#)]
62. Bettoni, M.C.; Andenmatten, S.; Mathieu, R. Knowledge cooperation in online communities: A duality of participation and cultivation. *Electron. J. Knowl. Manag.* **2007**, *5*, 1–6.
63. Zhuge, H. Discovery of knowledge flow in science. *Commun. ACM* **2006**, *49*, 101–107. [[CrossRef](#)]
64. Nonaka, I.; Toyama, R. The knowledge-creating theory revisited: Knowledge creation as a synthesizing process. In *The Essentials of Knowledge Management*; Edwards, J.S., Ed.; OR Essentials Series; Palgrave Macmillan: London, UK, 2015.
65. Millson, M.R. Exploring the nonlinear impact of organizational integration on new product market success. *J. Prod. Innov. Manag.* **2015**, *32*, 279–289. [[CrossRef](#)]
66. Esper, T.L.; Ellinger, A.E.; Stank, T.P.; Flint, D.J.; Moon, M. Demand and supply integration: A conceptual framework of value creation through knowledge management. *J. Acad. Market. Sci.* **2010**, *38*, 5–18. [[CrossRef](#)]
67. Bhosale, V.A.; Kant, R. Metadata analysis of knowledge management in supply chain: Investigating the past and predicting the future. *Bus. Process Manag. J.* **2016**, *22*, 140–172. [[CrossRef](#)]
68. Lin, C.Y.; Lee, A.H.; Kang, H.Y. An integrated new product development framework—An application on green and low-carbon products. *Int. J. Syst. Sci.* **2015**, *46*, 733–753. [[CrossRef](#)]
69. Felekoglu, B.; Moultrie, J. Top management involvement in new product development: A review and synthesis. *J. Prod. Innov. Manag.* **2014**, *31*, 159–175. [[CrossRef](#)]
70. Govindan, K.; Muduli, K.; Devika, K.; Barve, A. Investigation of the influential strength of factors on adoption of green supply chain management practices: An Indian mining scenario. *Resour. Conserv. Recycl.* **2016**, *107*, 185–194. [[CrossRef](#)]
71. Luthra, S.; Garg, D.; Haleem, A. An analysis of interactions among critical success factors to implement green supply chain management towards sustainability: An Indian perspective. *Resour. Policy* **2015**, *46*, 37–50. [[CrossRef](#)]
72. Burki, U.; Dahlstrom, R. Mediating effects of green innovations on interfirm cooperation. *Australas. Market. J.* **2017**, *25*, 149–156. [[CrossRef](#)]
73. Maditati, D.R.; Munim, Z.H.; Schramm, H.J.; Kummer, S. A review of green supply chain management: From bibliometric analysis to a conceptual framework and future research directions. *Resour. Conserv. Recycl.* **2018**, *139*, 150–162. [[CrossRef](#)]
74. Becerra-Fernandez, I.; Sabherwal, R. Organizational knowledge management: A contingency perspective. *J. Manag. Inf. Syst.* **2001**, *18*, 23–55.
75. Lee, H.; Choi, B. Knowledge management enablers, processes, and organizational performance: An integrative view and empirical examination. *J. Manag. Inf. Syst.* **2003**, *20*, 179–228.
76. Chang, T.W.; Chen, F.F.; Luan, H.D.; Chen, Y.S. Effect of Green Organizational Identity, Green Shared Vision, and Organizational Citizenship Behavior for the Environment on Green Product Development Performance. *Sustainability* **2019**, *11*, 617. [[CrossRef](#)]

