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Can Corporate Digitalization Promote Green Innovation? The Moderating Roles of Internal Control and Institutional Ownership

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Abstract: This study examined the impact of corporate digitalization on green innovation using data concerning A-share companies listed on the Shanghai and Shenzhen stock markets from 2012 to 2018. We measured the degree of corporate digitalization through a text analysis of annual reports and empirically tested its impact on green innovation using a panel data fixed effects model. We found that digital transformation can improve green innovation levels, especially when internal control is weak and institutional ownership is low. These findings support the theoretical expectation that digitalization can strengthen supervision. The relationship between digitization and corporate governance mechanisms was proved to be complementary. Additionally, the analysis of economic consequences showed that digitalization improves financial performance by promoting green innovation. The results clarify the determinants of corporate green innovation and provide relevant insights for increasing the value of corporate digital transformation.

Keywords: digitalization; information asymmetry; internal control; institutional ownership; green innovation; financial performance

1. Introduction

In recent decades, environmental problems caused by global warming have worsened, and the relationship between human beings and the natural environment has become one of the foremost global issues. Environmental pollution and ecological damage are generally attributed to corporate production and operational activities [1]. Green innovation substantially reduces the adverse impacts on the environment [2] and promotes the adoption and diffusion of environmental technologies at the industrial and national levels [3]. Therefore, green innovation not only reduces pollution outputs [4] but also produces positive externalities [5] and is regarded as reference for companies to balance profitability and environmental responsibility [1]. As global climate warming, oil crises, water pollution, haze, and other environmental problems are becoming increasingly problematic, the public’s awareness of environmental protection is increasing, and the social demands for environmental protection of companies are becoming stricter. Therefore, green innovation is regarded by companies as an important strategy for obtaining sustainable competitive advantage under the pressure of environmental protection [6,7]. Meanwhile, the rapid development of the digital economy facilitates enterprises to achieve breakthrough development and innovation by using digital technology [8]. Digital technologies provide unique opportunities for organizations to develop new business models that improve environmental sustainability [9] and have important potential value in improving resource utilization efficiency [10]. In particular, digital technology involves the use of high intelligence, which can improve process efficiency and realize the efficient utilization of resources by monitoring and analyzing production processes [11], thus providing strong support for green innovation. Existing studies have found that the main driving factors of enterprise
green innovation include environmental regulations [12], government subsidies [13], stakeholder requirements [14], and organizational characteristics [3]. However, there is a lack of research on how digital technology promotes green innovation and the sustainability of organizations and society [15]. Few studies have analyzed the role of digitalization in inducing green innovation from the perspective of enterprises as the subjects of digital transformation. Previous studies have paid attention to the environmental sustainability impact of enterprise digital transformation; however, empirical evidence to support the promoting effect of digitization on enterprise environmental sustainability practices is lacking. Thus, this study examined the impact of corporate digitalization on environmental sustainability from the perspective of green innovation.

China’s extensive development model of high investment, pollution, and consumption in recent decades has caused serious environmental pollution problems [1]. It is urgent for China to shift from an extensive factor input growth model to a green growth model driven by total factor productivity [16]. The Chinese government has actively implemented the concept of green development, and China has pledged that its carbon dioxide emissions will not increase until 2030 and that it will offset its own carbon dioxide emissions through afforestation, energy conservation, and emission reduction, with the scope of achieving “zero carbon dioxide emissions” by 2060. Concurrently, China’s digital economy is booming, with a complete data infrastructure and a huge amount of data. In China, digital technology has the potential to be applied in corporate green innovation. Based on this theoretical and practical background, we selected Chinese-listed companies as a sample and used a panel data fixed effects regression model to investigate the impact of digital transformation on green innovation and to add to existing research and provide managers guidelines for enterprises when implementing digital management and pursuing the related green advantages.

First, we analyze the relationship between corporate digitalization and green innovation in the context of digital transformation, providing empirical evidence for the environmental benefits of corporate digitalization. We respond to Zoppelletto’s [15] call for a detailed study on the relationship between digitalization and sustainable practices. Second, this study enriches the literature on corporate green innovation. Specifically, the factors that determine the difference in green innovation among enterprises are expanded from institutional pressure and organizational culture to the corporate information environment. Third, we provide a comprehensive understanding of the microeconomic effects of digitalization. Our study explored the positive role of digitalization in enhancing corporate environmental sustainability from the perspective of green innovation, providing new ideas for studying the impact of digitalization on corporate social responsibility behavior and providing reference for making full use of the environmental benefit potential of the digital economy, as only when the digital economy is combined with the real economy will it not lead to a bubble.

The remainder of this paper is organized as follows: Section 2 reviews the literature on digitalization and corporate green innovation; Section 3 presents our hypotheses; Section 4 describes the research design; Section 5 presents the results; Section 6 discusses the results; and Section 7 concludes the paper.

2. Literature Review

2.1. Economic and Environmental Value of Digitalization

In the era of the digital economy, digital technology reconstructs the business model and strategy of enterprises by creating new products, services, and new forms of business, promoting research on the economic and environmental value of digital transformation.

Thus far, the mechanisms and conditions of digital economic value acquisition have been widely discussed. Academics have analyzed the implementation mechanism of digital transformation [17,18], the driving factors of the openness of digital trading platforms [19], the role of digital entrepreneurship in the innovation system [20], and business strategies based on digital technological innovation [21,22]. Extant studies have found that
digitalization effectively contributes to high-quality economic development [23]. It can also improve the productivity and export level of small and medium-sized enterprises, increasing their chances of attracting foreign capital flows [24], and it can help address the outflow of youth migrants [25]. Pasqualino et al. [26] found that digital technology can lead to employment reduction and social welfare inequality. However, when developing digital strategies, a country should prepare for retraining vulnerable labor market groups [10] and consider the influences of college graduates and economic cycles [27].

Under the explosive growth of the digital economy and its deep integration with the real economy, the performance of enterprise digitalization has been comprehensively addressed in academic research. Corporate digitalization refers to the use of digital technology to improve the efficiency of business processes and promote the transformation of business models [28], which is then used to realize operation automation, management networks, and intelligent decision making, thus creating new value and sustainable core competitiveness. The application of digital technology optimizes the ratio between data and other production factors, improving the overall efficiency by optimizing the factor input structure [29,30]. Many scholars believe that the implementation of digital management can help enterprises improve their sustainable competitive advantages [31], financial performance [32], and organizational performance [33].

In recent years, the number of studies on the impact of digitalization on environmental sustainability has increased [34]. Costa and Matias [35] showed that digital transformation can build a sustainable innovation ecosystem through open innovation. Chen et al. [34] determined the key impact of digitalization on the environmental sustainability of the manufacturing industry, noting that digitalization can lead to more sustainable manufacturing by tracking and optimizing resource consumption and promoting effective communication between different processes over the product life cycle. Similarly, Pasqualino et al. [26] found that digital technology can lead to a more resource-efficient economic system by reducing pressure on the environment. Although academia has begun to pay attention to the impact of digitalization on environmental sustainability, there are still many gaps in the existing research on how industrial enterprises use digitalization to achieve sustainability benefits [36]. The positive effects of digitization on environmental sustainability practices must be supported by empirical evidence. Therefore, this study explored the role of corporate digitalization in realizing environmental sustainability benefits from the perspective of corporate green innovation. This will help deepen the understanding of the relationship between corporate digital transformation and environmental sustainability.

2.2. Determinants of Corporate Green Innovation

Research on green innovation originated in the 1990s; green innovation involves the innovation of technologies, processes, or products that reduce environmental pollution and save resources and energy [13]. As a way for enterprises to address environmental challenges [12], green innovation has dual externalities that traditional innovations do not possess [37]: It can reduce environmental pollution, save energy, and achieve green and sustainable development between environmental protection and corporate competitiveness. In contrast with other corporate efforts aimed at meeting the minimum environmental protection standards, green innovation emphasizes pollution prevention and treatment [38]; reduces enterprise environmental protection burden; and brings economic value by introducing new systems, products, and processes [39]. Studies have shown that green innovation reduces and prevents the generation of pollutants [40], improves corporate environmental performance [41], and positively affects financial performance [42,43]. Therefore, green innovation is a pivotal path for coordinated development between the economy and environment [44].

Existing studies on the driving factors of green innovation can be grouped at the institutional and organizational levels. Research at the institutional level is primarily based on the stakeholder and institutional theories. Furthermore, according to the Porter hypothesis, appropriate regulations from the institutional environment can help force enterprises to
perform green technological innovation and form “compensatory benefits” that exceed the cost of environmental regulations [45]. Enterprises can reduce their dependence on polluting production modes and effectively avoid the cost of environmental regulation by applying green innovation to the production process [12]. The compelling effect of the external environment on corporate green innovation is also reflected in the pressure from stakeholders to adopt environmental responsibility behaviors; these environmental protection demands of stakeholders are also the main factors stimulating corporate green innovation [14]. Bai et al. [13] found that government research and development (R&D) subsidies can promote the green innovation performance of energy-intensive enterprises, and Pan et al. [1] discussed the determinants of green innovation from the perspective of social trust. Recent literature shows that organizational characteristics can play a pivotal role in determining corporate green innovation [3]. Moreover, organizational basic characteristics [46], organizational resources and capabilities [47,48], organizational culture [49], strategic orientation [50], and inter-firm cooperation [51] are the main driving forces of green innovation.

Studies on the driving factors of green innovation have yielded fruitful results. However, the literature on these driving factors principally uses institutional and stakeholder theories to identify the driving roles of government, regulations, shareholders, and consumers on corporate green innovation [2], with few studies focusing on the role of internal factors of organizations [52]. Compared with the studies at the institutional level, there are few empirical studies at the organizational level, and the literature on green innovation does not consider the role of corporate digitalization. Consequently, this study explains the mechanism through which digitalization stimulates corporate green innovation at the organizational level and empirically tests the impact of digitalization on corporate green innovation.

3. Hypotheses Development

3.1. Corporate Digitalization and Green Innovation

The application of digital technologies such as big data and artificial intelligence not only improves the efficiency of fulfilling environmental responsibilities but also strengthens shareholders’ supervision over managers, which is becoming an important driver of corporate green innovation. From the perspective of internal production and operation, corporate digital transformation can explore and mine data based on digital technology, stimulate the internal data vitality of the system, and help enterprises indicate their existing production process by reducing the generation of harmful substances, reducing pollutant emissions, and improving energy efficiency. Enterprises have accumulated large amounts of data from product design to terminal distribution; however, these data can only have a positive effect when the data are used in the form of visualization and production decisions. Before conducting digital transformation, the processing of data is inefficient, and the implied laws cannot be effectively mined by enterprises. Digital transformation signifies that enterprises can better process massive, non-standardized, and unstructured data with the help of digital technology, encode and output these into structured and standardized information, and improve the availability of information. Enterprises can make full use of such information to serve their own production decisions and market-oriented tracking to optimize production processes [53], ensure that their production and manufacturing processes comply with environmental regulations, and reduce the adverse impacts on the environment through improved processes.

Digital capture and intelligent analysis speed up the integration of data resources, provide useful information for green innovation decision-making, and significantly improve companies’ management level and innovation decision-making efficiency. Digital transformation promotes data to be processed into useful information for innovation decisions through linking and aggregation; thus, enterprises have broader data mining space, a higher ability to make innovative decisions, and stronger insights into R&D projects. Factory digitalization includes the transformation from centralized control to decentralized
adaptive intelligent networks [54]; networked innovative resource allocation and extensive technical empowerment make production more flexible. An intelligent production system can realize the automatic collection, storage, and analysis of production data, as well as automatic production, digital monitoring, and management [55]. A data model can be established by studying the correlation between the key parameters of the production process and quality control index to determine the dynamic laws of the production process, find abnormal energy consumption, and stimulate green process innovation. Precision sensing technology and intelligent systems can also be used to monitor and analyze the production process and quickly complete the traceability and positioning of high energy consumption links, and they can be used with big data mining to continuously improve the subsequent production process—thus providing a reliable basis for the decision-making of green innovation projects. In addition to helping pinpoint the direction of green innovation, digital transformation also facilitates the virtualization of the innovation process, which strengthens the collaboration between R&D and manufacturing, improves the efficiency of R&D, and realizes the rapid penetration of scientific knowledge and information at a low cost [56,57]. Digitalization reduces the time of technical exchange between researchers and the cost of collaboration between teams [58], accelerates the formation of the learning effect, and improves environmentally sustainable performance by promoting knowledge creation [59]. Additionally, as a design tool, digital simulation, virtual reality, and other digital technologies can accurately simulate the various physical parameters of products and the environmental impact of different product life cycles, which facilitates the integration of environmental protection concepts into the product creation process to accelerate green product innovation.

Green innovation is the key to coordinating environmental protection pressure with corporate economic performance. However, compared with general innovation, the R&D of green technologies requires more capital investment and has a lower probability of success. This is because green innovation is faced with risks of high capital investment, long payback periods, and unclear financial returns. If the owner cannot obtain comprehensive information to reasonably price management efforts, professional managers tend to avoid implementing green innovation projects that create value for shareholders but have high risks [52]. Corporate digital transformation can greatly reduce this degree of information asymmetry and improve the efficiency of management monitoring, as traditional management monitoring requires complex reporting procedures and is often expensive [60]. Digitalization and related technologies facilitate the fusion and integration of complex scenarios using a single platform. The digitalization of processes and automation of data collection enable business owners to view complete business activity information comprehensively and quickly. Therefore, company shareholders can quickly obtain ample internal or external data that were previously difficult to retrieve or not stored in digital form and can monitor management through automatic data extraction and algorithm analysis [61], greatly reducing the cost and improving the efficiency of management supervision [62]. Corporate governance is the basis for a company’s sustainable operations [63]. Moreover, digitalization improves corporate transparency by strengthening corporate governance [64], adjusts information asymmetry between management (agent) and investors (principal), and effectively alleviates information asymmetry and agency problems in innovation activities. Data intelligence analytics also provide key performance indicators to help business owners assess management’s fiduciary performance based on a wide range of information. Greater information transparency can greatly improve the quality of supervision and reduce information asymmetry between business owners and management. Therefore, corporate digitalization guides management behavior toward increasing long-term shareholder value and encourages management to engage in green innovation activities. Our first hypothesis was formulated based on these arguments:

**Hypothesis 1.** Corporate digitalization has a positive impact on green innovation.
3.2. Corporate Digitalization, Internal Control, and Green Innovation

From the perspective of innovation risk, if the cost of environmental regulation is lower than the benefits of extensive development, managers who follow rational choice theory will not actively seek green transformation but will adopt easy-to-imitate and low-cost environmental governance technologies over green technologies to evade environmental regulation [52]. Internal control marks the entire process of corporate operations and management activities. Good internal control can help external investors clearly understand the real information inside a company more clearly and can help improve information transparency. Therefore, internal control can improve the supervision and incentive system of managers, alleviate agency conflicts, and effectively reduce managers’ egoistic behaviors [65]. Under effective internal control, corporate managers are more likely to make decisions conducive to shareholders and corporate value and to perform social responsibilities more actively [66]. Effective internal control can improve corporate environmental protection investment [67] and sustainability [68], thus helping improve the corporate green level [69].

Ineffective corporate governance may constitute a major obstacle to environmental efficiency, as companies with poor governance generate fewer green patents relative to all their innovations [3]. Digitalization integrates all workplaces in the enterprise into an information network, and the collection, analysis, and access of information related to management activities are integrated into a unified software environment. Visual data workflows, IT governance, and data mining greatly increase the information transparency of business decisions [64]. Furthermore, the digitalization of the decision-making process makes management slack easier to identify. Higher information transparency can greatly improve the quality of supervision, ensure higher management efficiency, and make management behavior increase shareholder value. Therefore, digitalization can effectively remedy the defects of internal control and help ensure the development of corporate green innovation.

We thus posited the following:

**Hypothesis 2.** The role of corporate digitalization in green innovation is more prominent when internal control is weak.

3.3. Corporate Digitalization, Institutional Ownership, and Green Innovation

Companies must often protect shareholders from losing their investments. When a company’s reputation is damaged owing to social problems caused by unethical activities, shareholders experience losses in the stock market [70,71]. When customers, employees, investors, and other stakeholders demand higher social and environmental performance, openness, and transparency, and when they expect products and services to be more sustainable, green innovation becomes the ideal choice for enterprises to cater to the different value demands of the diverse stakeholders. Compared with ordinary investors, institutional investors have more information, talent advantages, resource advantages, and richer experiences. As such, the sell-off of shares by institutional investors is likely to cause volatility in the stock market; thus, the cost of traditional “voting with their feet” increases. Therefore, with the increase in institutional ownership, institutional investors will choose long-term investment strategies—that is, improving long-term firm value through the supervision of corporate operations and management [72]. Higher institutional ownership is a mechanism to ensure that the social and environmental requirements of society, customers, employees, and other stakeholders are met [73]. Innovation is a long-term, special, and unpredictable process with an extremely high possibility of failure [74]. Agency conflicts caused by managers’ professional concerns and preferences for “quiet life” always hinder innovation [75]. As such, institutional investors oversee corporate operations by joining the board of directors, conducting field visits, and holding face-to-face discussions with managers to promote information acquisition, all of which can effectively reduce information asymmetry [76,77].
The supervision of institutional shareholders limits managers’ motivation to engage in self-interested behaviors, encourages managers to formulate and implement environmental protection and green development strategies, and ultimately promotes green innovation [78]. Existing evidence shows that different corporate governance mechanisms can substitute for each other [79]. When institutional ownership is low, digital technology, as a crucial means of supervision [62], has a more prominent supervision effect on managers. According to the law of diminishing edge utility, it is expected that digitalization will play a stronger role in promoting green innovation when institutional ownership is low. The corresponding hypothesis was formulated as follows:

Hypothesis 3. The role of corporate digitalization in green innovation is more prominent when institutional ownership is low.

4. Research Design
4.1. Sample and Data
This study used data from A-share companies listed on the Shanghai and Shenzhen stock markets from 2012 to 2018 as the research sample. The World Intellectual Property Organization (WIPO) provides the broadest definition of green innovation, including technologies related to the disposal of environmental pollutants and climate change mitigation. WIPO provides patent classification numbers for all relevant technologies. To obtain the number of green patents filed by sample companies each year, we obtained the patent classification number information for all A-share listed companies from the Chinese Research Data Services (CNRDS) and matched it with the “Green List of International Patent Classification” issued by the WIPO. We evaluated the level of corporate digitalization through text analyses of the annual reports of listed companies, which were obtained from the official websites of the Shanghai and Shenzhen stock exchanges. We obtained the internal control index from the Shenzhen DIB. The data on institutional ownership came from the CNRDS. Data on corporate financial characteristics were obtained from the China Stock Market and Accounting Research (CSMAR) database. The data were processed by excluding the following: (1) financial industry companies; (2) ST and PT companies, and (3) observations with missing data. In total, 9085 firm-year observations were obtained from 2254 companies from 2012 to 2018. To avoid the influence of outliers, all continuous variables are winsorized at the upper and lower 1% levels.

4.2. Main Variables
4.2.1. Dependent Variable
Referring to Pan et al. [1] and Chen et al. [52], we used green patent applications to measure corporate green innovation because patent application data are more stable, reliable, and timely than patent grant data. Patent applications provide detailed information about the key characteristics of an underlying invention, which helps classify innovations according to their technical content [3]. Patents can be divided into invention, utility, and design patents; among these, invention patents have the highest technical thresholds. To apply for green invention patents, enterprises should research and develop, promote, and apply corresponding green technologies to improve the performance of their products. Green invention patents reflect the ability to achieve high-level green innovation [80]. Therefore, in addition to using the total number of green patent applications to measure green innovation, we also used the number of green invention patent applications to measure the quality of green innovation. We took the natural logarithm of one plus the number of green patents filed in an application as the final proxy variable of green innovation, denoted as GINNOV1 and GINNOV2.

4.2.2. Independent Variable
We evaluated the level of corporate digitization based on the relevant information in annual reports. Additionally, managers have a comprehensive understanding of the
activities of the company, and their summary of the company’s operation is reflected in the relevant description in the annual report [81]. The statements in the annual reports can express corporates’ operational status [82] and reflect the corporate business philosophy and development path of the company. Digital transformation is a crucial strategy for high-quality corporate development, and it is relatively easier to reflect this information in a company’s annual report. We collected and sorted the annual reports of all A-share listed companies of the Shanghai and Shenzhen Stock Exchanges with a Python crawler function, and all text contents were extracted using R language. We evaluated the implementation of corporate digital transformation by analyzing statements containing digitalization-relevant keywords in the annual reports of the listed companies and measuring the degree of corporate digital transformation using an ordered classification variable, denoted as DGI.

The keywords included digital, big data, cloud, industrial Internet, artificial intelligence, data analysis, analyze data, data acquisition, data collection, visualization, information system, intelligent, knowledge graph, machine learning, Internet of Things, MES, Industry 4.0, and BI. Using the Python language, we extracted sentences containing the above digitalization-related keywords from the annual reports. Accordingly, we judged whether the enterprise had performed digital transformation and the degree of digitalization transformation through manual reading. If an enterprise implemented digital transformation in one operation process, including production, sales, service, R&D, and management, the DGI was equal to 1. However, if the enterprise implemented digital transformation in two of the above operation processes, the DGI equaled 2; if the firm implemented digital transformation in three or more of the above operation processes, it was committed to integrating digital technology into the entire operation process, wherein the DGI equaled 3. If the annual report did not contain digitalization-related keywords or if the related expression was a planning assumption, trend analysis, or about company products and services rather than actual actions, the firm was considered to have not implemented digital transformation, and the DGI equaled to 0.

4.2.3. Moderating Variables

Referring to a previous study [69], we used Shenzhen DIB’s internal control indexes to measure internal control quality. The Shenzhen DIB is a professional and authoritative internal control information data supplier in China. It develops internal control indexes, combined with the 2013 Internal Control-Integration Framework issued by COSO and its supporting guidelines, and the relevant standards and systems issued by the Ministry of Finance and the China Securities Regulatory Commission [69]. It focuses on the rationality and effectiveness of the corporate internal control system, and the variables in the index are selected from corporate strategy, operation, reporting, compliance, and asset safety. This helps comprehensively reflect the effect of implementing an internal control system. We calculated the proxy variable of internal control by taking the natural logarithm of one plus the internal control exponent, denoted as IC.

Institutional investors’ ability to influence corporate management is a function of their shareholding ratio [83]. We used the ratio of the number of institutional investors’ shareholdings to the total stock capital of the company, INS, as a proxy for institutional ownership.

4.2.4. Control Variables

Based on the literature [1,3,50], we introduced a series of control variables to control for other economic characteristics affecting corporate green innovation, including firm size (SIZE), financial leverage (LEV), company performance (ROA), growth rate (GROWTH), largest ownership (SHR1), managerial ownership (MSHARE), CEO duality (Dual), ownership (SOE), cash flow (CASH), and intensity of physical assets (PPE). In addition, the industry dummy variable IND and annual dummy variable YEAR were added to control for the influence of industry or macroeconomic factors in the regression analysis results. Table 1 presents the detailed definitions and construction of the variables.
| Variable   | Explanation                | Definition                                                                 | Data Source |
|------------|----------------------------|---------------------------------------------------------------------------|-------------|
| GINNOV1    | Green innovation           | Natural logarithm of 1 plus the aggregate number of green patents filed in application | CNRDS       |
| GINNOV2    | Green innovation           | Natural logarithm of 1 plus the aggregate number of green invention patents filed in application | CNRDS       |
| DGI        | Digitalization level       | An ordered classification variable, equal to 0–3 according to the relevant statements in the company’s annual report | Manual collection |
| IC         | Internal control quality   | Natural logarithm of 1 plus the internal control index                      | Shenzhen DIB |
| INS        | Institutional ownership    | The fraction of total shares outstanding held by institutional investors     | CNRDS       |
| SIZE       | Firm size                 | The natural logarithm of total assets at the fiscal year end                | CSMAR       |
| LEV        | Financial leverage        | The ratio of total liabilities to total assets                              | CSMAR       |
| ROA        | Return on assets          | The ratio of net income to total assets                                     | CSMAR       |
| GROWTH     | Growth rate               | The ratio of operating income change to operating income in the previous period at every year end | CSMAR       |
| SHR1       | Largest ownership         | The percentage ownership of the largest shareholder                        | CSMAR       |
| MSHARE     | Managerial ownership      | Percentage of shares held by directors, supervisors, and senior managers   | CSMAR       |
| DUAL       | CEO duality               | A dummy variable which equals one if the firm’s board chair is also its CEO and zero otherwise | CSMAR       |
| SOE        | Ownership                 | A dummy variable that equals one if a firm is a state-owned enterprise and zero otherwise | CSMAR       |
| CASH       | Cash flow                 | The ratio of net cash flow from operations to total assets                  | CSMAR       |
| PPE        | Intensity of physical assets | The ratio of net property, plant, and equipment to total assets            | CSMAR       |

Table 1. Variable definitions.

4.3. Regression Models

A panel data fixed-effects regression model was used to test the hypotheses: Model (1) was constructed based on Hypothesis 1 to test the influence of enterprise digitalization on green innovation; Model (2) was constructed based on Hypothesis 2 to test the moderating effect of enterprise internal control on the relationship between digitalization and green innovation; and Model (3) was constructed based on Hypothesis 3 to test the moderating effect of institutional investor ownership on the relationship between digitalization and green innovation.

\[
\text{GINNOV}_{it+1} = \beta_0 + \beta_1 \text{DIG}_{it} + \beta_2 \text{SIZE}_{it} + \beta_3 \text{LEV}_{it} + \beta_4 \text{ROA}_{it} + \beta_5 \text{GROWTH}_{it} + \beta_6 \text{SHR1}_{it} + \beta_7 \text{MSHARE}_{it} + \beta_8 \text{DUAL}_{it} + \beta_9 \text{SOE}_{it} + \beta_{10} \text{CASH}_{it} + \beta_{11} \text{PPE}_{it} + \sum \text{YEAR} + \sum \text{IND} + \gamma + \epsilon_{it}\]

\[
\text{GINNOV}_{it+1} = \beta_0 + \beta_1 \text{DIG}_{it} + \beta_2 \text{DIG}_{it} \times \text{IC}_{it} + \beta_3 \text{IC}_{it} + \beta_4 \text{SIZE}_{it} + \beta_5 \text{LEV}_{it} + \beta_6 \text{ROA}_{it} + \beta_7 \text{GROWTH}_{it} + \beta_8 \text{SHR1}_{it} + \beta_9 \text{MSHARE}_{it} + \beta_{10} \text{DUAL}_{it} + \beta_{11} \text{SOE}_{it} + \beta_{12} \text{CASH}_{it} + \beta_{13} \text{PPE}_{it} + \sum \text{YEAR} + \sum \text{IND} + \gamma + \epsilon_{it}\]

\[
\text{GINNOV}_{it+1} = \beta_0 + \beta_1 \text{DIG}_{it} + \beta_2 \text{DIG}_{it} \times \text{INS}_{it} + \beta_3 \text{INS}_{it} + \beta_4 \text{SIZE}_{it} + \beta_5 \text{LEV}_{it} + \beta_6 \text{ROA}_{it} + \beta_7 \text{GROWTH}_{it} + \beta_8 \text{SHR1}_{it} + \beta_9 \text{MSHARE}_{it} + \beta_{10} \text{DUAL}_{it} + \beta_{11} \text{SOE}_{it} + \beta_{12} \text{CASH}_{it} + \beta_{13} \text{PPE}_{it} + \sum \text{YEAR} + \sum \text{IND} + \gamma + \epsilon_{it}\]

Considering that a certain time lag is required for corporate digital transformation to affect green innovation, to improve the reliability of the regression analysis results, the explanatory variables in the model were treated with a one-period lag, which not only considered the transfer time between variables in practice, but also reduced the endogenous interference of reverse causality. GINNOVA_{it+1} represents green innovation, including two variables: GINNOVA_{1it+1} and GINNOVA_{2it+1}. DIG_{it} represents the level of corporate
digitalization. If the coefficient of DIG$_{it}$ in Model (1) was significantly positive, it would be assumed that Hypothesis 1 was supported. If the DIG$_{it} \times$ IC$_{it}$ coefficient in Model (2) was significantly negative, then Hypothesis 2 would be verified. If the coefficient of DIG$_{it} \times$ INS$_{it}$ in Model (3) was significantly negative, then Hypothesis 3 would be verified. Additionally, $\epsilon_{it}$ is the error term and $\gamma$ is the firm fixed-effect that was used to control for the influence of unknown time-invariant firm-level factors.

5. Empirical Testing

5.1. Correlation Analysis

Table 2 reports the correlation coefficients between the independent variables. DGI is significantly positively correlated with GINNOV1 and GINNOV2, which is consistent with Hypothesis 1. Moreover, DGI is also significantly positively correlated with SIZE, LEV, ROA, GROWTH, and CASH, indicating that companies with comparatively large-scale and high debt, profitability, growth, and cash holdings are likely to implement digital transformation. The correlations between other variables are also reasonable. For example, GROWTH is significantly positively correlated with ROA, indicating that a company with better growth has better profitability. LEV is significantly negatively correlated with ROA, indicating that companies with high financial leverage have worse profitability. Although the correlation coefficients between the independent variables are significant, the maximum value of multicollinearity, tested by variance inflation factor, is 1.99, which is lower than the empirical value of 5. Therefore, there was no serious multicollinearity problem between the independent variables in the model.

5.2. Descriptive Statistics

Table 3 reports the descriptive statistics of the variables. The mean value of GINNOV1 is 1.171 and that of GINNOV2 is 0.815. This indicates that, generally, the high-quality green innovation of sample companies approximately accounts for half the total innovation. The standard deviation of GINNOV2 is greater than the mean value, indicating that the high-quality green innovation level of sample companies varies greatly. The mean value of DGI is 0.098, indicating that the DGI of the sample companies is relatively low overall; moreover, the standard deviation of DGI is higher than the mean value, indicating that the DGI of different companies varies greatly. The minimum and maximum values of IC are 0 and 6.512, respectively, indicating that the internal control index of Chinese listed companies shows significant differences. The average shareholding ratio (INS) of institutional investors is 0.072; that is, institutional investors hold 7.2% of the total shares of listed companies, indicating the scale of institutional investors is small in China. The minimum value of LEV is 0.061, and the maximum value is 0.413, indicating that the sample companies have large differences in financial leverage. In addition, the minimum value of GROWTH is −19.471, while the maximum value is 13.387; that is, there are great differences in the growth levels of Chinese listed companies. The median SOE is 0, indicating that most listed companies in China are non-state-owned enterprises.

5.3. Fixed-Effect Regression Analysis Results

Table 4 reports the regression analysis results for Model (1). The regression coefficients on corporate DGI to GINNOV1 and GINNOV2 are 0.308 and 0.319, respectively, both being significantly positive at 1% level. This indicates that with the improvement of corporate digitalization, the corporate green innovation output increases. Moreover, corporate digitalization not only improves the quantity of green innovation but also improves its quality. The above results support Hypothesis 1.
Table 2. Correlation matrix.

| Variable | GINNOV1 | GINNOV2 | DGI  | IC    | INS   | SIZE  | LEV   | ROA   | GROWTH | SHR1  | DUAL  | MSHARE | SOE   | CASH  | PPE   |
|----------|---------|---------|------|-------|-------|-------|-------|-------|--------|-------|-------|--------|-------|-------|-------|
| GINNOV1  | 1       | 0.897***| 0.183***| 0.058***| 0.127***| 0.296***| 0.166***| −0.005| 0.056***| 0.008| −0.040***| −0.026**| 0.100***| −0.048***| −0.037***|
| GINNOV2  | 0.933***| 1       | 0.175***| 0.067***| 0.129***| 0.283***| 0.144***| 0.013| 0.060***| 0.013| −0.035***| −0.037***| 0.106***| −0.032***| −0.055***|
| DGI      | 0.213***| 0.206***| 1     | 0.082***| 0.077***| 0.130***| 0.058***| 0.075***| 0.063***| 0.019*| 0.015| 0.000| −0.003| 0.046***| 0.000|
| IC       | 0.019*  | 0.037***| 0.024**| 1     | 0.145***| 0.175***| 0.043***| 0.335***| 0.282***| 0.110***| −0.035***| −0.040***| 0.091***| 0.161***| −0.046***|
| INS      | 0.106***| 0.117***| 0.057***| 0.048***| 1     | 0.226***| 0.048***| 0.214***| 0.179***| −0.102***| −0.008| 0.021**| 0.006| 0.071***| −0.071***|
| SIZE     | 0.374***| 0.367***| 0.135***| 0.025**| 0.162***| 1     | 0.575***| −0.092***| 0.070***| 0.178***| −0.198***| −0.380***| 0.384***| 0.039***| 0.029***|
| LEV      | 0.192***| 0.171***| 0.056***| −0.036***| 0.038***| 0.570***| 1     | −0.406***| −0.026**| 0.099***| −0.136***| −0.335***| 0.307***| −0.144***| 0.013|
| ROA      | −0.005  | 0.009   | 0.069***| 0.146***| 0.196***| −0.045***| −0.361***| 1     | 0.433***| 0.045***| 0.053***| 0.197***| −0.159***| 0.406***| −0.093***|
| GROWTH   | 0.027***| 0.027** | 0.040***| 0.007***| 0.057***| 0.034***| −0.059***| 0.420***| 1     | −0.038***| 0.026**| 0.076***| −0.068***| 0.149***| −0.080***|
| SHR1     | 0.038***| 0.031***| 0.013   | 0.026**| −0.132***| 0.224***| 0.105***| 0.085***| −0.011| 1     | −0.045***| −0.259***| 0.245***| 0.090***| 0.075***|
| MSHARE   | −0.089***| −0.097***| −0.028***| 0.030***| −0.050***| −0.387***| −0.335***| 0.131***| 0.029***| −0.150***| 0.240***| 1     | −0.615***| −0.043***| −0.161***|
| SOE      | 0.122***| 0.130***| −0.008  | −0.016  | −0.016  | 0.397***| 0.310***| −0.120***| −0.048***| 0.248***| −0.264***| −0.494***| 1     | 0.018* | 0.116***|
| CASH     | −0.030***| −0.015  | 0.045***| 0.044***| 0.069***| 0.042***| −0.137***| 0.406***| 0.088***| 0.091***| −0.015| −0.035***| 0.013| 1     | 0.303***|
| PPE      | −0.029***| −0.044***| −0.011  | −0.029***| −0.084***| 0.115***| 0.070***| −0.099***| −0.073***| 0.094***| −0.071***| −0.169***| 0.177***| 0.289***| 1     |

Notes: This table presents the correlation matrix of the variables used in our analysis. The variable definitions are presented in Table 1. *, **, and *** indicate two-tailed significance at the 10%, 5%, and 1% levels, respectively. Pearson correlation coefficients are shown above the diagonal, and the Spearman correlation coefficients are below the diagonal.
Table 3. Descriptive statistics.

| Variable | Obs. | Mean  | Standard Deviation | Minimum | Median | Maximum |
|----------|------|-------|-------------------|---------|--------|---------|
| GINNOV1  | 9085 | 1.171 | 1.289             | 0.000   | 0.000  | 0.693   |
| GINNOV2  | 9085 | 0.815 | 1.094             | 0.000   | 0.000  | 0.000   |
| DGI      | 9085 | 0.098 | 0.314             | 0.000   | 0.000  | 0.000   |
| IC       | 9085 | 6.419 | 0.704             | 0.000   | 6.445  | 6.512   |
| INS      | 9085 | 0.072 | 0.068             | 0.000   | 0.018  | 0.052   |
| SIZE     | 9085 | 22.309| 1.272             | 20.013  | 21.398 | 22.120  |
| LEV      | 9085 | 0.042 | 0.019             | 0.000   | 0.019  | 0.019   |
| ROA      | 9085 | 0.044 | 0.001             | −0.226  | −0.296 | 0.115   |
| GROWTH   | 9085 | 0.080 | 0.149             | −19.471 | −0.296 | 0.115   |
| SHR1     | 9085 | 0.348 | 0.149             | 0.085   | 0.229  | 0.330   |
| DUAL     | 9085 | 0.270 | 0.444             | 0.000   | 0.000  | 0.000   |
| MSHARE   | 9085 | 0.142 | 0.475             | 0.000   | 0.000  | 0.000   |
| SOE      | 9085 | 0.343 | 0.343             | 0.000   | 0.000  | 0.000   |
| CASH     | 9085 | 0.045 | 0.066             | −0.153  | 0.007  | 0.043   |
| PPE      | 9085 | 0.211 | 0.156             | 0.003   | 0.093  | 0.178   |

Table 4. Corporate digitalization and green innovation.

| Variable | (1) GINNOV1 | (2) GINNOV2 |
|----------|-------------|-------------|
| DGI      | 0.308 ***   | 0.319 ***   |
| SIZE     | 0.283 ***   | 0.241 ***   |
| LEV      | 0.163       | 0.096       |
| ROA      | 0.380       | 0.057       |
| GROWTH   | 0.003       | 0.003       |
| SHR1     | −0.114      | −0.153      |
| MSHARE   | 0.044       | 0.044       |
| SOE      | 0.138       | 0.091       |
| CASH     | −0.068      | 0.044       |
| PPE      | −0.045      | −0.042      |
| Constant | −5.772 ***  | −4.905 ***  |

Notes: This table provides the results of estimating the regression Model (1). The definitions of the variables are provided in Table 1. The values between parentheses are t-statistics. *** indicates two-tailed significance at the 1% level.

Table 5 reports the regression analysis results for Model (2), showing that the coefficients on DGI \times IC (that is, the interaction term between digitalization and internal control) are −0.149 and −0.099, which are significantly negative at 1% and 5%, respectively, indicating that internal control plays a negative moderating role in the relationship between digitalization and green innovation. The regression result of Model (2) is consistent with
Hypothesis 2. That is, digitalization plays a more significant role in promoting green innovation when the quality of internal control is poor.

Table 5. Corporate digitalization, internal control, and green innovation.

| Variable | (1) GINNOV1 | (2) GINNOV2 |
|----------|-------------|-------------|
| DGI      | 1.273 ***   | 0.959 ***   |
|          | (4.01)      | (3.54)      |
| DGI × IC | −0.149 ***  | −0.099 **   |
|          | (−3.06)     | (−2.38)     |
| IC       | 0.018       | 0.023 **    |
|          | (1.36)      | (1.96)      |
| SIZE     | 0.281 ***   | 0.239 ***   |
|          | (9.48)      | (9.42)      |
| LEV      | 0.164       | 0.096       |
|          | (1.51)      | (1.04)      |
| ROA      | 0.381       | 0.041       |
|          | (1.17)      | (0.15)      |
| IC       | 0.003       | 0.003       |
|          | (0.92)      | (1.19)      |
| SHR1     | −0.124      | −0.156      |
|          | (−0.71)     | (−1.05)     |
| MSAHRE   | 0.041       | 0.042       |
|          | (1.25)      | (1.50)      |
| DUAL     | −0.158      | −0.108      |
|          | (−1.18)     | (−0.95)     |
| SOE      | 0.138       | 0.091       |
|          | (1.29)      | (0.99)      |
| CASH     | −0.073      | 0.044       |
|          | (−0.44)     | (0.31)      |
| PPE      | −0.055      | −0.050      |
|          | (−0.38)     | (−0.40)     |
| Constant | −5.859 ***  | −5.014 ***  |
|          | (−8.86)     | (−8.88)     |

Notes: This table provides the results of estimating the regression Model (2). The definitions of the variables are provided in Table 1. The values between parentheses are t-statistics. ** and *** indicate two-tailed significance at the 5% and 1% levels, respectively.

Table 6 reports the regression analysis results for Model (3). Regardless of whether the dependent variable is total green innovation or green invention innovation, the coefficient on DGI × INS is significantly negative at the 1% level, indicating that digitalization plays a significant promoting effect on corporate green innovation when institutional ownership is low, which supports Hypothesis 3.

5.4. Robustness Checks

Although firm fixed effects mitigate the concern about unobserved time-invariant firm characteristics that may affect both digitalization and green innovation, some time-varying factors may simultaneously affect the DGI and green innovation output. We used instrumental variables to address this endogeneity problem. Referring to Pang and Wang [84], we selected the average DGI of firms located in the same city and belonging to the same industry as the instrumental variable, expressed as CITY_DGI. Although the average DGI of the same industry in the same city is related to the digitalization degree of the company itself, it does not directly affect the company’s green innovation, ensuring
the correlation and externality of instrumental variable. The first-stage regression analysis results are shown in Column (1) of Table 7. The estimated coefficient on CITY_DGI is significantly positive at the 1% level and the Cragg–Donald F statistic is higher than the critical value under the 10% bias of the weak instrumental variable, indicating that the instrumental variable is correlated [85]. Columns (2–7) in Table 7 report the estimation results of the two-stage least-squares regressions. The directions of the coefficients on the main variables are consistent with those mentioned above and remain significant; thus, our conclusions are still valid.

Table 6. Corporate digitalization, institutional ownership, and green innovation.

| Variable (1) | GINNOV1 | (2) GINNOV2 |
|-------------|---------|------------|
| DGI         | 0.415 *** | 0.407 *** |
| DGI × INS   | −1.208 *** | −0.996 *** |
| INS         | 0.367 **  | 0.242 *   |
| SIZE        | 0.297 *** | 0.238 *** |
| LEV         | 0.340    | 0.035     |
| ROA         | 0.367 **  | 0.242 *   |
| GROWTH      | 0.003    | 0.003     |
| SHR1        | −0.076   | −0.129    |
| MSAHRE      | 0.043    | 0.043     |
| DUAL        | −0.154   | −1.040    |
| SOE         | 0.151    | 0.101     |
| CASH        | −0.064   | 0.048     |
| PPE         | −0.038   | −0.038    |
| Constant    | −5.753 ***| −4.895 ***|
| Year Fixed Effect | Yes | Yes |
| Industry Fixed Effect | Yes | Yes |
| Firm Fixed Effect | Yes | Yes |
| Obs. | 9085 | 9085 |
| R² | 0.189 | 0.163 |

Notes: This table provides the results of estimating the regression Model (3). The definitions of the variables are provided in Table 1. The values between parentheses are t-statistics. *, **, and *** indicate two-tailed significance at the 10%, 5%, and 1% levels, respectively.

5.5. Extended Analysis

5.5.1. Corporate Digitalization, Green Innovation, and Financial Performance

Enterprises can save resource costs, improve process technology, and realize environmental protection through green innovation. Additionally, green innovation helps enterprises build differentiated competitive advantages, such as a good green image and improving stakeholders’ trust in corporate environmental performance [40,41]. By improving differentiated product advantages, enterprises can obtain environmental premiums, thus improving their financial performance [44,45]. Therefore, financial performance can be used to judge whether an enterprise gains digital benefits through green innovation.
To test whether the green innovation effect of digitalization brings financial benefits to enterprises, the classical mediation effect test method of Baron and Ken 
[86] was adopted.

| Variable | (1) DGI | (2) GINNOV1 | (3) GINNOV2 | (4) GINNOV1 | (5) GINNOV2 | (6) GINNOV1 | (7) GINNOV2 |
|----------|---------|-------------|-------------|-------------|-------------|-------------|-------------|
| CITY_DGI | 1.020*** (45.33) | 0.339*** (5.26) | 0.377*** (6.47) | 1.448*** (2.80) | 1.223*** (2.77) | 0.566*** (5.42) | 0.553*** (6.19) |
| Instrument_DGI | 0.359 *** | 0.377 *** | 1.448 *** | 1.223 *** | 0.566 *** | 0.553 *** | 0.359 *** | 0.377 *** |
| Instrument_DGI × IC | −0.171 ** | −0.133 * | −2.15 | −1.95 | −2.252 *** | −1.904 *** | −2.85 | −2.82 |
| Instrument_DGI × INS | 0.019 | 0.025 ** | (1.33) | (2.08) | 0.448 ** | 0.311 ** | (2.50) | (2.03) |
| IC | | | | | | | | |
| INS | 0.025 *** | 0.284 *** | 0.240 *** | 0.283 *** | 0.238 *** | 0.280 *** | 0.237 *** | 0.237 ** |
| SIZE | (2.65) | (9.61) | (9.50) | (9.58) | (9.44) | (9.47) | (9.39) |
| LEV | 0.037 | 0.167 | 0.094 | 0.169 | 0.095 | 0.170 | 0.094 |
| ROA | (1.06) | (1.54) | (1.01) | (1.56) | (1.02) | (1.56) | (1.01) |
| GROWTH | 0.000 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 |
| SHRI | 0.016 | −0.115 | −0.158 | −0.127 | −0.164 | −0.075 | −0.333 |
| SOE | (0.29) | (−0.67) | (−1.07) | (−0.73) | (−1.11) | (−0.43) | (−0.89) |
| MSAHRE | −0.002 | 0.044 | 0.043 | 0.040 | 0.041 | 0.041 | 0.041 |
| DUAL | (−0.16) | (1.54) | (1.53) | (1.24) | (1.46) | (1.27) | (1.48) |
| Constant | 0.050 | −0.160 | −0.114 | −0.147 | −0.106 | −0.143 | −0.105 |
| OBS | (1.16) | (−1.20) | (−1.00) | (−1.10) | (−0.93) | (−1.07) | (−0.90) |
| Cragg–Donald Wald F statistic | 2035.154 |
| Stock–Yogo weak ID test critical values: 10% maximal IV size | 16.38 |

Notes: This table reports the 2SLS analysis regression results using an instrumental variable approach. The definitions of the variables are provided in Table 1. The values between parentheses are z-statistics. *, **, and *** indicate two-tailed significance at the 10%, 5%, and 1% levels, respectively.

The first step in determining the mediating effect was to test the relationship between digitalization and financial performance. Considering that the green innovation of year t + 1 was used to regress the explanatory variable of year t, the future financial performance indicator was constructed by dividing the average operating profit of year t + 2 by the total assets at the end of the year, represented by FEARN. The second step was to examine the effect of digitalization on corporate green innovation—that is, Hypothesis 1—and the third step was to analyze the effects of digitalization and green innovation on financial performance. Table 8 reports the test results. As the positive impact of digitalization on green innovation was verified in the previous test, it is not listed in Table 8. As shown in Column (1) of Table 8, when the explained variable is future financial performance, the coefficient on DGI is significantly positive, indicating that digitalization improves future financial performance; and the results in Columns (2) and (3) in Table 8 show that the coefficients on GINNOV1 and GINNOV2 are significantly positive, indicating that green innovation promotes the growth of corporate financial performance. Furthermore, the coefficients of DGI in Columns (2) and (3) of Table 9 decrease in value and significance compared with Column (1), indicating that digitalization is indirectly related to corporate financial performance through green innovation; that is, green innovation plays an intermediary role in the relationship between digitalization and financial performance.
between digitalization and financial performance. The Sobel, Goodman1, and Goodman2 tests are all significant, indicating that digitalization improves financial performance by promoting green innovation; that is, the green innovation effect of corporate digitalization has economic benefits.

### Table 8. Corporate digitalization, green innovation, and financial performance.

| Variable          | (1) FEARN | (2) FEARN | (3) FEARN |
|-------------------|-----------|-----------|-----------|
| DGI               | 0.007 *** | 0.005 **  | 0.005 **  |
|                   | (2.96)    | (2.25)    | (2.19)    |
| GINNOV1           |           | 0.003 *** |           |
|                   |           | (4.03)    |           |
| GINNOV2           |           |           | 0.003 *** |
|                   |           |           | (4.23)    |
| SIZE              | −0.005 ***| −0.006 ***| −0.006 ***|
|                   | (−6.47)   | (−7.44)   | (−7.53)   |
| LEV               | −0.019 ***| −0.020 ***| −0.019 ***|
|                   | (−3.96)   | (−4.03)   | (−3.93)   |
| ROA               | 0.831 *** | 0.829 *** | 0.829 *** |
|                   | (40.65)   | (40.55)   | (40.60)   |
| GROWTH            | −0.002 ***| −0.002 ***| −0.002 ***|
|                   | (−8.45)   | (−8.50)   | (−8.51)   |
| SHR1              | 0.032 *** | 0.033 *** | 0.033 *** |
|                   | (6.54)    | (6.62)    | (6.66)    |
| MSAHRE            | 0.005     | 0.004     | 0.004     |
|                   | (1.10)    | (1.00)    | (1.06)    |
| DUAL              | −0.000    | −0.000    | −0.000    |
|                   | (−0.11)   | (−0.09)   | (−0.15)   |
| SOE               | 0.001     | 0.001     | 0.001     |
|                   | (0.61)    | (0.45)    | (0.39)    |
| CASH              | 0.187 *** | 0.189 *** | 0.188 *** |
|                   | (15.11)   | (15.22)   | (15.16)   |
| PPE               | 0.010 *   | 0.012 **  | 0.013 **  |
|                   | (1.81)    | (2.09)    | (2.19)    |
| Constant          | 0.125 *** | 0.148 *** | 0.150 *** |
|                   | (7.87)    | (8.77)    | (8.85)    |

* Year Fixed Effect: Yes
  ** Industry Fixed Effect: Yes
  *** Obs.: 9364

Notes: This table reports the results of the analysis of the mediating effect of green innovation on the relationship between corporate digitalization and financial performance. The definitions of the variables are provided in Table 1. The values between parentheses are t-statistics. *, **, and *** indicate two-tailed significance at the 10%, 5%, and 1% levels, respectively.

5.5.2. Application of Digital Technology and Green Innovation

Regional digital infrastructure constitutes a pivotal basis for enterprises to apply digital technology. It changes the degree of application of digital technology from two aspects: digital technology supply and digital technology demand. On the one hand, an increase in the supply of digital technology will enhance the application degree of digital technology in enterprises, and a perfect digital infrastructure can promote the application of digital technology in businesses [87]. On the other hand, improved information infrastructure will increase the demand for digital technology application in local enterprises. Therefore, we further used the level of regional digital infrastructure to evaluate the degree of enterprise digital technology application and test the impact of digital technology application on green innovation. According to recommendations from the European Commission [88], we
measured the level of digital infrastructure based on Internet usage, utilizing the number of broadband Internet access users, obtained from the National Bureau of Statistics of China. By taking the natural logarithm of the number of such users, we measured the level of digital economy infrastructure in the province where the enterprise was located, and denoted it as PRV_DGI, which regressed the enterprise’s green innovation. To further exclude the influence of economic development levels in different regions, we also controlled the regional gross domestic product (GDP) level, which was obtained by taking the natural logarithm of regional GDP and was expressed as PRV_GDP. Table 9 presents the regression analysis results; the results listed in Columns (1) and (2) used the same control variables as in Model (1), and Columns (3) and (4) are the results of further controlling the regional economic development level. The coefficients of DGI_PRV are all significantly positive, indicating that the application level of digital technology has a positive impact on green innovation.

### Table 9. Application of digital technology and green innovation.

| Variable      | (1) GINNOV | (2) GINNOV | (3) GINNOV | (4) GINNOV |
|---------------|------------|------------|------------|------------|
| PRV_DGI       | 0.120 *    | 0.104 *    | 0.132 *    | 0.110 *    |
|               | (1.83)     | (1.87)     | (1.84)     | (1.79)     |
| SIZE          | 0.297 ***  | 0.254 ***  | 0.298 ***  | 0.254 ***  |
|               | (10.01)    | (9.98)     | (10.02)    | (9.98)     |
| LEV           | 0.192 *    | 0.118      | 0.192 *    | 0.118      |
|               | (1.75)     | (1.26)     | (1.75)     | (1.25)     |
| ROA           | 0.451      | 0.119      | 0.448      | 0.118      |
|               | (1.38)     | (0.42)     | (1.37)     | (0.42)     |
| GROWTH        | 0.003      | 0.003      | 0.003      | 0.003      |
|               | (0.90)     | (1.20)     | (0.90)     | (1.20)     |
| SHR1          | −0.100     | −0.145     | −0.104     | −0.146     |
|               | (−0.58)    | (−0.97)    | (−0.60)    | (−0.98)    |
| MSAHRE        | 0.044      | 0.043      | 0.044      | 0.043      |
|               | (1.34)     | (1.53)     | (1.34)     | (1.54)     |
| DUAL          | −0.145     | −0.098     | −0.145     | −0.098     |
|               | (−1.08)    | (−0.85)    | (−1.08)    | (−0.85)    |
| SOE           | 0.139      | 0.097      | 0.139      | 0.098      |
|               | (1.29)     | (1.06)     | (1.29)     | (1.06)     |
| CASH          | −0.069     | 0.043      | −0.067     | 0.044      |
|               | (−0.41)    | (0.30)     | (−0.40)    | (0.31)     |
| PPE           | −0.032     | −0.021     | −0.032     | −0.021     |
|               | (−0.22)    | (−0.17)    | (−0.22)    | (−0.17)    |
| PRV_GDP       | −0.055     | −0.024     |           | −0.024     |
|               | (−0.42)    | (−0.21)    |           | (−0.21)    |
| Constant      | −5.914 *** | −5.372 *** | −5.442 *** | −5.166 *** |
|               | (−6.31)    | (−6.70)    | (−3.71)    | (−4.12)    |
| Year Fixed Effect | Yes     | Yes       | Yes       | Yes       |
| Industry Fixed Effect | Yes    | Yes       | Yes       | Yes       |
| Firm Fixed Effect | Yes     |           |           | Yes       |
| Obs.          | 9085       | 9085       | 9085       | 9085       |
| R²            | 0.178      | 0.146      | 0.178      | 0.146      |

Notes: This table provides the regression analysis results of the application of digital technology to green innovation. The definitions of the variables are provided in Table 1. The values between parentheses are t-statistics. * and *** indicate two-tailed significance at the 10% and 1% levels, respectively.

### 6. Discussion

The global economy is moving into a new era of a digital economy. Automatic collection, real-time monitoring, and intelligent analysis of big data provide strong support for green innovation by improving production processes and reducing information asymmetry. This study evaluated the degree of corporate digitalization through text analysis of annual
reports, and empirically tested the impact, mechanism, and economic consequences of corporate digitalization on green innovation. The results of our analysis show that digital transformation significantly improves the level of corporate green innovation and that the impact of digitalization on green innovation is more obvious in terms of poor internal control quality and low ownership of institutional investors. These results not only support the theoretical expectation that digitalization can strengthen supervision but also identify a complementary relationship between digitalization and corporate governance mechanisms. An additional investigation of economic consequences shows that digitalization leads to better financial performance by promoting green innovation.

This study makes several contributions to extant literature. First, this study enriches the literature on the determinants of green innovation. With increasingly severe environmental problems, corporate green innovation has attracted close attention from governments, shareholders, and the public. This study tested the promotion effect of enterprise digitalization on green innovation in the context of the rapid development of digitization. The factors that determine corporate green innovation are further expanded from institutional pressure and organizational culture to the enterprise digitization level. Second, this study provides empirical evidence of the environmental benefits of digitalization. The relationship between digitization and sustainable practices has received significant attention from the academic world. We examined the positive environmental effects of digitization from an empirical perspective, deepening the research in the fields of digitization and sustainable practice. Finally, this study provides a comprehensive understanding of the microeconomic effects of digitization. Using text analysis to measure the level of digitization of enterprises, we explored the positive role of digitization in improving enterprises’ operating conditions from the perspective of green innovation and providing incremental contributions to research on the consequences of the digital economy.

Our research has several crucial practical implications. For enterprises that have not yet undergone digital transformation, increasing the budget allocated to digital transformation has key benefits in promoting sustainability. Enterprises should follow the rapid development of the digital economy and pay attention to the deep integration of operation processes and digital technology. Digital transformation can play a more meaningful role in promoting green innovation in the context of poor internal control and low institutional ownership; therefore, insufficient internal supervision can be achieved with digitalization. Simultaneously, enterprises should formulate more accurate digitalization implementation plans based on the characteristics of their corporate governance. Finally, digitalization can efficiently utilize resources and effectively reduce pollution, leading to increased economic performance. Moreover, enterprises can achieve profit growth through digital transformation. The digitalization level of a company can be included as a reference factor for investors to make decisions. It can be expected that enterprises that promote digital transformation can achieve higher green innovation output and financial performance.

In addition, this study has implications for policymaking. Green innovation leads to technological leadership and improves environmental governance capabilities. It can also generate positive externalities through knowledge spillovers. Green innovation promotes the adoption and diffusion of environmental technologies in both industries and countries. Therefore, corporate digital transformation is beneficial to a society’s sustainability by strengthening the incentives for green innovation. To fully realize this effect, local governments should strengthen the guidance and assistance to enterprises to perform digital construction and encourage the deep integration of digital technology with corporate production and operation systems. To strengthen the support and driving role of digitalization in green innovation, a positive incentive mechanism of green innovation should be perfected from the perspective of systems design. Specifically, the government should build a market-oriented green technology innovation system through multi-level institutional arrangements to create a macro environment supporting green innovation, which would be conducive to fully mobilizing the enthusiasm of enterprises to use digital technology to perform green innovation.
7. Conclusions

Digital technology is bringing all-encompassing changes to the global economy. With the help of digital technology, enterprises have greatly improved the efficiency of their information processing and resource use, and digitalization has shown a new potential to promote sustainability. However, research on the role of digitalization in corporate sustainable practices is not extensive [12]. Thus, we introduced digitalization into the study of green and sustainable development of enterprises, emphasizing the positive impact of digitalization on green innovation and providing new evidence for understanding digitalization and sustainability.

However, this study has several limitations. Although annual report information can capture the semantic characteristics of corporate digital transformation, we used the manual reading method to ensure accurate measurement of the corporate digitalization level. Enterprise digitization involves many aspects, such as daily operation, organizational mode, and resources and capabilities; however, a company’s annual report cannot cover all the key information about digitization strategies. In addition, we evaluated the level of corporate digitalization by manually analyzing the relevant descriptions in company annual reports, which causes subjectivity in variable measurement. Digitization affects various aspects of enterprise activities, and enterprise digitization is widely concerned with enterprise stakeholders and the public. Our study only examined the impact of digitalization on green innovation from the perspectives of internal control and institutional investors, and the analysis of the mechanism of digitalization was limited to internal corporate governance.

Future research can be conducted on the following aspects: First, obtaining accurate data on enterprise digitization applications is helpful in improving the reliability of research. How to measure corporate digitization levels more effectively remains to be explored. Second, in addition to strengthening supervision, enterprises’ digitalization can promote green innovation in more diversified ways, and other mechanisms of digitalization on green innovation may be worthy of further study. Finally, this study used a sample from China; in the wave of the global digital revolution, whether the role of digitalization in corporate green innovation is universal, whether digitalization can play a crucial role in corporate green innovation in other countries, and how it play its role are questions worthy of further exploration.

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