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Digitalization and Sustainability Integration: The Impact of Digital Sustainability Orientation on Responsible Innovation in Emerging Technology Enterprises

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Abstract

The integration of digitalization and sustainability has become a prevailing trend in China's current economic and social development. However, existing research rarely focuses on how emerging technology enterprises achieve responsible innovation through digital sustainability orientation. Based on resource orchestration theory, this study investigates the impact of digital sustainability orientation on responsible innovation, and explores the mediating role of resource orchestration and the moderating role of scientific ties, using a sample of 287 emerging technology enterprises. The empirical results show that: digital sustainability orientation positively influences responsible innovation; resource orchestration mediates the relationship between digital sustainability orientation and responsible innovation; scientific ties positively moderates the relationship between digital sustainability orientation and resource orchestration, and also positively moderates the mediating effect of resource orchestration on the relationship between digital sustainability orientation and responsible innovation. Furthermore, heterogeneity analysis reveals that the leading role of the sustainability orientation is greater than the enabling role of the digital orientation. This research clarifies the theoretical relationship and mechanism between digital sustainability orientation and responsible innovation, and offers practical guidance for emerging technology enterprises to promote responsible innovation.

Keywords: digital sustainability orientation; resource orchestration; scientific ties; responsible innovation

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1. Introduction

While emerging technologies, exemplified by artificial intelligence and nanotechnology, spearhead rapid economic and social development, they simultaneously engender significant challenges, including environmental degradation, information security breaches, and complex ethical dilemmas [1,2]. The traditional innovation paradigm predominantly prioritizes technological feasibility and economic returns, thereby marginalizing social needs and ethical considerations [3]. Concomitant with the traditional paradigm's focus on commercial value [4], responsible innovation emphasizes that the innovation process must maintain close alignment with societal needs and collective will. Consequently, responsible innovation serves as a vital mechanism for mitigating the adverse social consequences inherent in conventional innovation methods [5,6]. Therefore, fostering the implementation of responsible innovation within emerging technology enterprises represents a critical research imperative that warrants urgent exploration.

As a systemic process, responsible innovation in emerging technology enterprises entails the active integration of stakeholder engagement from the inception of the innovation lifecycle, anticipating potential technological ramifications, engaging in continuous reflexive examination of corporate values, and ultimately aligning innovation activities with societal needs and expectations [3,5,6]. This framework imposes dual imperatives upon enterprises: first, the adoption of sustainability as a foundational strategic orientation to balance economic value creation with social and environmental responsibilities; second, the cultivation of organizational capabilities such as outcome anticipation, communicative responsiveness, and agile iteration, which increasingly necessitates a strategic focus on digitalization. However, extant literature often examines the impact of digitalization and sustainability on responsible innovation in isolation [7,8], resulting in a paucity of research that synthesizes these two dimensions.

Indeed, within today's complex competitive landscape, digital transformation and sustainability have transcended being independent paths and are increasingly converging [9,10]. Digital technology is emerging as a pivotal catalyst for driving economic and social value creation to achieve sustainable development [11,12]; conversely, sustainability goals furnish the fundamental impetus and strategic direction for corporate digital transformation [13], giving rise to the concept of "digital sustainability" [9,14,15]. Conceptualized as an extension of digital sustainability within the strategic domain, digital sustainability orientation is defined as a strategic posture whereby enterprises leverage digital technology to empower sustainable value creation and advance digital upgrades through sustainable value propositions, thereby fostering synergy between the two [16,17]. Thus, digital sustainability orientation systematically incorporates both digitalization and sustainability factors, providing a novel lens through which to explore the drivers of responsible innovation; yet, empirical inquiries linking these constructs remain sparse. Furthermore, as a multi-dimensional construct jointly constituted by digitalization and sustainability, the configuration of different dimensions within the digital sustainability orientation may exert heterogeneous effects on responsible innovation. Therefore, it is imperative to demystify and systematically categorize the effects of digital sustainability orientation on responsible innovation [11,17,18].

Digital sustainability orientation suggests that enterprises pursue the dual goals of digitalization and sustainability, thereby necessitating heightened efficiency in resource utilization [19,20]. Resource orchestration theory posits that achieving a competitive advantage is contingent not merely on resource endowment but, more crucially, on the efficacious management and deployment of these assets [21]. Therefore, delineating how to allocate and marshal limited resources to reconcile potential tensions between digitalization and sustainability objectives, while catalyzing their synergy or fusion, represents a significant research avenue [21–23]. Sirmon et al. (2007) [21] underscored the significance of the resource management process in cultivating competitive advantage and validated the pivotal role of resource structuring and integration. Furthermore, extant scholarship has predominantly examined the contingent effects of external environmental contingencies, such as environmental turbulence [24] and stakeholder mandates [25], or internal factors like strategic flexibility [26], on firm innovation. Conversely, inter-organizational determinants remain relatively under-explored. Indeed, inter-organizational linkages and collaborative networks—particularly knowledge-based exchanges—often empower enterprises to orchestrate resources with enhanced efficiency and reduced transaction costs under strategic guidance, thereby fostering innovative behavior through knowledge spillover and technology transfer [27–29]. Based on this, this study introduces scientific ties as a moderating variable to further explore its moderating influence in the aforementioned path.

In summary, this study constructs an integrated framework to explore how digital sustainability orientation influences responsible innovation, with resource orchestration as the mediating mechanism and scientific ties as the pivotal boundary condition. By doing so, this research offers four distinct marginal contributions:

First, based on prior research and the strategic complementarity perspective, this study deconstructs digital sustainability orientation into four distinct types and three degrees, while systematically elucidating their defining characteristics. This refinement enriches and extends the theoretical framework of "digital sustainability" [18]. Second, this study explores the overall positive impact of digital sustainability orientation on responsible innovation, while identifying the differentiated effects that various internal dimensional configurations have on innovative outcomes, thus expanding the research on the drivers of responsible innovation. Third, grounded in resource orchestration theory, we uncover the underlying logic of "efficiency through orchestration" through which digital sustainability orientation drives responsible innovation, elucidating how enterprises transform potential goal conflicts into synergistic advantages under resource constraints. Fourth, by shifting the analytical focus from intra-organizational and extra-organizational factors to inter-organizational dynamics, this study identifies and validates the moderating effect of scientific ties, providing a deeper explanation of the boundary conditions under which digital sustainability orientation promotes responsible innovation.

Through these systematic investigations and heterogeneity analyses, this study clarifies the theoretical relationship between digital sustainability and responsible innovation, providing both academic insights and practical guidance for emerging technology enterprises.

2. Theoretical Analysis and Research Hypotheses

2.1. Digital Sustainability Orientation

Strategic orientation refers to the long-term guiding principles and operational philosophies that enterprises follow in their business operations [30,31]. Numerous studies indicate that digital orientation and sustainability orientation are mutually influential and complementary [9,10]. On the one hand, digital orientation can provide substantial support for sustainable development; however, if an enterprise only possesses digital orientation but lacks sustainability orientation, it may result in unregulated digitalization, leading to negative consequences such as technological redundancy, environmental pollution, and moral hazards [32]. On the other hand, to achieve sustainable development goals, enterprises often require digital technology for the real-time monitoring and optimization of production processes, which in turn accelerates their digital transformation [30]. Building on this, scholars adopting the strategic complementarity view have proposed the concept of digital sustainability orientation, integrating these two formerly independent constructs into unified sub-dimensions [33,34]. In this integrated concept, digital orientation emphasizes process enablement while sustainability orientation focuses on goals and missions, with the two intertwining to form a systemic criterion that guides the entire operational process. Specifically, digital orientation refers to the guiding principle of seeking technology-enabled opportunities to achieve competitive advantage, encompassing the empowerment propensity across areas such as digital technology scope, digital capabilities, ecosystem coordination, and architecture configuration [31]. Sustainability orientation refers to the extent to which an enterprise integrates sustainable development principles into its core business objectives to guide its operating behaviors [30]. In essence, the interplay between these two orientations constitutes the core of digital sustainability orientation [17].

As research continues to advance, scholars have successively explained "digital sustainability" from the perspectives of strategic orientation [17], business models [14,15], and

dynamic capabilities [35]. However, most treat it as a holistic construct and lack further deconstruction of its internal structure. Falcke et al. (2024), from a strategic perspective, conducted a pioneering classification of "digital sustainability," analyzing how enterprises achieve environmental sustainability goals through the execution of innovation paths, and classified digital sustainability strategies into four types based on the varying levels of digital and sustainable strategies [18]. Unlike specific strategic behaviors, strategic orientation is a more focused cognitive-level concept that can guide an enterprise's subsequent behaviors and outcomes; as a significant antecedent and key influencing factor of strategic behavior, it has remained a central focus of scholarly attention [30,31]. In addition, an enterprise's sustainable development is not merely environmental sustainability, but an integrated issue encompassing economic, social, and environmental dimensions [36]. Therefore, drawing on the conceptual framework of Falcke et al. (2024) [18], this paper defines digital sustainability orientation as a strategic system jointly formed by digital orientation and sustainability orientation. It categorizes this orientation into four distinct types based on the relative emphasis placed on each dimension. The level of digital sustainability orientation can be determined by assessing the intensity and interaction between the two, as illustrated in Figure 1. These four types are dynamic rather than static; they can be transformed and adjusted in response to shifts in the external environment and internal organizational endowments to better align with an enterprise's strategic objectives.

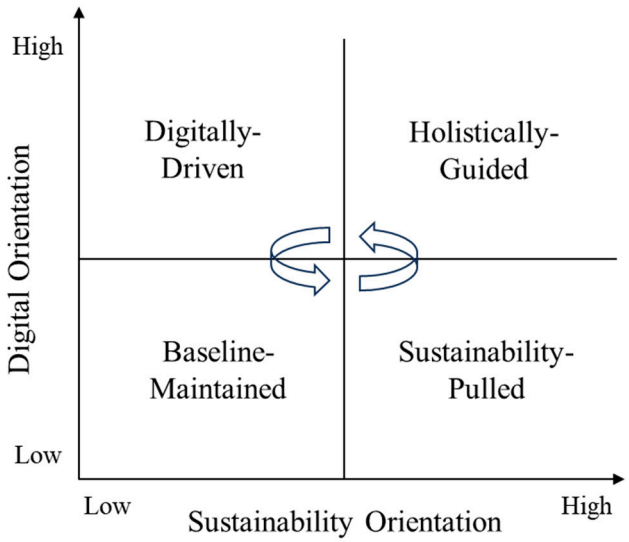

Figure 1. Schematic diagram of the deconstruction of digital sustainability orientation.

Among them, the Holistically-Guided type (High DO-High SO) represents enterprises that strategically prioritize both digitalization and sustainability. These enterprises attain a profound integration of digital and sustainable logics at the strategic-cognitive level; they perceive digital capabilities as pivotal drivers for addressing sustainability issues, while simultaneously emphasizing the ongoing cultivation of digital competencies grounded in a sustainable mission. Consequently, these firms are well-positioned to leverage the synergistic effects between digital orientation and sustainability orientation [18,37]. The Digitally-Driven type (High DO-Low SO) characterizes enterprises that prioritize digital orientation, complemented by a marginal sustainability orientation. Driven by technological innovation, these firms utilize digital technology to improve economic efficiency and social-environmental benefits by enhancing quality and reducing emissions, thereby leveraging digital-sustainable synergies to some extent. However, as their commitment to sustainability primarily stems from the spillover effects of digital technology, addressing foundational sustainability challenges remains difficult [38]. The Sustainability-Pulled

type (Low DO-High SO) represents enterprises that center on sustainability orientation, supplemented by a lower level of digital orientation. These firms are driven by strong sustainable values; however, digital tools are often regarded merely as instruments for attaining sustainability goals. While they can leverage synergies to a degree, limited digital cognition and investment often result in efficiency bottlenecks [18,39]. The Baseline-Maintained type (Low DO-Low SO) represents enterprises with a low degree of focus on both digitalization and sustainability. Such firms often pay minimal attention to digital construction and sustainability due to stakeholder pressure or market demands, while resource allocation still follows traditional short-term economic interest orientations. Lacking necessary digital empowerment and sustainable value guidance, these firms often struggle to form differentiated sustainable competitive advantages in the digital age and can hardly realize any synergy between the two [38,40]. Based on this, each type is divided into three degrees of digital sustainability orientation based on the levels of digital orientation, sustainability orientation, and their synergistic effects. Among them, the Holistically-Guided type represents a high level of digital sustainability orientation; the Digitally-Driven and Sustainability-Pulled types represent medium levels of digital sustainability orientation; and the Baseline-Maintained type represents a low level of digital sustainability orientation [33,34].

2.2. The Impact of Digital Sustainability Orientation on Responsible Innovation

Responsible innovation is an interactive and transparent process where all participants in the innovation activity fully exchange and cooperate from multiple perspectives to organically integrate the development sustainability of the innovation process and output, ethical acceptability, and social needs, thereby deeply embedding innovation within social development expectations [41]. Responsible innovation not only requires technological advancement and feasibility, capable of driving economic growth and efficiency improvement, but also emphasizes collaboration among different stakeholders, integrating the development sustainability of the innovation process and output, ethical acceptability, and social needs to realize accountability and prevent the potential ethical and social risks brought by innovation [42,43].

Evidently, responsible innovation encompasses the value propositions of both digitalization and sustainability strategic orientations. Specifically, sustainability orientation refers to the extent to which an enterprise integrates the principles of sustainable development into its core business objectives, which subsequently guides its operating behaviors, reflecting the enterprise's willingness and actions towards creating social and environmental value [30]; digital orientation, on the other hand, emphasizes an enterprise's pursuit of digital transformation and digital technology change to achieve efficiency improvement and the construction of competitive advantage [31]. Based on this, this paper argues that digital sustainability orientation can leverage the synergistic advantages of digital orientation and sustainability orientation. On one hand, digital orientation enhances the economic efficiency of innovation and facilitates more efficient promotion of stakeholder collaboration. On the other hand, sustainability orientation enables the enterprise to fully consider social needs during the innovation process, thereby achieving accountability [44]. The combined effect of the two orientations is more likely to give rise to an operational system conducive to responsible innovation: prior to innovation decisions, the consideration of social needs driven by sustainability orientation, leveraging the predictive capabilities of artificial intelligence large models and other tools, can systematically assess the social and environmental impacts resulting from the innovation, allowing for timely measures; during the innovation process, guided by the concept of sustainable development, enterprises can optimize innovation processes using sensors, data, and analytics, simultaneously im-

proving quality and efficiency as well as reducing emissions and negative social impacts, thereby meeting the requirements of various stakeholders; simultaneously, the combination of digital orientation and sustainability orientation is also conducive to timely reflection on shortcomings during the innovation process, with relevant information promptly fed back through digital technology and equipment, enabling timely corrections [3,42,43]. Furthermore, sustainability orientation is crucial for integrating business practices with social and environmental goals, and it facilitates the enterprise in integrating economic value creation with logical social and environmental sustainability requirements under resource constraints, thereby promoting the achievement of responsible innovation [45]. Accordingly, the following hypothesis is proposed:

H1: *Digital sustainability orientation positively influences responsible innovation in enterprises.*

2.3. The Mediating Role of Resource Orchestration

Sirmon et al. (2007) [21] constructed a theoretical model of resource management actions, exploring the specific process of organizational resource formation and allocation, emphasizing the importance of resource management, and thereby forming the concept of resource orchestration. Resource orchestration is the process by which an enterprise builds, integrates, and leverages resources through resource management behaviors to gain a competitive advantage [21,46].

This paper proposes that digital sustainability orientation can promote corporate resource orchestration. Firstly, digital sustainability orientation can enhance the breadth and precision of enterprise resource identification. Based on the Internet of Things, big data, and artificial intelligence technologies, enterprises can obtain multi-dimensional environmental and social data in real time, breaking through the economic value limitations of traditional resource identification and incorporating sustainability standards into the resource screening system [21,47,48]. Digital sustainability orientation facilitates the acquisition of diverse resources from the market and enables firms to effectively preserve, accumulate, and extract these resources, providing a robust resource base for resource building [49]. Secondly, digital sustainability orientation can enhance the agility and synergy of resource integration. Enterprises can use digital tools to eliminate information silos and promote the flow of resources and knowledge sharing across departments and organizations [50,51]. Digital sustainability orientation requires enterprises to embed environmental and social responsibility indicators into the resource integration process. This digital technology-enabled integration mechanism not only accelerates the efficiency of internal and external resource fusion but also reduces the risk of resource mismatch through data-driven decisions, effectively enhancing the enterprise's ability to integrate resources, thereby achieving better resource integration [21]. Lastly, the enhancement of strategic flexibility brought by digital sustainability orientation enables enterprises to effectively perceive external environment and internal resource conditions and make rapid responses [52]; the embedding of corporate social responsibility brought by sustainability orientation allows for a better understanding and grasp of how resources should be used to balance sustainable value creation during the responsible innovation process [45]; coupled with the synergistic effect of digitalization and sustainability, which allows the advantages of one strategic orientation to be used to minimize the weaknesses of the other, this paper suggests that digital sustainability orientation can effectively enhance the enterprise's resource utilization capability [21,53]. Accordingly, the following hypothesis is proposed:

H2: *Digital sustainability orientation positively influences resource orchestration.*

This paper argues that resource orchestration is crucial for promoting responsible innovation because it can effectively tap into and utilize resources to create advantages [54]. Firstly, through resource orchestration, enterprises can acquire, accumulate, and divest relevant resources, forming resource portfolios to ensure that the firm's resource endowment meets the economic and social-environmental requirements necessary for responsible innovation [3,55]. Simultaneously, resource orchestration allows enterprises to better leverage the potential of existing resources and effectively reduce sunk costs [56]. Since responsible innovation simultaneously emphasizes economic goals and sustainability goals, inherently placing high demands on enterprise resources, this cost control is highly beneficial for increasing redundancy to cope with potential conflicts arising from the enterprise's dual objectives, thereby promoting responsible innovation [41]. Secondly, resource orchestration integrates different resources to form the enterprise's core capabilities, including stabilizing existing capabilities, enriching current capabilities, and pioneering new capabilities [21]. Capabilities such as strategic flexibility and market sensing, developed through resource orchestration, effectively facilitate the firm's anticipation, reflexivity, inclusion, and responsiveness during the responsible innovation process. This not only helps seize market opportunities to achieve technological feasibility and enhanced economic efficiency but also satisfies societal expectations and environmental protection requirements, promoting responsible innovation in a sustainable manner [3,57]. Additionally, resource orchestration helps enhance the enterprise's collaborative capacity [52]. Through cross-organizational and cross-departmental knowledge sharing and capability coupling, the enterprise achieves full stakeholder participation, incorporating external factors such as public demands and policy guidance into the innovation management process, thereby promoting responsible innovation [41]. Thirdly, achieving responsible innovation requires effective resource allocation. resource orchestration enables the enterprise to become more proficient in applying current resources, helping to improve work efficiency, which can thus meet the needs of responsible innovation faster and better [58]. Enterprises can better mobilize, coordinate, and deploy resources based on the needs of responsible innovation through resource orchestration. Accordingly, the following hypothesis is proposed:

H3: *Resource orchestration mediates the relationship between digital sustainability orientation and responsible innovation.*

2.4. The Moderating Role of Scientific Ties

Scientific ties refer to the linkages between an enterprise and subjects that produce scientific knowledge, such as research institutions, universities, and scientists, serving as a crucial channel for enterprises to acquire necessary technology and knowledge and build competitive advantage [27,59,60].

This paper proposes that scientific ties play a positive moderating role in the process by which digital sustainability orientation influences resource orchestration in enterprises. Firstly, scientific ties are conducive to integrating diverse knowledge and accelerating information dissemination, which provides advantages for enterprises such as rapidly transforming resource usage, improving resource utilization efficiency, and reducing resource cost consumption during the innovation process [59]. This, in turn, facilitates the identification and leveraging of existing resources, the strategic divestiture of obsolete resources, and the provision of a more robust resource base [27]. Simultaneously, the cutting-edge technological information and technical support brought by scientific ties are beneficial for enhancing the enterprise's resource utilization capability, better coordinating various resources, more accurately uncovering synergistic elements among different resources, and further reducing resource mismatch risks, effectively boosting the efficiency of enterprise resource integration, thus better building and improving enterprise capabili-

ties [21]. Additionally, the higher scientific ties imply that the enterprise possesses strong inter-organizational penetrability, which is beneficial for the organization to establish closer and more coordinated cooperative relationships with partners [1]. In this context, the enterprise can better leverage external forces to effectively configure resources, providing a foundation for resources to exert greater utility. Accordingly, the following hypothesis is proposed:

H4: *Scientific ties positively moderate the influence of digital sustainability orientation on resource orchestration.*

Given the moderating effect of scientific ties on resource orchestration, this study proposes that the mediating effect of resource orchestration between digital sustainability orientation and responsible innovation is also moderated by scientific ties. Specifically, strong scientific ties enable an enterprise to better balance the economic and non-economic objectives of digital sustainability orientation, facilitating more efficient and lower-cost integration of heterogeneous resources to manage tensions and achieve synergy: First, scientific ties promote enterprise resource building, enriching the resource base and better meeting the resource requirements of responsible innovation [1]. Second, scientific ties provide enterprises with channels for in-depth communication with other scientific knowledge producers, which facilitates the acquisition of cutting-edge technological information, technical support, and other innovation support. This, in turn, helps enterprises build the necessary capabilities for responsible innovation through resource integration. This capability is beneficial for both better identifying and assessing potential risks in innovation, and providing creative resource management solutions for social risks associated with innovation [27]; it also helps optimize the feedback loop during the innovation process, better satisfying the needs of responsible innovation [5,6]. Third, scientific ties help enterprises gain a deeper understanding of social needs, public expectations, and policy guidance from different perspectives, thereby ensuring that the enterprise's resource utilization aligns with societal demands [27,42,43]; concurrently, communication with stakeholders also facilitates the enterprise's continuous reflection on its own conduct during the innovation process [5,6]. That is, scientific ties amplify the effect of digital sustainability orientation promoting responsible innovation through resource orchestration. Accordingly, the following hypothesis is proposed:

H5: *Scientific ties positively moderate the mediating effect of resource orchestration on the relationship between digital sustainability orientation and responsible innovation.*

In summary, the theoretical model of the impact mechanism of digital sustainability orientation on responsible innovation is constructed as shown in Figure 2.

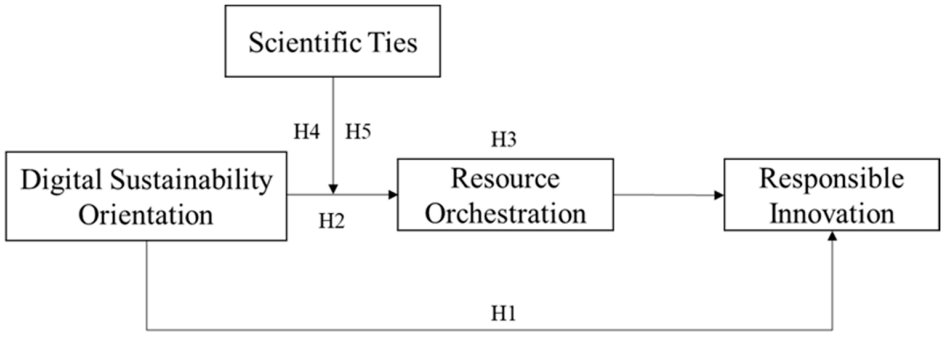

Figure 2. Theoretical model.

3. Research Design

3.1. Research Sample and Data Collection

This paper takes emerging technology enterprises as the survey subjects, with the criterion that these enterprises primarily belong to emerging technology sectors such as information technology, electronics, energy saving and environmental protection, new materials, and new energy [28]. The questionnaire survey was conducted based on the research team's cooperation with local government departments and venture capital institutions. Based on these relationships, the research team initially identified approximately 600 potential enterprises and formulated a candidate list. Subsequently, the team initiated preliminary communications with the listed enterprises via telephone, WeChat, or email to confirm their operating status, primary business affiliation, and willingness to participate. After filtering out firms that had ceased operations, those outside the target industries, and those unwilling to participate, 350 enterprises were ultimately selected as the target respondents. The formal investigation was carried out from February to April 2025. At the commencement of the formal investigation, the research team contacted the respondents again through face-to-face meetings, telephone, WeChat, email, or other methods, clarifying that this study is for academic research purposes only and explicitly explaining the filling requirements and precautions. Questionnaires were distributed through both online and offline methods, with one questionnaire distributed per enterprise, all of which were completed by senior managers or heads of key middle-management departments such as digitalization or environmental compliance to ensure data quality.

A total of 350 questionnaires were distributed, yielding 306 responses. After filtering out responses with obvious errors, duplicates, or missing values in core variables, a total of 287 valid questionnaires were obtained, resulting in an effective response rate of 82.00%. Detailed information regarding the sample is presented in Table 1. As illustrated, the sample is predominantly composed of private enterprises, with state-owned enterprises accounting for only 19.16%. This composition aligns with the characteristics of China's economic structure, where private firms serve as the primary drivers of technological innovation. Geographically, the sample firms are highly concentrated in the eastern region (68.99%), consistent with the actual spatial agglomeration patterns of emerging technology industries in China. In terms of core business sectors, the sample covers various emerging fields, including Information Technology and Information Services (21.60%), Biomedicine and New Materials (10.80%), Advanced Equipment Manufacturing (13.85%), and New Energy (38.33%), thereby ensuring the broad applicability of the research findings. Furthermore, the distributions of firm age and number of employees meet the requirements for statistical analysis. Overall, the sample exhibits strong representativeness and is well-suited to the objectives of this study.

Table 1. Descriptive statistics of the sample (N = 287).

Indicator	Category	Percentage (%)	Cumulative Percentage (%)
Enterprise Ownership Nature (NE)	State-owned enterprises	19.16	19.16
	Private enterprises	68.64	87.80
	Foreign-funded enterprises	3.83	91.63
	Others	8.37	100.00
Enterprise Age (AGE)	3 years or less	4.88	4.88
	3–5 years	7.32	12.20
	6–10 years	32.06	44.25
	11–15 years	36.24	80.49
	Over 15 years	19.51	100.00

Table 1. *Cont.*

Indicator	Category	Percentage (%)	Cumulative Percentage (%)
Enterprise Size (SIZE)	10 employees or less	3.83	3.83
	11–50 employees	9.41	13.24
	51–100 employees	45.99	59.23
	101–500 employees	32.06	91.29
	Over 500 employees	8.71	100.00
Enterprise Location (AER)	Eastern region (Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan, and Liaoning)	68.99	68.99
	Non-Eastern regions	31.01	100.00
Industry Category (IND)	IT and Information	21.60	21.60
	Biomedicine	10.80	32.40
	High-end equipment manufacturing	13.59	45.99
	New materials and New energy	38.33	84.32
	Energy saving and environmental protection	6.97	91.29
	Others	8.71	100.00

3.2. Variable Measurement

To ensure the reliability, validity, and accuracy of the wording used in the scales, this paper adopted the method of back-translation, dividing the research group members into two teams. One team translated the English scales into Chinese, and the other team back-translated the Chinese results into English. Discussions and careful consideration of the wording were conducted regarding the differences between the back-translated scales and the original scales to improve translation accuracy. Furthermore, after the initial design of the questionnaire, 15 managers from emerging technology enterprises were selected for a pilot survey. Based on the results of the preliminary pilot survey and feedback from the respondents, the questionnaire content was further refined and revised to form the final questionnaire; the specific measurement system is detailed in Table 2. All variables were measured using a 7-point Likert scale, where 1 indicates "strongly disagree" and 7 indicates "strongly agree."

The dependent variable is responsible innovation, measured by referring to the study by Zhang et al. (2023) [24], which covers four dimensions: anticipation, reflexivity, inclusion, and responsiveness, totaling 4 items. The independent variable is digital sustainability orientation. As a concept jointly constituted by two correlated dimensions, it is measured using K-means clustering followed by assignment: "High-High" is assigned a value of 3, "High-Low" and "Low-High" are assigned a value of 2, and "Low-Low" is assigned a value of 1. To ensure the relative independence of the evaluation system, this paper separately defined the measurement items for digital orientation and sustainability orientation. digital orientation refers to the study by Arias-Pérez and Vélez-Jaramillo (2022) [61], totaling 7 items; sustainability orientation refers to the study by Muñoz and Dimov (2015) [62], totaling 6 items. The mediating variable is resource orchestration, measured by referring to the study by Wang et al. (2020) [46], covering three aspects: resource absorption, integration, and utilization, totaling 3 items. The moderating variable is scientific ties, measured by referring to the studies by Lin et al. (2022) [63] and Yang et al. (2025) [28], covering three aspects: subject of connection, function, and effect, totaling 5 items.

Concurrently, this paper controls for enterprise-level influencing factors: enterprise ownership nature, enterprise age, enterprise size, enterprise location, and business scope. Furthermore, enterprise ownership nature, enterprise location, and industry category were processed using dummy variables. State-owned enterprises were assigned a value of 1, and other ownership natures were assigned a value of 0; the Eastern region was assigned

a value of 1, and non-Eastern regions were assigned a value of 0; additionally, five dummy variables were used to control for six categories of business scope.

Table 2. Scale rtems and psychometric properties of the variables.

Variable	Specific Measurement Items	Factor Loading	Related Metrics
Digital Orientation (DO)	Our firm has a clear vision of how emerging digital technologies can enhance business value.	0.731	KMO: 0.901 Cronbach α: 0.920 CR: 0.923 AVE: 0.631
	Our firm is committed to using digital technologies to empower its business strategy.	0.784	
	Our firm's management and various functional departments understand the investment value of digital technologies.	0.802	
	Our firm can keep pace with cutting-edge digital technologies.	0.791	
	Our firm has the capability and will to experiment with new digital technologies when necessary.	0.730	
	Our firm fosters an environment that supports experimenting with new digital technologies.	0.832	
	Our firm continuously seeks new methods to improve the effectiveness of digital technology application.	0.880	
Sustainability Orientation (SO)	I believe our firm has the capability to help solve many of the problems our society faces.	0.791	KMO: 0.928 Cronbach α: 0.944 CR: 0.945 AVE: 0.743
	Our firm's obligations to society extend beyond just making profits.	0.895	
	Our firm must give back to society because its profits come from society.	0.870	
	Regardless of the nature of our business, our firm must deal fairly with customers and suppliers.	0.870	
	Regardless of the nature of our business, our firm must use natural resources responsibly.	0.843	
	When choosing between different business concepts, our firm always selects the one that helps build a better society.	0.898	
Resource Orchestration (RO)	Our firm is capable of absorbing diverse resources.	0.834	KMO: 0.732 Cronbach α: 0.852 CR: 0.853 AVE: 0.659
	Our firm is capable of integrating diverse resources.	0.801	
	Our firm is capable of leveraging diverse resources.	0.800	
Science Ties (ST)	Our firm maintains sound collaborative relationships with multiple universities and scientists (experts and scholars).	0.772	KMO: 0.869 Cronbach α: 0.868 CR: 0.869 AVE: 0.570
	Our firm maintains sound collaborative relationships with multiple research institutions.	0.785	
	Our firm frequently conducts in-depth collaborations with universities, research institutions, and scientists on activities such as technological innovation/upgrading and new product development	0.754	
	Our firm frequently obtains cutting-edge knowledge and information about new technologies and products from universities, research institutions, and scientists.	0.746	
	Collaboration with universities, research institutions, and scientists generates significant value for our firm.	0.717	
Responsible Innovation (RI)	Our firm involves diverse stakeholders in the early stages of innovation.	0.835	KMO: 0.858 Cronbach α: 0.922 CR: 0.923 AVE: 0.747
	In the initial phase of innovation activities, our firm conducts prospective analysis on their future impacts, thereby guiding them towards morally acceptable and socially desirable outcomes and ensuring controllable risks.	0.873	
	During the innovation process, our firm continuously reflects on the assumptions, requirements, objectives, implementation process, and outcomes of the innovation itself.	0.858	
	The actors and governance models in our firm's innovation activities are established through interactive, sustainable, and adaptive processes, enabling proper guidance and real-time correction of the innovation process.	0.894	

4. Empirical Analysis

4.1. Common Method Bias Test

Since the measured variables in this study all come from the self-assessment of the enterprises by their senior executives, common method bias may exist. This study employed Harman's single-factor test for examination. The unrotated factor analysis revealed five common factors with eigenvalues greater than 1. Among these, the first factor accounted for 33.90% of the explained variance, which is less than the 40% threshold, and the cumulative explained variance was 73.97%, which is greater than the 60% threshold. Therefore, there is no serious common method bias problem.

4.2. Confirmatory Factor Analysis

The results for reliability and validity are shown in Table 2. The factor loading for each item is greater than 0.5, the Cronbach's α value for all variables is above 0.852, the Composite Reliability (CR) is above 0.7, and the Average Variance Extracted (AVE) value is above 0.5. Concurrently, given the relatively large number of measurement items and the limited sample size, direct computation using initial item data is likely to result in larger biases in the estimated parameters. Therefore, Confirmatory Factor Analysis (CFA) was performed by constructing competing models. The results, shown in Table 3, indicate that the six-factor model has fit indices of $\chi^2/df = 1.558$, IFI = 0.971, TLI = 0.967, CFI = 0.971, SRMR = 0.046, and RMSEA = 0.044. The model fit indices are good and superior to those of the other competing models, Moreover, as presented in Table 4, the square roots of the AVE for each construct are greater than the corresponding correlation coefficients with other constructs, confirming that the discriminant validity of the variables meets the required standards.

Table 3. Results of confirmatory factor analysis.

Model	Factor Combination	χ^2/df	IFI	TLI	CFI	SRMR	RMSEA
Five-Factor	DO, SO, RO, ST, RI	1.558	0.971	0.967	0.971	0.046	0.044
Four-Factor	DO + SO, RO, ST, RI	6.290	0.721	0.686	0.719	0.174	0.136
Three-Factor	DO + SO, RO + ST, RI	7.813	0.636	0.596	0.634	0.205	0.154
Two-Factor	DO + SO + RO + ST, RI	9.615	0.536	0.489	0.534	0.203	0.174
Single-Factor	DO + SO + RO + ST + RI	11.978	0.404	0.349	0.401	0.230	0.196

Table 4. Correlation analysis matrix.

	Mean	SD	DO	SO	RO	ST	RI
DO	4.534	1.366	0.794				
SO	4.721	1.386	0.163 **	0.862			
RO	5.578	1.029	0.357 ***	0.365 ***	0.812		
ST	5.783	0.930	0.198 ***	0.207 ***	0.170 **	0.754	
RI	4.601	1.230	0.348 ***	0.560 ***	0.512 ***	0.274 ***	0.864

Note: Two-tailed test, ** indicates $p < 0.01$, *** indicates $p < 0.001$, applies hereafter. The values along the diagonal represent the square roots of the AVE.

4.3. Descriptive Statistics and Correlation Analysis

As shown in Table 4, the means and standard deviations of the main variables are all within a reasonable range. Furthermore, the correlation coefficients between the variables are free of abnormalities and indicate existing correlation relationships.

4.4. Cluster Analysis

The K-Means clustering method assigns observations to the cluster with the nearest mean through continuous iteration, thereby minimizing within-cluster variance and maximizing between-cluster variance. This ensures the statistical significance and distinctiveness of the classification results, making it widely used in management research [64,65]. Referring to the study by Anees-ur-Rehman et al. (2017) [66], the K-Means cluster analysis method was employed to determine the specific classifications of digital sustainability orientation. Initially, the threshold was set to 4. Then, based on the intensity of the enterprises' digital orientation and sustainability orientation, observations were iteratively clustered to their nearest means. After nine iterations, all samples were ultimately divided into four categories, with the specific information detailed in Table 5. Based on previous research, cluster analysis results, and the preceding discussion [18,37,66], we assigned numerical values to represent the degree of digital sustainability orientation: Holistically-Guided type (High DO-High SO cluster) was assigned a value of 3, Digitally-Driven (High DO-Low SO) and Sustainability-Pulled (Low DO-High SO) types were assigned a value of 2, and Baseline-Maintained type (Low DO-Low SO) was assigned a value of 1.

Table 5. Cluster analysis results.

Dimension	Low DO-Low SO Cluster (n = 50)	High DO-Low SO Cluster (n = 70)	Low DO-High SO Cluster (n = 73)	High DO-High SO Cluster (n = 94)
DO	2.811	5.376	3.456	5.660
SO	3.333	3.371	5.580	5.798

4.5. Hypothesis Testing

To unify the dimensions and avoid multicollinearity, all variables were standardized before the regression analysis. This paper further conducted a collinearity test on all variables, and the results showed that the Variance Inflation Factor (VIF) values for all variables were less than 4, confirming that there is no serious multicollinearity problem.

4.5.1. Direct Effect Test

As shown in M1 and M2 in Table 6, after controlling for the influence of control variables, digital sustainability orientation has a significant positive influence on responsible innovation ($\beta = 0.510$, $p < 0.001$). Therefore, Hypothesis H1 is supported.

Table 6. Hierarchical regression results.

Variable	RI			RO			
	M1	M2	M3	M4	M5	M6	M7
Constant	0.002 (0.006)	0.112 (0.370)	0.051 (0.183)	0.080 (0.232)	0.159 (0.490)	0.212 (0.654)	0.137 (0.426)
NE	0.401 ** (2.664)	0.118 (0.869)	0.023 (0.188)	0.450 ** (2.980)	0.246 (1.689)	0.218 (1.493)	0.188 (1.300)
AGE	−0.095 (−1.497)	−0.061 (−1.091)	−0.056 (−1.096)	−0.038 (−0.592)	−0.013 (−0.220)	−0.021 (−0.346)	−0.030 (−0.509)
SIZE	−0.022 (−0.303)	0.023 (0.353)	0.029 (0.506)	−0.050 (−0.689)	−0.018 (−0.263)	−0.016 (−0.239)	−0.006 (−0.084)
AER	0.036 (0.277)	0.138 (1.217)	−0.002 (−0.016)	0.290 * (2.247)	0.364 ** (2.984)	0.374 ** (3.077)	0.386 ** (3.222)
IND	Control	Control	Control	Control	Control	Control	Control
DSO		0.510 *** (9.132)	0.369 *** (6.791)		0.367 *** (6.122)	0.347 *** (5.710)	0.355 *** (5.934)
ST						0.104 (1.789)	0.159 ** (2.654)
DSO × ST							0.178 ** (3.083)
RO			0.385 *** (7.519)				
R^2	0.059	0.278	0.401	0.055	0.168	0.178	0.205
adjR^2	0.278	0.251	0.377	0.024	0.138	0.145	0.170
F	1.943 *	10.608 ***	16.723 ***	1.797	5.579 ***	5.403 ***	5.898 ***

Note: Standardized regression coefficients are reported, * indicates $p < 0.05$, ** indicates $p < 0.01$, *** indicates $p < 0.001$, with T-values in parentheses. Digital sustainability orientation is abbreviated as DSO.

4.5.2. Mediation Effect Test

This study first used the three-step analysis method for mediation effects for testing. According to M5 in Table 6, digital sustainability orientation has a significant positive influence on resource orchestration ($\beta = 0.367$, $p < 0.001$), thus supporting Hypothesis H2. According to M3, after including resource orchestration, the influence of digital sustainability orientation on responsible innovation changed from ($\beta = 0.510$, $p < 0.001$) to ($\beta = 0.369$, $p < 0.001$), and at the same time, resource orchestration significantly positively influences responsible innovation ($\beta = 0.385$, $p < 0.001$). This indicates that resource orchestration plays a partial mediating role in the influence of digital sustainability orientation on responsible innovation, meaning Hypothesis H3 is supported.

4.5.3. Moderation Effect Test

As seen in M7 in Table 6, the interaction term of digital sustainability orientation and scientific ties have a significantly positive influence on resource orchestration ($\beta = 0.178$, $p < 0.01$). This indicates that scientific ties enhance the positive influence of digital sustainability orientation on resource orchestration, thus supporting Hypothesis H4. That is, the stronger the scientific ties, the greater the positive influence of digital sustainability orientation on resource orchestration, and vice versa; this is specifically illustrated in Figure 3.

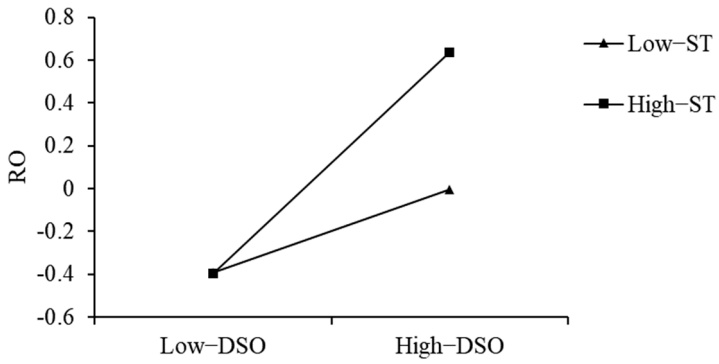

Figure 3. Moderating effect of scientific ties on digital sustainability orientation and resource orchestration.

4.5.4. Test of Moderated Mediation Effect

This study adopted Hayes' Process (Model 7) and used Bootstrap sampling 5000 times for testing, with the results shown in Table 7. The difference in the indirect effect of digital sustainability orientation on responsible innovation through resource orchestration is significant across groups, with a 95% Confidence Interval (CI) of [0.026, 0.103]. Since the confidence interval does not include zero, Hypothesis H5 is supported.

Table 7. Test of moderated mediation.

Mediator	Moderator	Indirect Effect	SE	95%CI	
				LL	UL
RO	Low ST	0.075	0.031	0.019	0.137
	Medium ST	0.137	0.034	0.077	0.207
	High ST	0.199	0.047	0.116	0.298

4.6. Heterogeneity Test

Heterogeneity testing was conducted using One-Way Analysis of Variance (ANOVA). First, a normality test was performed, which showed that the maximum absolute value of kurtosis was 0.342 and the maximum absolute value of skewness was 0.427, meeting the

requirements for normal distribution. Levene's test based on the mean showed a *p*-value of 0.137, which is greater than 0.05, indicating that there is no significant difference in variance among different groups, thus allowing for the One-Way ANOVA.

The ANOVA results show that the four types of digital sustainability orientation have a significant difference in their influence on responsible innovation ($F = 41.814$, $p < 0.001$). Among these, the Holistically-Guided type (High DO-High SO) had the strongest driving effect on responsible innovation, followed by Digitally-Driven type (Low DO-High SO), then Sustainability-Pulled type (High DO-Low SO), and finally Baseline-Maintained type (Low DO-Low SO), as specifically shown in Table 8. Considering the exploratory nature of the study, and to supplement the findings of the One-Way ANOVA, this paper performed a post hoc pairwise comparison test using the Least Significant Difference (LSD) method, which found that all four categories of digital sustainability orientation show significant differences in promoting responsible innovation, as detailed in Table 9. Furthermore, based on the result that (Low DO-High SO) is significantly superior to (High DO-Low SO) in promoting responsible innovation, it can be inferred that even at the same level of digital sustainability orientation, there are differences in promoting responsible innovation. For emerging technology enterprises, the leading role of sustainability orientation is greater than the enabling role of digital orientation.

Table 8. Results of One-Way ANOVA.

	Low DO-Low SO (*n* = 50)	**High DO-Low SO (*n* = 70)**	**Low DO-High SO (*n* = 73)**	**High DO-High SO (*n* = 94)**
Mean	3.515	4.114	4.846	5.351
SD	1.097	1.138	0.989	0.933

Table 9. Post hoc test results.

(I) Group	**(J) Group**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval**	
					Lower	**Upper**
Low DO-Low SO	Low DO-High SO	−1.331 ***	0.189	0.000	−1.703	−0.959
	High DO-High SO	−1.836 ***	0.180	0.000	−2.191	−1.482
	High DO-Low SO	−0.599 **	0.191	0.002	−0.974	−0.224
High DO-Low SO	Low DO-High SO	−0.732 ***	0.172	0.000	−1.070	−0.393
	High DO-High SO	−1.237 ***	0.162	0.000	−1.557	−0.917
	Low DO-Low SO	0.599 **	0.191	0.002	0.224	0.974
Low DO-High SO	High DO-High SO	−0.505 **	0.161	0.002	−0.821	−0.189
	Low DO-Low SO	1.331 ***	0.189	0.000	0.959	1.703
	High DO-Low SO	0.732 ***	0.172	0.000	0.393	1.070
High DO-High SO	Low DO-High SO	0.505 **	0.161	0.002	0.189	0.821
	Low DO-Low SO	1.836 ***	0.180	0.000	1.482	2.191
	High DO-Low SO	1.237 ***	0.162	0.000	0.917	1.557

Note: ** indicates $p < 0.01$, *** indicates $p < 0.001$.

5. Research Conclusions and Implications

5.1. Research Conclusions

Grounded in resource orchestration theory and the strategic complementarity perspective, this study employs a sample of emerging technology firms to clarify the structural dimensions of digital sustainability orientation, examine its influence on responsible innovation, and investigate the mediating effect of resource orchestration and the moderating effect of scientific ties. The following conclusions are drawn: First, the construct of digital sustainability orientation is further refined and categorized into four types and three levels. Second, digital sustainability orientation positively influences responsible innovation. Third, digital sustainability orientation facilitates responsible innovation through resource

orchestration. Fourth, scientific ties strengthen the positive effect of digital sustainability orientation on responsible innovation. Additionally, by deconstructing digital sustainability orientation, structural differences in its driving effect on responsible innovation are identified: the dominant role of sustainability orientation outweighs the facilitative role of digital orientation. This indicates that for current emerging technology firms, promoting responsible innovation relies more on the philosophy and practical implementation of sustainable development.

5.2. Theoretical Contributions

First, based on the perspective of strategic complementarity, this study defines digital sustainability orientation as a strategic system jointly formed by digital orientation and sustainability orientation. By further deconstructing its internal structure, this research enriches the theoretical inquiry into digital sustainability. While existing studies have explained "digital sustainability" from aspects such as strategic orientation [35], business models [14,15], and dynamic capabilities [36], most treat it as a holistic construct and lack further taxonomic deconstruction. Through qualitative research, Falcke et al. (2024) defined the concept and types of digital sustainability strategy based on digital innovation and environmental sustainability [18]. Extending this work, this paper conducts research from the cognitive level of strategic orientation with two major incremental improvements: on the one hand, it breaks through the limitation of focusing solely on environmental sustainability by adopting a more systemic triple bottom line perspective encompassing economic, social, and environmental sustainability. This offers a more inclusive framework that better reflects the multi-dimensional goals of emerging technology enterprises. It classifies the orientation into four categories based on the levels of digitalization and sustainability orientations, elucidates their characteristics and evolutionary patterns, and thus enriches the theoretical system of digital sustainability [33]. On the other hand, it categorizes these four types into three degrees of digital sustainability orientation, providing a foundation for subsequent empirical research [67].

Second, this study combines digital sustainability orientation with responsible innovation, expanding the research on the drivers of responsible innovation. Responsible innovation is key for emerging technology enterprises to break through the limitations of traditional innovation and achieve sustainable development. However, existing research often discusses the impact of digitalization and sustainability factors on corporate responsible innovation separately, lacking research from the perspective of digital sustainability orientation [7,8]. By introducing digital sustainability orientation, this paper clarifies its overall positive impact on responsible innovation. Moreover, unlike previous studies that only focused on the overall impact [17], this paper, based on the deconstruction of the internal structure of digital sustainability orientation, further clarifies the differentiated impacts of different internal dimension configurations on responsible innovation. In particular, it finds that the Sustainability-Pulled (Low DO-High SO) type outperforms the Digitally-Driven (High DO-Low SO) type in driving responsible innovation. It can be seen that while digitalization provides a "technical toolset," it remains value-neutral. Without the guidance of explicit and strong sustainability goals, any sustainable outcomes generated in "digitally-driven" companies tend to be passive "spillover effects" from improved digital efficiency (such as incidental energy savings from process optimization), rather than fundamental, long-term systemic transformations. In contrast, the Sustainability-Pulled type ensures that innovation resources are strategically allocated to address sustainability challenges across economic, social, and environmental dimensions; even if a lower emphasis on digitalization might lead to reduced efficiency, this model still drives responsible innovation

more effectively than the Digitally-Driven type [11,17,18]. These findings provide a useful supplement to how emerging technology enterprises can achieve responsible innovation.

Third, based on resource orchestration theory, this study constructs a theoretical model of digital sustainability orientation, promoting the development of responsible innovation and refining the research on the underlying mechanisms of digital sustainability orientation [18,21]. By revealing the mediating effect of resource orchestration and the boundary effect of scientific ties in this relationship, this study further clarifies the process mechanisms and boundary conditions through which digital sustainability orientation operates. Existing scholars have explored digital sustainability based on dynamic capabilities theory [17] and institutional theory [68], but there is a lack of exploration based on resource orchestration theory. Resource orchestration refers to the orchestration behaviors of building, integrating, and leveraging resources within an enterprise, which is conducive to gaining competitive advantage in dynamic environments [48]. For enterprises that take digital sustainability as their core strategic orientation, resources are more likely to be under strain due to the dual pursuit of multiple goals; therefore, effective resource orchestration is crucial. This study empirically tests the mediating mechanism of resource orchestration in the process of digital sustainability orientation driving responsible innovation, clarifying the economic logic of "efficiency through orchestration" within the context of dual goals. Under the guidance of the twin objectives of digital transformation and sustainable development, firms can significantly lower the marginal costs of responsible innovation and transform potential goal conflicts into synergistic advantages by effectively structuring, bundling, and leveraging resources [21]. These findings both enrich the research on the functional process of digital sustainability and expand the application fields of resource orchestration theory.

Finally, this paper introduces scientific ties as a moderating variable, deepening the understanding of the driving mechanism of responsible innovation. Research shows that relationships with stakeholders are important boundary conditions affecting corporate innovation behavior [69], but there is currently a lack of research on scientific ties in the context of digital sustainability. Good relationships with research institutes and universities are often key boundary conditions affecting corporate innovation, especially for responsible innovation that needs to balance economic benefits and social responsibility [3]. Through empirical testing, this paper finds that scientific ties can effectively amplify the positive effect of digital sustainability orientation on resource orchestration and, based on this, further drive responsible innovation. This study finds that scientific ties serve as a vital boundary mechanism that reduces information asymmetry and barriers to resource flow. By bridging the gap between academic research and industrial application, scientific ties facilitate the inflow of low-cost, high-value knowledge resources into the firm [29]. This enables enterprises to better align their digital capabilities with sustainability goals, thereby amplifying the promoting effect of resource orchestration on responsible innovation [28]. By incorporating scientific ties into the theoretical framework of digital sustainability orientation affecting responsible innovation and deeply exploring its boundary effects, this study further deepens the understanding of the mechanism of digital sustainability orientation.

5.3. Practical Implications

The conclusions of this study offer several implications for enterprises and government policy-makers.

For emerging technology enterprises: First, enterprises should value the positive role of digital sustainability orientation. Enterprise managers should recognize that digital transformation and sustainability are not mutually exclusive but complementary; they should not be confined to a single strategic orientation but should focus on leveraging the synergistic effects between digitalization and sustainability orientations. Specifically, enterprises could consider establishing long-term strategic plans for digital sustainabil-

ity and strengthening organizational members' awareness and understanding of digital sustainability within the organizational culture. Simultaneously, when resources and capabilities are sufficient, prioritizing both digital transformation and sustainable development simultaneously can effectively promote responsible innovation. Under resource constraints, it is more advantageous to prioritize the sustainability orientation dimension within the digital sustainability orientation system, supplemented by a certain degree of digital orientation, to facilitate responsible innovation. Furthermore, enterprises should focus on leveraging the transmission role of resource orchestration and the regulatory role of scientific ties. Guided by digital sustainability orientation, enterprises should recognize the importance of resource management activities, break organizational boundaries, and strengthen internal and external interaction based on scientific ties to better build, integrate, and utilize resources, thereby promoting responsible innovation. For example, enterprises can strengthen ties with universities and research institutions, acquiring tangible or intangible forward-looking technological resources through methods such as "talent enclaves," joint laboratories, or industry-university-research cooperation. Additionally, they can establish "resource-sharing pools" among scientific partners to integrate the resources required for responsible innovation at lower costs and with higher efficiency.

For policy-makers such as the government: They should recognize the positive role of digital sustainability orientation and, therefore, strengthen guidance and support. This should involve mechanisms like equity mixing and government-backed guidance funds to encourage emerging technology enterprises to embed sustainability logic. Simultaneously, they should rely on policy enablement and public service support to encourage and accelerate enterprises' digital transformation, which in turn promotes corporate responsible innovation for better realization of economic and social sustainable development. At the same time, attention should also be paid to leveraging the synergistic role of government guidance and relevant policies, creating "policy synergy" to amplify the synergistic effects of digitalization and sustainable development. The government can further improve top-level design by deeply integrating digital transformation with sustainable development goals—for example, by coordinately using policy supports targeting corporate digital construction and green finance, complemented by constraints such as environmental regulations. This would encourage enterprises to strategically value digital sustainability and achieve the synergistic development of digitalization and sustainability through responsible innovation.

5.4. Limitations and Future Research Directions

Constrained by research conditions and environmental limitations, this paper has limitations in the following aspects:

First, this study adopted a questionnaire survey method for a cross-sectional study, making it difficult to reflect the trend of causal relationships between variables over time. Future research can consider combining secondary data to conduct a time-series study to better explain the causal relationships between variables. Meanwhile, although the digital sustainability orientation measure constructed through psychological scale-based surveys and the K-Means clustering method is sufficient to reveal the direction and approximate magnitude of relationships between variables, it inevitably compromises the continuity and richness of the concept. Future research could consider employing machine learning techniques to mine secondary data to develop more comprehensive and precise metrics, thereby better elucidating the relationships among variables.

Second, while this paper explored the mediating effect of resource orchestration in the influence of digital sustainability orientation on responsible innovation, other po-

tential pathways may have been overlooked, such as the mediating mechanism of inter-organizational collaboration. More mechanism explorations can be carried out in the future.

Third, this paper primarily focused on organizational-level variables. Nevertheless, the effect of digital sustainability orientation on corporate responsible innovation is influenced by multi-level factors, including the external environment, the organization itself, and individuals within the organization. Future research can incorporate more boundary conditions to conduct heterogeneity analysis and enrich the theoretical system of digital sustainability orientation research.

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