Do Major Customers and Suppliers Affect Green Innovation? Empirical Evidence from China

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Abstract. In recent years, both enterprises and academia have focused their attention on green innovation, but few studies have explored at the conditions and mechanisms that explain the relationship between major customers (suppliers) and green innovation. Based on the research perspective of supply chain management, this paper explores the impact of major customers (major suppliers) on corporate green innovation through an empirical study, using Chinese A-share listed companies from 2013 to 2020 as a sample. Our results indicate that both major customers and major suppliers have negative effects on green innovation. The negative impacts of major customers and major suppliers on green innovation are mediated by R&D investment. The results of the heterogeneity test show that the negative effect of major customers (major suppliers) on green innovation is more significant in the sample of enterprises with low digital transformation, suggesting that enterprises may consider digital transformation to promote green innovation activities.

Keywords: green innovation · major costumers · major suppliers · costumer concentration · supplier concentration

1 Introduction

Green innovation is the driving power behind high-quality development and the green transformation, just as innovation is the driving force behind development [1]. China proposed the goals of "carbon neutrality" and "carbon peaking" in 2020, green and innovation have become the main theme of China's industrial upgrading and economic development in the future. In the context of tightening resource constraints and the process of innovation-driven growth strategy, green innovation has become a core component and effective driver of the green growth approach. It is a natural choice for enterprises to decouple environmental pressures from economic growth in conditions of increasingly restrictive environmental regulations, and can give them an advantageous position in the competitive marketplace. This study focuses on green innovation and examines the role of major customers and major suppliers in the enterprise.

Existing research on the factors influencing green innovation primarily focuses on the influence of institutional pressures [2–4] and government subsidies [5, 6] on the

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green innovation of firms, ignoring the significant role of the supply chain as a heterogeneous resource for enterprises to obtain green innovation. Academics seldom concern the impact of customer concentration and supplier concentration on green innovation. Customer concentration (supplier concentration) indicates the dependence of an enterprise on its major customers (suppliers). Higher customer concentration and supplier concentration can influence development decisions such as product pricing and R&D investment, which in turn can affect an enterprise's business strategy [7]. Research on customer concentration and supplier concentration in relation to green innovation is critically needed. We are motivated to further enrich the research on green innovation by promoting research on the role of major customers and major suppliers in green innovation and exploring the mechanisms by which major customers and major suppliers influence green innovation.

It has been noted that R&D investment can contribute to green innovation. Xu et al. (2021) [8] point out that R&D investment has a positive impact on the concept of green innovation performance. Fan & Teo (2022) [9] found a significant double-threshold effect of R&D investment on lagged three-period green innovation performance when the level of regional technological innovation was used as the threshold variable. The importance of major customers and suppliers for green innovation has also been established by other scholars [10–12]. However, the role of R&D investment in mediating the influence of major customers (suppliers) on green innovation has not yet been investigated and therefore needs to be further explored.

We used a fixed effects model to examine the impact of customer concentration and supplier concentration on green innovation among Chinese listed enterprises in 2013–2020, and explored whether R&D investment played a mediating role in this. We find that there is a negative relationship between customer concentration and green innovation, and supplier concentration also negatively affects green innovation; R&D investment plays a partial mediating role in both types of negative relationships. In addition, the negative relationship between customer concentration (suppliers) and green innovation is more significant in non-state-owned enterprises than in state owned enterprises; both negative relationships are more evident in enterprises in the eastern region.

The main contributions of this study are as follows. First, unlike existing studies that explore the role of institutional pressure and government subsidies in driving green innovation, this study focuses on the influence of key customers and key suppliers on green innovation, providing a new perspective on green innovation research and extending the study of green innovation influencing factors. Second, this study investigates the mechanism of customer concentration (supplier concentration) on green innovation. The literatures have shown that major customers and major suppliers are important for green innovation, that major customers and major suppliers have a significant impact on R&D investment, and that R&D investment has a positive effect on green innovation. This study uses R&D investment as a mediating variable, which is not only innovative but also can provide a reference for the R&D management of enterprises. Third, we examine the effects of customer concentration (supplier concentration) on green innovation by taking into account the type of ownership and the enterprise's location. The results of the study show that the negative relationship between customer concentration (supplier concentration) and green innovation is more significant in the sample of low

digital transformation enterprises, suggesting that the digital transformation also have an impact on the major customers (suppliers)-green innovation relationship.

2 Literature Review and Research Hypotheses

2.1 Green Innovation

Due to the severity of the present environmental issues, enterprises are becoming more and more concerned about how their activities and production affect the environment. All enterprises, especially those that produce a lot of pollution, actively engage in green innovation activities, green transformation, and enhancement of their green core competitiveness, including green innovation of their technology and products [13]. A special subject on eco-innovation was established by the EU in 2007 (Measuring Eeco-innovation, MEI). The MEI project defined ecological innovation as innovations that can successfully reduce environmental risks, different pollution, and resource consumption throughout the activity cycle, including new products, production technologies, services, management of all production, adoption, or development of enterprise practices. Green innovation can be categorized as green processes and green goods, including technological advancements in green product design, energy conservation, pollution control, resource recovery, or enterprise environmental management [14]. Green innovation is the process of helping to create new production and technologies with the aim of reducing environmental risks, such as reducing air pollution and land degradation [15].

The most popular research topics in the field of green innovation are the benefits of putting green innovation into practice [11, 14, 16]. Previous studies [1, 5, 16, 17] mostly examined enterprises in the manufacturing sector, and questionnaire surveys were frequently utilized in these studies [14, 17]. From the perspective of external driving factors of green innovation of enterprises, scholars focus on the impact of environmental regulation and government subsidies on the performance of green innovation of enterprises. Pascual Berrone et al. (2013) [18] argued that greater regulatory and normative pressures concerning environmental issues positively influence firms' propensity to engage in environmental innovation. Qi & Jia (2021) [4] believed both regulatory pressure and imitative pressure had a positive influence on firms' green technology innovation. Besides, some scholars have studied the influence of environmental rights market [4], corporate social responsibility practices [19] and other factors on the green innovation of firms.

Among the external factors influencing green innovation of enterprises, customers and suppliers who are closely related to enterprises and are in the same supply chain have become the main objects for enterprises to seek heterogeneous resources externally [12]. Collaboration between enterprises and various sorts of organizations allows enterprises access external diverse resources, which boosts the effectiveness of green innovation. Enterprises increasingly rely on resources from the supply chain during the research and development of new products, and they frequently work with supply chain partners to complete innovation-related activities. Nevertheless, few studies have examined the impact on green innovation from the perspective of major customers and major suppliers. Therefore, the purpose of this study is to clarify the impact of major customers (major suppliers) on green innovation and to identify possible mechanisms.

2.2 Major Customers and Suppliers

It is challenging for enterprises to innovate effectively in the current highly competitive market climate if they only rely on their own resources, and their ability to do so is intimately correlated with those of other supply chain participants [20]. Customers and suppliers who are part of the same supply chain are significant direct stakeholders for an enterprise and have an impact on its operations, particularly its green innovation activities. Enterprise s may opt to form strategic alliances with a small number of major customers and suppliers in order to get an advantage in the fierce market rivalry. Because major customers and major suppliers are precisely related to the enterprise's operating activities, national accounting standards bulletins, the Securities and Exchange Commission, etc. have been regulating and requiring the disclosure of information on major customers in recent years. SFAS 131, Sect. 39, issued by the U.S. Accounting Standards Board, stated that "if revenue from transactions with a single external customer amounts to 10 percent or more, the enterprise should disclose that fact, the total revenue per customer". In China, the Securities and Exchange Commission also required listed enterprises to disclose information about their top five customers and suppliers in 2012.

Scholars often use customer concentration (supplier concentration) to examine the relationship between major customers (suppliers) and the enterprise [7, 21–23]. Numerous empirical investigations have demonstrated a connection between customer concentration (supplier concentration) and enterprises operations. Peng et al. (2019) [24] proposed that customer concentration is positively correlated with informal financing; Cao et al. (2021) [25] found through empirical research that reduced customer concentration significantly reduces the risk borne by firms; Gu et al. (2022) [26] believed that a higher concentration of core suppliers and customers could have a negative impact on an enterprise's financial performance. A few scholars have also studied the relationship between customer concentration (supplier concentration) and innovation. Chen et al. (2022) [27] proposed a U-shaped relationship between supplier concentration and corporate innovation; Zou & Zhang (2022) [28] concluded through empirical research that the higher the concentration of suppliers, the lower the investment in innovation.

Scholars have focused on the impact of major customers(suppliers) on firms' financial performance, while less research has been conducted on the impact of major customers(suppliers) on firms' non-financial performance (e.g., green innovation). According to the research findings, major customers (suppliers) did influence firm green innovation, but there was debate among researchers as to whether this influence was positive or negative. In order to accurately assess the role of differentiation brought on by major customers and major suppliers, the existing literature has neither extensively investigated the internal mechanisms of major customers and major suppliers nor made a comprehensive distinction between the characteristics of enterprises. The relationship between major customers (suppliers) and firm green innovation, requires further study. Therefore, drawing on previous research, we use customer concentration (supplier concentration) as a proxy variable for a firm's relationship with its major customers (suppliers) to investigate the impact of major customers (suppliers) on green innovation.

2.3 Hypothesis Development

According to the stakeholder theory, it is important to take into account the interests of persons and groups connected to the enterprise as well as one's own during the development of an enterprise [29]. The enterprise risks of an enterprise are not only borne by shareholders, but also by customers. Therefore, customers will influence the enterprise operation of the enterprise in some ways, so as to obtain benefits matching the risks they bear. Major customers must be considered in the research framework for corporate governance because they are important stakeholders in the enterprise and will affect its operations directly or indirectly. Enterprises mostly get their operating earnings from major customers in the supply chain. Enterprise activities, including production, are centered on customer requirements, which promotes enterprise expansion. In essence, enterprises use green innovation to gain a sustainable competitive benefit in order to increase market share, to occupy more customers in order to increase development opportunities. Therefore, whether from an active or passive perspective, major customers have an important impact on the enterprise activities of enterprises.

The following factors can be used to examine how major consumers and green innovation are related. First, from a financial standpoint. An enterprise requires more specialized investment to sustain the contractual relationship with its core consumers. The more concentrated its consumer is, the increase of specialized investment scale may result in firms being locked up by important customers (major customers), as the value of specialized investment will be significantly diminished once it is employed for other purposes [21, 23]. Under the pressure of core customers, enterprises may need to make compromises in reducing sales prices, extending enterprise credit and reserving excess inventory, which will reduce their valuable working capital and aggravate their financing constraints [30]. Creditors will also demand that enterprises with major customer concentration pay higher debt financing charges when issuing bonds in anticipation of this [7]. Strong relationships with major customers will make the enterprise's financial restrictions worse, which will be negative for green innovation. Second, from the perspective of operational risk, there is typically a correlation between high ratio of major customers and high operational risk. Once the enterprise loses its main customers, its sales revenue will drop quickly and it will run the risk of losing the product market [21]. In the initial stage of relationship building with major customers, in order to maintain the relationship with key customers, enterprises will make a lot of proprietary investment. Enterprises that lose major customers are difficult to find new and suitable customers in the short term. The above risks will inhibit enterprises from carrying out green innovation activities. On the one hand, major customers occupy the resources that enterprises can carry out innovation activities. On the other hand, enterprises often choose conservative investment strategies to deal with the above risks, thus reducing innovation investment. Therefore, a concentrated customer base will likely inhibit green innovation. These arguments lead to the first hypothesis:

H1a: Customer concentration has a negative impact on green innovation.

As an important stakeholder of enterprises, suppliers' heterogeneous resources are one of the sources of green innovation driving forces of enterprises [27]. Suppliers cannot share the same technology or knowledge. Each supplier has its own differentiation advantage, which is the result of their continuous accumulation of heterogeneous resources

in development [31]. Generally speaking, the more the number of suppliers, the richer the heterogeneous resources of suppliers. Such heterogeneous resources include scientific research talents, cutting-edge technologies and new product processes. Therefore, from the perspective of heterogeneous resource acquisition, the number of suppliers of a firm is positively associated with the availability of heterogeneous green innovation resources.

High percentage of major suppliers means that enterprises are more dependent on their major suppliers. When there is a competitive connection between the two parties, this dependency increases the major suppliers' bargaining position. Strong supplier bargaining strength encourages suppliers to raise prices, lower quality, et al., raising procurement expenses, making it more difficult for enterprises to supply the downstream market, and impacting enterprises' operational revenue [32]. On the one hand, these behaviors of major suppliers transfer part of their own enterprise risks to enterprises; on the other hand, they require enterprises to invest more in special assets needed to maintain relationships [28], which brings double pressures of risks and funds to enterprises and limits enterprises' investment in green innovation activities. Based on the above analysis, in order to study the impact of major suppliers on enterprise green innovation, the following assumptions are proposed:

H1b: Supplier concentration has a negative impact on green innovation.

As the stakeholders of the enterprise, the major customers of the enterprise have an important impact on the enterprise decisions of the enterprise [22]. Enterprises must raise their investment in specific assets in order to retain the contractual relationship with major customers. Investment in special assets is specific and irreversible. Once the use is altered, the value of special assets will decline, which will lead to significant conversion expenses for enterprises and aggravate their financial crisis and economic burden. When external investors anticipate an increase in the enterprise risk and financial risk of the enterprise, they will demand a higher risk premium, increasing the cost of the enterprise's external financing and possibly leading to a capital shortage. Dhaliwal et al. (2016) [7] verified through empirical research that increasing concentration of major customers will increase financing costs for enterprises. If major customers face financial risks, the enterprise is not only difficult to complete the expected sales plan to achieve the expected cash flow, but also difficult to recover the previous sales revenue (accounts receivable), which makes the financial risks of major customers transferred to the enterprise to a large extent. Due to its prolonged investment cycle, high level of uncertainty, and challenges in evaluation and measurement, innovation is viewed as a high-risk investment. Presence of major customers concern make it challenging for enterprises to manage the risks brought on by green innovation, lower their capacity to do so, and drive them to cut down on innovation investment.

H2a: Customer concentration has a negative impact on R&D investment.

R&D investment activities often have a long cycle, require high investment and have a large risk. Enterprises must devote a significant amount of resources to innovation activities and development investments. An enterprise's financial condition will worsen if it fails to make investments in R&D, which will have a bigger detrimental effect on suppliers. Future profits, even if it is successful, will not be distributed to suppliers. In this situation, major suppliers will prohibit enterprises from investing in high-risk projects

in order to guarantee the stability of their own revenues. As major suppliers become more concentrated, their bargaining power increases, forcing enterprises to cut down on R&D investment. In addition, in order to maintain the relationship with major suppliers, which is an important external stakeholder of the enterprise, the enterprise will conduct large-scale relationship specific investment, which will make the enterprise face higher financial risks. A large amount of relationship specific investment means that once the major supplier changes, it will bring large switching costs to the enterprise. Enterprises must prepare sufficient cash flow as a safeguard because increased supplier concentration involves higher risks. In this situation, the enterprise won't have enough money to invest in R&D. Therefore, enterprises become less free to invest in R&D the higher the supplier concentration. Based on the above analysis, we propose the hypothesis H2b.

H2b: Supplier concentration has a negative impact on R&D investment.

Innovation is a crucial strategy for firms seeking to achieve a competitive edge. The capacity of new goods to innovate can have a significant impact on an enterprise's ability to increase its market share. The R&D investment of the enterprise has a significant impact on the enterprise's product production, technology development, and other aspects during this process and serves as the material foundation for the conversion of technological innovation ability into competitiveness [33]. The acquisition of hardware, software, and equipment for green process technology can be ensured through the use of R&D investment; however, employee creativity serves as the foundation and origin of green innovation. The guarantee of R&D investment helps to strengthen the green innovation awareness of relevant personnel, provide training, learning and other conditions for carrying out corresponding work, which helps to improve the green innovation ability in an all-round way from equipment to personnel quality. Therefore, we propose the following hypothesis about the relationship between R&D investment and enterprise green innovation:

H3: R&D investment has a positive impact on green innovation.

To sum up, both concentration of major customers and concentration of major suppliers can have a significant negative impact on enterprise green innovation. When customer concentration and supplier concentration are high, enterprises will reduce R&D investment to deal with the operational risks brought by high customer concentration and supplier concentration, and the reduction of R&D investment is not conducive to the improvement of enterprises' green innovation ability. Based on the above analysis, we propose the following conclusions.

H4a: R&D investment mediates customer concentration and green innovation.

H4b: R&D investment mediates supplier concentration and green innovation.

We provide an integrated framework for this study, as shown in Fig. 1.

3 Data and Methods

3.1 Sample Selection

The A-share listed firms in China from 2013 to 2020 were chosen as the initial sample due to the data of listed enterprises' open and transparent characteristics. Because the China Securities Regulatory Commission required listed enterprises to publish additional

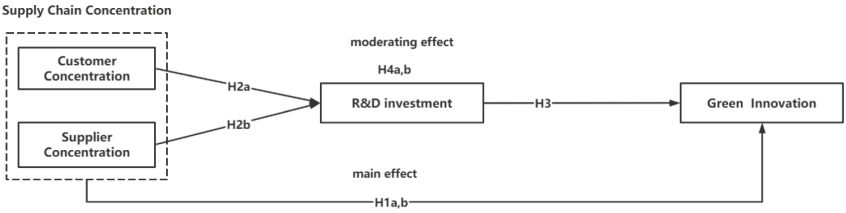

Fig. 1. Conceptual model

pertinent information about their customers and suppliers in 2012, the year 2013 was chosen as the sample data period. The sample data is therefore made more thorough and accessible by choosing the data of the listed firms after 2012 for study.

Similar to other studies [1, 25, 30], we exclude (1) financial firms, (2) special treatment firms, (3) firms that also issue B- or H-shares, and (4) firms with missing accounting and financial information. In order to minimize the influence of outliers on the results of estimation, winsorization was performed on the 1% and 99% quantiles of all continuous variables.

We collected data from multiple sources. In this study, the information and suppliers of customers data are from the "enterprise research series" sub database in the China stock market and accounting research (CSMAR) database, the listed enterprise governance data and financial data used in the research are from other sub databases in CSMAR database. The green patent application data of listed enterprises comes from the China research data service platform (CNRDS), this database fully complies with the green patent standards of the world intellectual property office for the classification of green patents, and counts patents from the state intellectual property office and google patent. Stata 16.0 is used for data sorting and analysis.

3.2 Variable Definition

3.2.1 Independent Variables

Customer concentration (supplier concentration) is the independent variables in this study to measure the relationship between major customers (suppliers) and enterprise. In existing research, researchers often use the proportion of sales (purchasing) of the largest customer (supplier) or the proportion of sales (purchasing) of the top five customers (suppliers) as a measure of customer (supplier) concentration index. The measurement of customer (supplier) concentration in this study draws on the measurement method of market concentration in the theory of industrial organization. This measurement method can reflect the number of customers and suppliers in the supply chain, and also takes into account the impact of each customer and supplier on the enterprise. Referring to the research of Dhaliwal et al. (2016) [7], this research uses the following method to measure the customer(supplier) concentration, taking the Herfindahl-Hirschman Index (HHIc) of the top five customers as a measure of enterprise customer concentration, and taking the Herfindahl-Hirschman Index (HHIs) of the top five suppliers as the measurement of an enterprise's supplier concentration.

The formula for calculating the Herfindahl-Hirschman Index of the top five customers is: $HHIC = \sum_{i=1}^{5} \left(\frac{Xi}{X}\right)^2$, Xi is the sales volume of the ith largest customer, and X is the total sales volume of the enterprise. The formula for calculating the Herfindahl-Hirschman Index of the top five suppliers is: $HHIS = \sum_{i=1}^{5} \left(\frac{Yi}{Y}\right)^2$, Yi is the purchase amount of the ith largest supplier, and Y is the total purchase amount of the enterprise. In the robustness test, the proportion of the top five customers in the annual sales volume (the proportion of suppliers in the annual purchase volume) is used as a measure of customer (supplier) concentration for the robustness test.

3.2.2 Dependent Variable

Green innovation is the dependent variable in this study. There are two main ways to measure green innovation: one is to choose the number of green patent applications; the second is to choose green patent licensing. Referring to the practice of Liu et al. (2022) [34], the study also uses the number of green patents applied by listed enterprises to characterize the green innovation of enterprises. It usually takes one to two years for a patent to be applied for and authorized. In contrast, the patent application data will be more stable, reliable and timely than the amount granted. Considering that there is a certain lag in the number of green patent applications, and in order to reduce the possible heteroscedasticity of the data, we use the data lagging one period (GIt + 1) to measure enterprise innovation. In the robustness test, the data of the dependent variable (GIt + 3) lagging behind three periods were used for regression analysis again.

3.2.3 Mediating Variable

R&D investment is the mediator of this study. In the existing research, there is no uniform standard for scholars to measure innovation input. It mainly includes the following methods: logarithm of R&D investment, ratio of R&D investment to operating income, logarithm of R&D staff, etc. This study uses the logarithm of R&D investment as the measurement index of R&D investment.

3.2.4 Control Variables

Considering that the enterprise green innovation is affected by multiple factors, refer to the existing research. This study selects the following control variables: (1) enterprise characteristic indicators: enterprise scale and years of being listed; (2) corporate governance indicators: integration of two positions and the number of directors; (3) enterprise financial indicators: asset-liability ratio, return on assets, return on equity, operating cash flow ratio, cash asset ratio and Tobin Q value. Because the above variables will affect the innovation performance of enterprises, they are set as control variables and controlled in the regression analysis.

This study also controls for the fixed effects of year and industry. Each variables' definitions are shown in Table 1.

Table 1. The main variable definition

Variable Nature	Variables	Symbol	Variable Description
Dependent variables	Green Innovation	GI_{t+1}	Ln (Number of green invention applications $_{t+1}$ + 1)
Independent variables	Customer concentration	HHIc	Top 5 customers Herfindahl-Hirschman Index
	Supplier concentration	HHIs	Top 5 suppliers Herfindahl-Hirschman Index
Mediator	R&D investment	R&D	Ln (R&D investment + 1)
Control variables	Enterprise scale	Size	Ln (Total assets)
	Date of being listed of the enterprise	List time	Ln (Years of enterprise establishment + 1)
	Innovation input	LEV	Ln (R&D investment)
	Return on assets	ROA	Net profit/ Total assets
	Return on net assets	ROE	Net profit/ Average balance of shareholders' equity
	Two positions in one	Dual	The chairman and general manager are the same person, and the value is "1", otherwise, the value is "0"
	Tobin Q value	Tobin Q	Market value / Total assets
	Number of Directors	Board	Ln (Number of Directors)
	Degree of shareholding checks and balances	Balance	The sum of the shareholdings of the second to fifth largest shareholders/ Shareholding of the first largest shareholder
	Book to market ratio	BM	Shareholders' equity/Market value
	The audit comes from the four major international accounting firms	Big4	The value of audit from the four major accounting firms is "1", otherwise it is "0"
Year	Year effect	Year	The year virtual variable
Industry	Industry effect	Industry	Industry virtual variables

3.3 Empirical Model

In view of the core problem of research, the impact of customer (supplier) concentration on green innovation, refer to Huang et al. (2022) [12]. The study constructs the following model:

$$GI_{t+1}yi = \beta 0 + \beta 1HHIc(HHIs) + \delta 1X + \varphi 1y + \eta 1i + \varepsilon_1 \quad (1)$$

In the model, green innovation (GI_{t+1}) is the dependent variable; HHIC(HHIs) is the core independent variable: customer (supplier) concentration; X represents a series of control variables; y represents the year, and i represents the industry; ε1 is the residual. For the year fixed effect, control the impact of external economic environment and policies on enterprises; φ1y is the year fixed effect, η1i is the industry fixed effect, control the impact of industry economic environment and innovation ability on green innovation.

4 Empirical Results

4.1 Descriptive Statistics

Descriptive statistics of variables are shown in Table 2. The maximum value of the dependent variable green innovation (GI t + 1) is 7.639, the minimum value is 0, and the standard deviation is 1.76, indicating that the number of green patent applications between enterprises is significantly different.

From the perspective of the independent variable indicators HHIc, the average customer concentration is 0.053 and the maximum value is 0.569, indicating that some listed enterprises have significant differences in customer concentration, and some listed enterprises have high dependence on the first few customers. The average of the supplier concentration degree is 0.054, the maximum value is 0.486, the minimum value is 0.001, indicating that there is a large difference in the supplier concentration between different enterprises. Comparing the two types of concentration, the supplier concentration of listed enterprises is higher than the customer concentration.

The minimum value of R&D investment is 14.065, the maximum value is 22.064, and the standard deviation is 1.431, indicating that different listed enterprises have large differences in R&D investment. From the perspective of control variable indicators, the average enterprise size is 22.305, and the standard deviation is 1.307; the average of the enterprise's years of being listed is 1.952, and the standard deviation is 0.992, indicating that there is little difference between the enterprise size and the enterprise's years of being listed in the sample. In general, the changes of control variable indicators selected by the sample are within a reasonable range.

4.2 Main Effects Regression Results

This study analyzes the relationship between customer concentration (supplier concentration) and green innovation. Table 3 shows the regression results. It can be seen from the results in Table 3 that R-squared is over 0.3, which indicates that the model fit in Sect. 4.3 is good. As shown in model (1), the coefficient of HHIc is − 0.541, which is

Table 2. Descriptive statistics

Variables	Min	P25	Mean	Median	P75	Max	Std.
GI_{t+1}	0.000	0.000	1.239	0.693	1.946	7.639	1.762
HHI_c	0.000	0.005	0.053	0.017	0.056	0.569	0.095
HHI_s	0.001	0.009	0.054	0.023	0.060	0.486	0.083
R&D	14.065	17.213	18.083	18.043	18.931	22.064	1.431
Size	20.007	21.372	22.305	22.124	23.029	26.407	1.307
List time	0.000	1.386	1.952	2.079	2.773	3.296	0.922
LEV	0.059	0.255	0.412	0.405	0.558	0.853	0.194
ROA	-0.285	0.017	0.042	0.041	0.071	0.205	0.063
ROE	-0.483	0.036	0.077	0.080	0.129	0.350	0.112
Dual	0.000	0.000	0.310	0.000	1.000	1.000	0.462
Tobin Q	0.000	0.808	2.135	1.543	2.757	10.691	1.999
Board	0.000	1.946	2.115	2.197	2.197	2.890	0.199
Balance	0.011	0.384	0.87	0.705	1.193	4.000	0.64
BM	0.000	0.317	0.919	0.580	1.087	6.245	1.039
Big4	0.000	0.000	0.057	0.000	0.000	1.000	0.232

significant at the 5% significance level. The results in model (2) show the coefficient of HHIs is -1.079, which is significant at the 1% level, thereby indicating that both HHIc and HHIs are negatively related to green innovation. Hypotheses 1a and 1b are supported.

4.3 Mediating Effect Regression Results

In order to further test the mechanism of customer concentration (supplier concentration) on enterprise green innovation, the mediating effect model is used to start from the path of R&D investment how customer concentration (supplier concentration) affects green innovation. The mediating effect test is completed in three steps. The first step is to study the impact of customer concentration (supplier concentration) on green innovation, the second step is to study the impact of supplier concentration on R&D investment, and the third step is to study the impact of supplier concentration on green innovation after adding mediating variable. Equation (2) examines the relationship between customer concentration (supplier concentration) and R&D investment, and Eq. (3) examines the impact of customer concentration (supplier concentration) and R&D innovation on green innovation.

$$\text{RD yi} = \gamma 0 + \gamma 1\ \text{HHIc(HHIs)} + \delta 2\text{X} + \phi 2\text{y} + \eta 2\text{i} + \varepsilon_2 \tag{2}$$

$$\text{GIt} + 1\ \text{yi} = \theta 0 + \theta 1\ \text{HHIc(HHIs)} + \theta 2\,\text{R\&D}\ \delta 3\text{X} + \varphi 3\text{y} + \eta 3\text{i} + \varepsilon_3 \tag{3}$$

Table 3. Regression analysis results

Variables	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)	Model (7)
	$GI1_{t+1}$	$GI1_{t+1}$	R&D	R&D	GI_{t+1}	GI_{t+1}	GI_{t+1}
HHI_c	−0.541**		-0.737***			−0.455**	
	(0.212)		(0.126)			(0.225)	
HHI_s		-1.079***		-1.098***			−0.994***
		(0.213)		(0.126)			(0.227)
R&D					0.241***	0.230***	0.235***
					(0.019)	(0.022)	(0.022)
size	0.680***	0.688***	0.896	0.879	0.492***	0.508***	0.515***
	(0.024)	(0.025)	(0.014)	(0.015)	(0.028)	(0.032)	(0.033)
List time	-0.071***	−0.063**	0.015	0.031*	−0.033	-0.089***	−0.089***
	(0.027)	(0.028)	(0.016)	(0.016)	(0.025)	(0.028)	(0.029)
LEV	0.592***	0.597***	0.028	0.067	0.650***	0.716***	0.723***
	(0.119)	(0.122)	(0.070)	(0.071)	(0.113)	(0.123)	(0.127)
ROA	−0.449	−0.385	0.435**	0.446**	-0.685*	−0.529	-0.443
	(0.342)	(0.344)	(0.203)	(0.203)	(0.354)	(0.360)	(0.362)
ROE	0.337**	0.310**	0.024	0.034	0.499***	0.340**	0.305*
	(0.157)	(0.157)	(0.092)	(0.091)	(0.161)	(0.163)	(0.163)
Dual	−0.089**	– 0.091**	−0.040**	−0.037*	−0.063*	−0.076**	−0.082**
	(0.035)	(0.036)	(0.020)	(0.020)	(0.032)	(0.035)	(0.036)
Tobin Q	0.006	0.011	0.034***	0.037***	0.002	−0.005	−0.001
	(0.008)	(0.009)	(0.005)	(0.005)	(0.008)	(0.009)	(0.009)
Board	0.165*	0.152	0.077	0.103*	0.117	0.121	0.121
	(0.090)	(0.092)	(0.052)	(0.053)	(0.085)	(0.093)	(0.095)
Balance	−0.053**	−0.045*	0.026*	0.022	−0.056**	−0.056**	−0.046
	(0.026)	(0.027)	(0.015)	(0.016)	(0.025)	(0.027)	(0.028)
BM	-0.247***	-0.231***	-0.354***	-0.345***	-0.165***	-0.217***	−0.205***
	(0.031)	(0.031)	(0.022)	(0.022)	(0.031)	(0.040)	(0.041)
Big4	0.037	0.008	0.302***	0.304***	−0.122	−0.048	−0.080
	(0.098)	(0.099)	(0.056)	(0.057)	(0.089)	(0.101)	(0.103)

(*continued*)

Table 3. (*continued*)

Variables	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)	Model (7)
	$GI1_{t+1}$	$GI1_{t+1}$	R&D	R&D	GI_{t+1}	GI_{t+1}	GI_{t+1}
Year FE		Y					
Firm FE		Y					
Adj R^2	0.3448	0.6036	0.6050	0.3539	0.3590	0.3587	0.3587
N	7162						

***, **, and * indicate 1%, 5%, and 10% significance, respectively.

Models (1), (3) and (6) in Table 3 test whether R&D investment plays a mediating role between customer concentration and green innovation via stepwise regression. Model (3) is the regression result of Eq. (2). There is a negative correlation between customer concentration and R&D investment, which passes the significance test with a significance level of 1%, supports H2a. Model (6) verifies Eq. (3). It is found that the coefficient between HHIc and R&D becomes -0.455 after the R&D investment index is added, and R&D and GIt + 1 are significantly positively correlated at the level of 1%, with a coefficient of 0.230. The results show that R&D investment plays a part of mediating role in the negative impact of customer concentration on green innovation, assuming that H4a is partially supported. H4a are partially supported. Model (5) shows that the regression coefficient of R&D investment is 0.241, passing the significance test with a significance level of 1%, indicating that the increase of R&D investment can significantly positively affect the green innovation of enterprises. H3 is supported.

The models (2), (4) and (7) in Table 3 test whether R&D investment plays a mediating role in the relationship between supplier concentration and green innovation. In model (4), the regression coefficient of HHIs is −1.098 and through the significance test with a significance level of 1%, which shows that supplier concentration inhibits R&D investment, and H2b is supported. It can be seen from model (7) that the regression coefficient of HHIs becomes −0.994 after adding R&D investment, which is significant at the 1% significance level, and the regression coefficient of R&D is 0.235, which is also significant at the 1% significance level. The regression results show that R&D investment also plays a part of the mediating role in the impact of supplier concentration on green innovation, assuming that H4b is partially supported.

4.4 Endogeneity Test

4.4.1 PSM Sample Inspection

In this study, the PSM sample test method is used to overcome the endogenous problems that may exist in the sample. First, depending on whether the top1 enterprise's customer concentration is higher than 10% [35], the enterprise with high customer concentration is regarded as the treatment group; Secondly, control the variables at the enterprise level, such as the size of listed enterprises, ROA, Tobin Q, and use the 1:4 proximity matching principle to obtain enterprises with low customer concentration; Finally, the samples are

Table 4. PSM sample inspection results

Variables	(1)	(2)
	$\_GI_{t+1}$	$\_GI_{t+1}$
HHIc	-0.260^{***}	
	(0.099)	
HHIs		-0.426^{***}
		(0.117)
Control variables	Control	
Year FE	Y	
Industry FE	Y	
Adj R^2	0.3376	0.1961
N	10964	

***, **, and * indicate 1%, 5%, and 10% significance, respectively.

combined for the re test of Eq. (1). According to whether the top1 enterprise's supplier concentration is higher than 10%, the enterprise with high supplier concentration is regarded as the treatment group; Secondly, control the variables at the enterprise level, such as the size of listed enterprises, ROA, Tobin Q, and use the 1:4 proximity matching principle to obtain enterprises with low customer concentration; Finally, the samples are combined for the re test of Eq. (1).

Table 4 reports the regression results of PSM samples, which are consistent with Table 3.

4.4.2 Heckman Two-Step Method

This study may also have endogenous problems caused by sample selection. So we adopts Heckman two-step method to solve the problem of sample selection caused by voluntary disclosure of customer (supplier) concentration. Using the research of Baumann & Kritikos (2016) [36] for reference, in the first stage, the inverse Mills coefficient (IMR) is calculated according to the Probit equation of customer (supplier) information disclosure. In the second stage, the Inverse Mills coefficient (IMR) is included in the model to correct the sample selection deviation. The test results are shown in Table 5. The customer' IMR in column (2) of Table 5 is 4.435, and the supplier' IMR in column (4) is 4.520, both of which are significant at the 1% level, indicating that the problem of sample selection is well controlled. The regression coefficient of customer concentration in column (2) in Table 5 is -0.664, and it is significantly positive at the level of 1%; The regression coefficient of supplier concentration in column (4) is -1.052, which is significantly positive at the level of 1%, consistent with the test conclusions of H1a and H1b above.

Table 5. Heckman two-step method results

Variables	HHIc and GI_{t+1}		HHIs and GI_{t+1}	
	(1)	(2)	(3)	(4)
	One step	Two step	One step	Two step
HHIc		−0.664***		
		(0.207)		
HHIc IMR		4.435***		
		(0.224)		
HHIs				−1.052***
				(0.207)
HHIs IMR				4.520***
				(0.229)
size	0.437***	1.762***	0.434***	1.786***
	(0.014)	(0.059)	(0.014)	(0.061)
List time	0.017	−0.013	0.010	−0.004
	(0.015)	(0.027)	(0.017)	(0.027)
LEV	0.053	0.695***	0.040	0.686***
ROA	(0.078)	(0.116)	(0.080)	(0.119)
	0.012	-0.245	−0.328	−0.193
	(0.280)	(0.333)	(0.318)	(0.334)
ROE	0.297**	1.286***	0.469***	1.292***
	(0.147)	(0.160)	(0.169)	(0.160)
Dual		−0.664***		−0.093***
		(0.207)		(0.035)
Tobinq		−0.089***		−0.002
		(0.034)		(0.008)
board		−0.005		0.164*
		(0.008)		(0.090)
balance		0.185**		−0.034
		(0.087)		(0.026)
BM		−0.041		−0.174***
		(0.026)		(0.031)
big4		−0.196***		−0.050
		(0.030)		(0.097)

(*continued*)

Table 5. (*continued*)

Variables	HHIc and GI_{t+1}		HHIs and GI_{t+1}	
	(1)	(2)	(3)	(4)
	One step	Two step	One step	Two step
Year FE	Y			
Industry FE	Y			
Adj R^2	/	0.3762	/	0.3809
N	10317	7160	10317	7160

***, **, and * indicate 1%, 5%, and 10% significance, respectively.

4.5 Robustness Test

4.5.1 Replace the Measures of Customer (Supplier) Concentration

The regression analysis of the model in Table 3 uses the top five customer (supplier) Herfindahl-Hirschman Index as a measure of the customer (supplier) concentration. Referring to the study of Chen et al. (2022) [27], in this study, we select the ratio of the top five suppliers' purchases (SC) to the total annual purchases and the ratio of the top 5 customers' sales (CC) to the total annual sales for the robustness test. The regression results are shown in (1) and (2) columns of Table 6. The regression results are consistent with the previous research conclusions, the high customer concentration and the high supplier concentration negatively suppresses the enterprise green innovation. This shows that the previous research conclusions still hold after replacing the customer (supplier) concentration measurement.

4.5.2 Replace the Samples

The sample used in this study is Chinese A-share listed enterprises from 2013 to 2020. However, the information of customers and suppliers is voluntarily disclosed by enterprises, the willingness of enterprises to disclose information to customers and suppliers may cause bias in the results of empirical research. Therefore, a robustness test was conducted on a sample of Chinese manufacturing listed enterprises from 2013 to 2020, and the same data processing steps as those in Sect. 4.1 were carried out. The regression results are shown in columns (3) and (4) of Table 6. The regression results show that both customer concentration and supplier concentration inhibit green innovation, and the research conclusion after replacing the sample is consistent with the previous results.

4.5.3 Lagging Dependent Variable

The above uses the number of green innovation patent applications to measure the green innovation behavior of enterprises, which supports the negative correlation between customer (supplier) concentration and green innovation of enterprises. However, green innovation input can only be converted into green patent output after a certain period, so the impact of changes in customer concentration and supplier concentration on green

Table 6. Robustness Test

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	GI_{t+1}	GI_{t+1}	GI_{t+1}	GI_{t+1}	GI_{t+3}	GI_{t+3}
CC	-0.241***					
	(0.082)					
SC		-0.599***				
		(0.089)				
HHIC(manufacturing)			-0.649**			
			(0.264)			
HHIs(manufacturing)				-1.521***		
				(0.279)		
HHIc					-0.682***	
					(0.259)	
HHIs						−1.168***
						(0.266)
Control variables	Control					
Year FE	Y					
Industry FE	Y					
Adj R^2	0.3465	0.3533	0.3260	0.3343	0.3269	0.3296
N	8850		5331		5222	

***, **, and * indicate 1%, 5%, and 10% significance, respectively.

innovation may also have a time lag. In order to avoid the negative impact of the lag of the number of green innovation patent applications on the empirical results, this study regresses the number of green innovation patent applications after three periods of lag. The test results are shown in columns (5) and (6) of Table 6. It can be found that customer concentration and supplier concentration are still highly negatively correlated with the level of green innovation of enterprises, which again verifies the main hypothesis of this study.

4.5.4 Mediation Effect Test with Sobel Test

Considering the limitations of three-step regression method in testing mediation effects this study uses Sobel test to test the robustness of mediation effects. Table 7 reports the results after controlling the above control variables and the industry and year dummy variables. The results show that R&D investment has a partial intermediary effect of 0.275 in the relationship between customer concentration and green innovation; R & D investment has part of the intermediary effect of 0.206 in the relationship between supplier concentration and green innovation and the robustness of the intermediary effect has been verified.

Table 7. Sobel test results

Path model	Soble Z	P > |Z|	Proportion of Mediating effect
HHIc - > R&D - > GI	−5.445	5.185e−08	0.275
HHIs - > R&D - > GI	−6.680	2.393e−11	0.206

***, **, and * indicate 1%, 5%, and 10% significance, respectively.

4.6 Heterogeneity Test

In the context of the digital economy, the widespread use of digital information technologies such as big data, mobile internet and cloud computing has greatly facilitated the high-speed flow of information, which can thus effectively reduce the information asymmetry between various business entities [37, 38]. For example, investors are able to use data collected by means such as big data to judge the feasibility and specific economic benefit value of innovative projects to be realized, thus reducing the information asymmetry between investors and enterprises regarding innovative projects [39]. Increased information transparency helps to alleviate the financing constraints faced by firms, thus enabling them to access significant external investment at a lower price, and the external resources needed for green innovation are secured. At the same time, digital transformation can improve the input-output efficiency of green innovation activities by increasing productivity and resource allocation efficiency. Therefore, digitally transformed companies are better suited to the development needs of the digital economy, gaining the attention and recognition of external investors, and are more likely to gather innovation resources to support green innovation activities.

This paper divides the high and low groups of the degree of digital transformation and re-runs the regression test to explore the differentiated role of large customers (large suppliers) on corporate green innovation under different digital transformation development base conditions. This study divided the sample into a high digital transformation group (DT-high) and a low digital transformation group (DT-low) based on the criterion of whether the degree of digital transformation was higher than the mean value of the degree of digital transformation. The regression results are shown in Table 8. DT denotes the degree of digital transformation of enterprises, and the measurement method used was textual analysis [37] to build a lexicon of words in the annual reports of enterprises on the segmentation indicators of cloud computing technology, big data technology, digital technology application, blockchain technology and artificial intelligence technology, and use Python to identify the count and take the logarithm of the frequency of occurrence of the words. In this study, based on Tu et al. (2023) [40], the digital transformation lexicon was divided into "underlying technology application layer" and "digital technology application layer" and intersected to form the digital transformation Thesaurus.

From the results in Table 8, the negative effect of customer concentration on green innovation is not significant in enterprises with a higher degree of digital transformation; the negative effect of supplier concentration on green innovation is lower than in the sample with a lower degree of digital transformation, indicating that digital transformation by enterprises is conducive to alleviating the problem of information asymmetry,

Table 8. Heterogeneity test result

Variables	DT-low		DT-high	
	(1)	(2)	(3)	(4)
	GI	GI	GI	GI
HHIc	−0.714**		−0.239	
	(−2.355)		(−0.796)	
HHIs		−1.138***		−0.900***
		(−3.856)		(−2.888)
Control variables	Control			
Year FE	Y			
Industry FE	Y			
Adj R^2	0.359	0.360	0.317	0.326
N	4068	3934	3085	2821

***, **, and * indicate 1%, 5%, and 10% significance, respectively.

facilitating the rational allocation of innovation resources, and can mitigate the negative effect of customer concentration (supplier concentration) on the negative effect of green innovation.

5 Discussion and Conclusions

This study examines the impact of the major customers (suppliers) on green innovation by combining theoretical analysis and empirical research, using China's A-share listed enterprises from 2013 to 2020 as the research sample. The following are the study's research findings:

First, enterprise innovation is negatively impacted by customer and supplier concentration. The findings of the empirical research demonstrate that customer concentration has a negative impact on enterprise green innovation. The number of green patent applications decreases as customer concentration increases; supplier concentration also has a negative impact on green innovation. As supplier concentration develops, fewer enterprises are submitting green patent applications.

Second, this study investigates the impact mechanism of R&D investment as a mediating variable, discusses the process of customer(supplier) concentration inhibit enterprises' R&D investment and having a negative influence on green innovation, and establishes that R&D investment is an effective mediating variable through stepwise regression and the Sobel intermediary effect test.

Enterprises are essential to achieving the strategic objective of green innovation-driven development. Enterprises need to achieve sustainable competitiveness through green innovation in order to achieve a favourable market position as a consequence of the evolving social environment and intense market rivalry. This study's empirical research reveals that the supply chain's upstream and downstream customers and suppliers can

affect the green innovation of enterprises. This finding suggests that enterprises should incorporate external major customers and major suppliers into their corporate governance frameworks, manage their relationships with them in a rational and scientific way, and encourage the growth of their green innovation. The following are the implications of this study:

First, enterprise must consider how their major consumers and major suppliers in the external supply chain may affect innovation when they engage in green innovation activities. Despite the fact that there are numerous factors that influence green innovation, as firms increasingly rely on external, heterogeneous resources obtained from the supply chain when conducting their green innovation activities, the impact of the supply chain on green innovation of enterprises is becoming more noticeable. In order to avoid the negative effects of excessive customer and supplier concentration on enterprise green innovation, enterprises must take major customers and major suppliers into account when making strategic decisions. This can be done by enhancing relationship management between major customers and major suppliers.

Second, the government must take into account the potential effects of major customers and major suppliers in the supply chain on enterprise innovation when forming relevant policies to encourage the development of green innovation. Additionally, the government must offer insurance needs support to encourage the entire supply chain to engage in green innovation activities from the perspective of value co-creation of the entire supply chain where the enterprise is located. Governments should improve relevant institutional safeguards, particularly for non-state-owned enterprise s and those in eastern regions.

This study has several limitations as well. Although significant conclusions are drawn in the empirical analysis, there are limitations in the source and diversity of the sample data which may affect the reliability of the empirical test results. Listed enterprises were the research sample for this study and the findings may not be generalizable to SMEs. Further empirical tests of this research question can be conducted in the future using a larger sample. On the other hand, the impact on enterprise innovation is explored separately in terms of two dimensions: customer concentration and supplier concentration, but this only measures the importance of major customers and suppliers from the perspective of business relationship structure. In supply chain management, many participants such as suppliers, suppliers' suppliers, core enterprises, customers and customers' customers form a large network of supply chain insertions. In the future, the influence of relationship characteristics on enterprise innovation can be investigated in terms of the triadic network structure of suppliers, enterprises and customers, deepening the study of enterprise innovation from a supply chain perspective. At the same time, the impact of the development of supply chain structure and supply chain management on enterprise innovation can be further explored in the future.

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