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# Value Chain Digitalization, Global Value Chain Embeddedness, and Distributed Innovation in Value Chains

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**Abstract:** How does a firm's value chain digitalization contribute to its innovation in value chains? This study investigates innovation activities in value chains from a combination of distributed innovation perspective and technology affordance theory. We posit that a digital value chain (DVC) plays a pivotal role in driving distributed innovation in value chains. Our focus is specifically directed toward exploring the interconnected dynamics of the DVC, global value chain (GVC), and diversification strategy, elucidating the influence of their interactions on a firm's distributed innovation in value chains. Leveraging the data of 862 manufacturing firms from the World Bank Enterprise Survey (WBES) in China, our empirical analysis reveals several key findings: (1) value chain digitalization positively influences distributed innovation in value chains and GVC embeddedness, (2) GVC embeddedness enhances distributed innovation in value chains, and (3) product diversification serves as a positive moderator, strengthening the effects of both value chain digitalization and GVC embeddedness on distributed innovation in value chains. In summary, this paper deepens our understanding of the relationships between DVC, GVC, diversification strategy, and distributed innovation in value chains. Our research provides theoretical and policy implications for digitalization and innovation strategies which are significant sources of sustainable development for firms and GVCs.

**Keywords:** value chain digitalization; GVC embeddedness; distributed innovation; technology affordance theory; collaboration; co-creation



**Citation:** Qin, L.; Xie, W.; Jia, P. Value Chain Digitalization, Global Value Chain Embeddedness, and Distributed Innovation in Value Chains. *Sustainability* **2024**, *16*, 2845. https://doi.org/10.3390/su16072845

Received: 19 February 2024
Revised: 27 March 2024
Accepted: 27 March 2024
Published: 28 March 2024



## 1. Introduction

How does a firm's value chain digitalization drive its innovation in value chains? A firm's value chain is an interdependent system consisting of design, manufacturing, delivery, marketing, and other related strategic activities [1]. It entails the participation and interaction of diverse actors such lead firms, suppliers, and client firms [2–5]. Value chains serve as conduits for knowledge flow and thus gestation for innovation. Innovation is important for establishing sustainable competitive advantages [6]. However, internal innovations fall short of finishing the overall design and development of a product or service. Modern innovations are increasingly complex and unpredictable, designed and constructed by multiple actors with different skills and interests, and involving collaborations that travel beyond the boundaries of single communities [6–8]. Innovation in value chains is increasingly distributed among and codeveloped by geographically dispersed value chain participants. Innovation emerges from not only inside a firm but also from suppliers, buyers, and other stakeholders. Ambos et al. [9] and Buciuni and Pisano [10] proposed innovation in GVCs be turned into a distributed innovation paradigm from a closed, linear innovation mode. The term "distributed innovation" involves two key aspects: knowledge is not concentrated but dispersive among diverse agents and locations;

innovation is distributed to external stakeholders within a community, such as the case of open-source software [11–13].

Researchers have dedicated substantial efforts to exploring innovation in value chains over the past two decades. On one hand, a multitude of value chain, supply chain, and GVC research efforts focus on global buyers or downstream firms' innovation, particularly examining the contributions originating from suppliers [14–17]. On the other hand, a few studies investigate how suppliers promote innovation and profit most with buyer–supplier relations, supplier abilities, or network structure [18–24]. However, these studies fail to theorize and examine innovation in value chains with a more complete and systemic view. Recent theoretical and case studies have started to explore innovation model in GVCs and proposed an interactive and open innovation model and globally distributed innovation, to reveal the nature of innovation in GVCs or its impact on the lead firms' innovation. However, these inquiries lack in-depth analyses on the nature and influencing mechanisms of distributed innovation in value chains. To address this gap, we explore and empirically examine the nature and mechanism of innovation within the value chain context from the distributed innovation perspective.

The locus of innovation is increasingly identified in multiparty relationships where suppliers, customers, and others external entities serve as pivotal sources of innovation [13,25]. Firms must reconcile tensions and diverse interactions arising from the divergent perspectives of the value chain actors being integrated into the innovation process [26]. At the same time, value chains are not immune to regional or global disruptions. Numerous studies have highlighted that the connectivity advantage from GVCs faced considerable challenges during the COVID-19 crisis [27,28]. Choksy et al. [29] emphasizes the necessity of building more resilient and robust value chain infrastructure. The transformation of an existing value chain system requires improving exchange facilitation, where digitalization plays a crucial role in both integrating and upgrading the supply chain [30]. In addition, value chain digitalization could be environmentally sustainable for business growth by saving time and resources [31].

As digital technologies are increasingly applicated in value chains, they play a vital role in shaping distributed innovation through processes of encapsulation, convergence, and generativity, which provide novel value propositions to diverse stakeholders [32,33]. A central focus of this literature has been the nature and role of digital encapsulation, convergence, and generativity in enabling innovation in value chains. Digital technology application in a firms' value chain opens avenues for integrating supplier knowledge and user experiences, while also incorporating new capabilities after the initial design and research of new products or services [13,32,34]. Organizations seeking to leverage digital encapsulation, convergence, and generativity find they must align their innovation processes with multiple value chain participants, including suppliers, complementors, and users [7,35]. Given suppliers and client firms are primary participants in value chains, this study focuses on collaborative innovation with suppliers and client firms as distributed innovation in value chains.

Drawing from technology affordance theory, we maintain that value chain digitalization has a positive effect on distributed innovation in value chains characterized by modulization, lead firm orchestration, and collaboration and co-creation among value chain partners. The encapsulation, convergence, and generativity features of digital technologies applied to value chains empower the sets of affordances that foster distributed innovation in value chains. Meanwhile, value chain digitalization positively affects GVC embeddedness due to the digital encapsulation and the convergence of digital technologies, which brings previously separate parties together more easily, blurring the boundaries amongst products, entities, and industries, achieving an effective linkage and interaction between diverse innovation agents. Value chain digitalization enables firms to grow in a more sustainable manner by constantly reconstructing their value chain activities. Furthermore, we argue firms engaging in GVCs are more likely to conduct distributed innovation. The fine-slicing, modularity, interconnection, and co-creation traits inherent in GVCs enable innovation activities to be geographically distributed and decoupled from other tangible activities. Lastly, we posit product diversification is beneficial for increasing the effect of value chain digitalization and GVC embeddedness on distributed innovation in value chains. Product diversification implies firms are exposed to diverse markets with distinct knowledge and demands. Firms can build up a reservoir of diverse knowledge that can be implemented across different business activities, and thus conducive to collaboration in a distributed innovation process.

To empirically test the hypotheses, we use the World Bank survey data on Chinese firms' investment environments, collected between December 2011 and February 2013. After a data filtering process, we exclude firms with missing information on innovation and sales. Our final sample includes a total of 862 observations. We employ a probit regression with robust errors for our main analysis. Given that value chain digitalization and GVC embeddedness may be endogenous, we check and elucidate their endogeneity using an extended probit model approach. The results show that (1) value chain digitalization significantly affects distributed innovation and GVC embeddedness, (2) GVC embeddedness has a positive influence on distributed innovation in value chains, and (3) product diversification positively moderates the effect of value chain digitalization on distributed innovation and the effect of GVC embeddedness on distributed innovation.

This study has several important contributions. First, this paper understands innovation activities in value chains from a unique perspective, a distributed innovation perspective, which has been largely underemphasized in the literature. Recent research has emphasized using value chains to enhance innovation [2,36,37]. However, these studies fail to conceptualize and theorize innovation in value chains with a more complete framework. To address this gap, we propose the mode of innovation in value chain be featured by distributed innovation. Second, we explore influencers of distributed innovation in value chains by focusing on important digital drivers, value chain digitalization based on technology affordance theory. We propose three affecting mechanisms of value chain digitalization: digital encapsulation, convergence, and generativity. Through linking digital encapsulation, convergence, and generativity in value chain digitalization with modulization, the orchestration of lead firms, collaboration, and the value co-creation of distributed innovation in value chains, we elaborate how DVC drives distributed innovation. In addition, we deepen GVC research by exploring how value chain digitalization affects GVC embeddedness and GVC's role on distributed innovation by the data from the WBES. Furthermore, this article extends research on diversification strategy by exploring moderating roles of product diversification on the effect of value chain digitalization and GVC embeddedness on distributed innovation in value chains. We provide more nuanced and complicate mechanisms of DVC, GVC, and distributed innovation in value chains. Finally, our theoretical framework and findings carry important policy implications in DVC and distributed innovation in value chains.

The remainder of the paper is organized as follows to construct and examine the mechanism of distributed innovation in value chains. Section 2 gives the literature review. Section 3 presents the theory development and hypotheses. Section 4 describes the research methodology. Section 5 reports and interprets the results. Section 6 introduces a discussion. Section 7 presents conclusions.

## 2. Literature Review

### *2.1. Innovation in Value Chains*

Value chain activities involve pivotal actors encompassing lead firms, turn-key suppliers and component suppliers, integrated firms, and retailers. Lead firms particularly take responsibility for designing production process, selecting suppliers, and participating in suppliers' production activities. The modular nature of production allows for geographical fragmentation when production is codified and organized in modules. Lead firms motivated by the advantages of effective offshore outsourcing activities and thus competitive and innovation potential, adopt distributed production around value chains and a modular governance to coordinate suppliers [38].

Extensive work has been devoted to exploring innovation in value chains, especially from the GVC or supply chain-related literature. On one hand, most research on innovation focuses on buyer firms or downstream firms' innovation from buyer–supplier relationships [14–17,39]. Conceptual research suggests that firms can derive benefits from complementary knowledge and resources, capabilities, and collaborative efforts with suppliers [40]. On the other hand, the exploration of how supplier or upstream innovation benefits from value chain remains limited and fragmented. Existing research concentrates on how suppliers enhance their performance through buyer–supplier relationship, supplier abilities, value chain traits, or network structures [18–24,41,42].

In addition, previous research has explored the linear, closed innovation mode. Recent research has proposed that innovation become distributed and dispersed among value chain participants, aligning with the trend of GVC embeddedness. Buciuni and Pisano [10] present four different innovation modes: globally distributed innovation, captive innovation, buyer-driven innovation, and producer-driven innovation. These modes are used to reveal the impact of geography and organization of pre- and production stages in GVCs on lead firms' innovation development. Ambos, Brandl, Perri, Scalera, and Van Assche [9] conceptually explore the nature of innovation in GVCs and propose and study an interactive and open innovation model.

To sum up, these studies fall short of theorizing innovation in value chains, exploring interactions between value chain participants, and influencing mechanism from a more comprehensive and systemic perspective. To address this gap, we explore the mechanism of innovation in value chains from a distributed innovation perspective and analyze its features concerning orchestration and coordination on distributed innovation in value chains.

### 2.2. Value Chain Digitalization

Digitalization entails the application of digital technologies and their integration and cross-fertilization with a firm's internal and external activities and scenarios [43]. Zhou et al. [44] posit that digitalization can be delineated into internal or external digitalization. Internal digitalization aims to reduce costs and increase the efficiency of internal operations including product design, manufacturing, marketing, and so on. External digitalization emphasizes using digital technology to enhance interactions between stakeholders, such as lead firms, clients, and suppliers. The value chain digitalization of a firm is regarded as embedding and applying digital technology in a firm's value chain segments or activities' sequences, such as design, production, management and operation, and market service and sales [45–47]. Value chain digitalization involves not only internal digitalization but also external digitalization.

Researchers have classified the digitalization of value chains. Oliveira, Fleury, and Fleury [45] distinguish between fully digitized value chains and partially digitized ones through observing if all activities exist digitally or virtually. The United Nations Conference on Trade Development (UNCTD) [48] classifies three kinds of digitalization in GVCs: thin integration, platform digitalization, and full digitalization. Thin integration involves firms introducing information and communication technologies (ICTs) into their operations, without fundamentally altering the structure of the chain. Platform digitalization, in turn, signifies the infusion and permeation of platforms into the value chain through the application of digital technology. Finally, full digitalization entails a state of fully digitally integrated systems, wherein information and data from diverse levels, sources, and locations are integrated into a singular system employed in the decision-making processes of production. Recognizing the staged evolution of firms' value chain digitalization, from the partial to the entire chain, variations emerge in the breadth of value chain digitalization among firms. Consequently, this paper directs its attention to and scrutinizes the extent of value chain digitalization from its application scope.

Current research emphasizes the impact of digitalization on business models, process and product innovations, and performance at the firm level, overlooking the synergies within value chains. This stream of research commonly concludes that digitalization in specific segments serves as a crucial driver for performance, business model, product and process innovations, subsequently enhancing dynamic and innovation capabilities, altering product supply, service structures, and performance [49–53]. An alternative stream of literature focuses on developing new theoretical frameworks for digital innovation and entrepreneurial management in the digital age [33,54,55]. Another strand examines the role of digital technology in GVC embeddedness, positing that digital technology application can alter firm participation, labor division, and locations in GVCs [30,56–60].

Despite these advancements, existing studies on the relationship between digitalization and innovation in value chains are lacking. First, there's a dearth of literature specifically addressing the enabling effect of digitalization from the value chain perspective, necessitating the integration of digital technology characteristics into theoretical frameworks. Second, the data scarcity of a digital value chain, especially first-hand large sample data, demands further empirical testing. Third, limited investigation into the enabling effects of digital technology within specific value chains hinders a comprehensive, global, systematic perspective. The assessment of digital technology's effect under orchestration and coordination among value chain participants is overlooked. Addressing these gaps calls for more empirical research, emphasizing the urgent need for a holistic understanding of the economic consequences of value chain digitalization.

In addressing open and interactive innovation within value chains, previous research has primarily concentrated on connectivity and coordination issues among a diverse and geographically dispersed value chain participants. These participants include buyers and suppliers with divergent knowledge and insights. Given the transformative impact of digital technology from its encapsulation, convergence, and generativity traits [61], we posit that value chain digitalization can influence coordination mechanisms within value chains, consequently shaping distributed innovation. Building on this premise, we formulate preliminary, theory-driven propositions to guide our quantitative investigation. Our conceptual model posits distributed innovation as an outcome of orchestration and co-creation efforts, influenced by both the extent of value chain digitization and firm-specific factors.

### *2.3. Technology Affordance Theory*

The technology affordance theory provides a foundational framework for exploring the role of value chain digitalization through the interactions between digital technologies and innovators [55,62]. Technology affordance refers to an action potential, delineating what an actor with a particular purpose can do through a technology or information system [63]. Based on the technology affordance theory, innovation in value chains is contingent not only on the affordance of technology but also on the conditions of actors.

In addition, GVCs imply global production for profit and may lead to distributed innovation, while value chain digitalization is conducive to firms' participating in GVCs. On the other hand, firm diversification is a key strategy for surviving and maintaining a competitive position in a contemporary complex and fast-changing environment. However, diversity induces various requirements and constraints, and knowing whether value chain digitalization aids in overcoming these constraints and fulfilling diverse needs is critical for firms [62,64]. An exploration of the potential interplay between value chain digitalization and firm diversification and the GVC mechanism can elucidate why certain firms are more likely to conduct distributed innovation in value chains. However, related research is scarce.

To address these gaps, this paper adopts the technology affordance theory to take a deep step into exploring the effect of value chain digitalization on innovation in value chains from the aspects of encapsulation, convergence, and generativity of technology affordance. Firstly, digital technology serves as a bridge between the physical and digital realms, achieved through the encapsulation of product design and production information into distinct digital artifacts known as "digital encapsulation" [65]. Digital encapsulation involves integrating product development and production-process instructions to generate an independent digital artifact. These digitally encapsulated artifacts contain the essential characteristics or "genes" of the associated physical objects. These genes dictate the information on the interaction of the artifact with its environment and the information on physical expression of digital encapsulation information. The encapsulation construct also includes standard interfaces derived from modularity while allowing modifications within the digital artifact.

Secondly, digital technology provides an open technological architecture that aggregates information from diverse sources, enabling participation from multiple parties, and bringing together previously separate products, entities, and even industries [32,62]. This is characterized as the "convergence" of digital technology, enabling the boundary dissolution of industry, organizational, sector, and product boundaries, and making knowledge more transparent [33]. Simultaneously, convergence fosters a more open environment, expanding the scope of knowledge and innovation for a variety of products and services for new markets.

Thirdly, digital technology possesses "the overall capacity to produce unprompted change driven by large, varied, and uncoordinated audiences" [34]. That is to say, as an enabling technology, digital technology contributes to generate new technology-enabled products, services, and production, termed as "generativity" [66]. The generativity of digital technology derives from its dynamics, self-referentiality, extendibility, and editability [67], allowing continuous improvement and change in innovation activities.

Digital technology is characterized by digital encapsulation, convergence, and generativity, which empower value chain digitalization to drive distributed innovation activities. The application of digital technologies to value chains enables the digital encapsulation and convergence of products, entity or actors, and value chains. Digital encapsulation and convergence act on interactions between actors, such as orchestration and coordination between value chain upstream and downstream, thereby promoting distributed innovation in value chains. Although this affordance induces a digital capability that may enable distributed innovation in value chains, the potential for conducting such innovation through digital value chains varies significantly [33,68]. Therefore, the technology affordance theory aligns well with our research question by enabling us to explore whether and how the application of digital technologies in value chains by different actors can lead to different innovation outcomes in value chains.

## 3. Theory Development and Hypotheses

### *3.1. Distributed Innovation in Value Chains*

The term "distributed innovation" was initially introduced by Von Hippel [13] to describe a system where innovation arises not solely from manufacturers but from various sources, including users and competitors. Researchers use the term to signify two key aspects: knowledge is disperse among diverse actors and locations, and innovation occurs outside focal firms, distributed to stakeholders within a community [11,12]. Distributed innovation, recognized for enhancing the system through knowledge flow and collaboration, involves not only buyers and suppliers but also users and rivals [11,25]. The distributed nature of innovation implies an increased interdependence and interaction among actors for successful outcomes [69].

Distributed innovation has the following characteristics: (1) It emphasizes the geographical distribution of innovation activities; (2) the governance structure is between hierarchical and completely open; (3) the focus of innovation activities is to realize knowledge sharing; (4) it takes projects as the main carrier to carry out various forms of coordination [11]. The value chain is not only becoming more "distributed" and "open", but the expectation is also that a firm's suppliers and customers become more collaborative, participative, and responsive in whatever roles they take on. Coordinating interactive actors in value chains involves orchestration by lead firms and collaboration between buyers and suppliers.

Coordination in distributed innovation processes is challenging due to numerous search directions individual innovators can take, where traditional governance mechanisms may be limited or counterproductive [50].

Three mechanisms are identified to address the challenges of coordination in value chains, particularly in the context of GVCs: modularization, orchestration by lead firms, and collaboration for value co-creation among suppliers and buyers. The first mechanism is to rely on modularity, i.e., an architecture where interdependencies are bundled within modules, while modules are independent of each other and have standardized interfaces [70–72]. By constraining interdependencies within modules and managing those between modules with standardized interfaces, modularity diminishes the need to actively provide coordination. In the specific GVC literature, modularity is the most explicit mechanism.

The second mechanism refers to the orchestration of lead firms. As architects and strategic leaders in value chain governance, lead firms play a pivotal role in orchestrating knowledge creation and diffusion within the value chain. To maintain distributed innovation activities in order, such an innovation process requires an orchestrator and screening mechanisms for coordinating proper contributions. Value chains, functioning as asymmetrical networks, involve lead firms orchestrating and coordinating dispersed operations for crucial innovation and business activities around the final product [73,74].

The third mechanism emphasizes supplier–supplier or buyer–supplier collaboration for value co-creation, particularly in terms of complementary knowledge. Value chain actors contribute complementary technologies for product development and provide each other with access to novel knowledge beyond physical goods and services. Collaboration within value chains is essential for developing final products or services. Distributed innovation involves recombining available knowledge outside a firm's boundaries across external stakeholders. The ability of knowledge combination promotes the co-creation of innovation.

We focus on innovation in the context of value chains, where suppliers and clients are the primary members. Firms mainly collaborate with suppliers or clients along the value chain, and innovation is distributed externally to them. Therefore, we consider distributed innovation in a value chain mainly involves collaborative innovation with suppliers or clients. We then explore how value chain digitalization affects distributed innovation in value chains through the three mechanisms. Figure 1 shows the theoretical framework of our research.

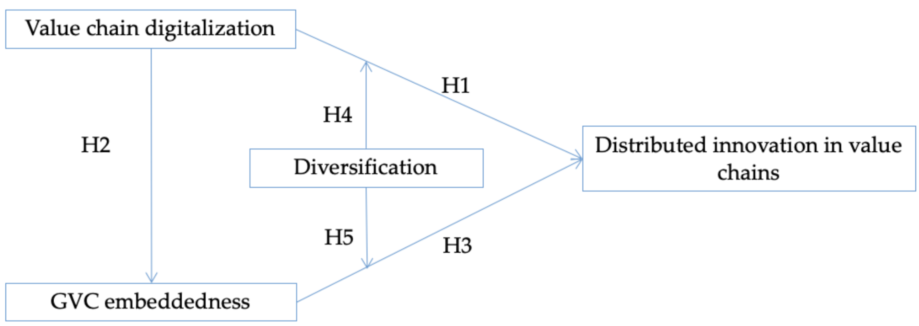


**Figure 1.** Theorical Framework.

*3.2. Value Chain Digitalization and Distributed Innovation in Value Chains*

From a technology affordance theory perspective, we contend that applying digital technology with characteristics of encapsulation, convergence, and generativity in value chains empowers affordances for distributed innovation in value chains. Firstly, with encapsulation features, value chain digitalization paves a way to more open, interactive systems on which many participants can rely for co-innovation and development. By digitally encapsulating the knowledge and information for making, delivering, and using artefacts, scattered suppliers and customers gain opportunities for collaborative product design and decisions [65,75]. Stable interorganizational interfaces created through digital encapsulation simplify complex knowledge process for lead firms to orchestrate participants' collaborative innovation activities. Through integrating and storing product and process information within digital encapsulation, firms can guide lifecycle processes and dynamically bridge the requirements of the physical world with virtual models and representations. This facilitates effective collaboration for product or process innovation. Digital encapsulation is beyond modulization which promotes distributed innovation.

Secondly, the convergence of digital technology as a catalyst for value chain digitalization facilitates the connection and integration of previously separate parties, such as customers and business partners [76]. This integration enhances knowledge transfer and synergies for product design and manufacturing distributed to diverse participants [32,33]. Lead firms may benefit from such innovations by capitalizing on convenient access to and coordination with various actors and resource, thus fostering distributed innovation [76,77]. Notably, the initiative of Volvo Cars' digital platform created possibilities for collaborations with application developers [62,78]. The collaborative engagement of external parties infuses the focal firm with fresh new ideas and conduces to utilizing the focal firm's capabilities to recognize opportunities for co-innovation in a complex and uncertain environment. Value chain digitalization can realize efficient link and interaction among multiple innovation entities, enrich knowledge source, shorten knowledge transfer process, and strengthen co-innovation in the combination of a variety of knowledge across departments, organizations, and regions.

Thirdly, the generativity feature of digital technology promotes distributed innovation by expanding the opportunity space for innovation. The feature implies that innovations driven by digital technology are inherently malleable and dynamic [32,79]. The integration of digital technology blurs the boundaries between physical and digital spaces, allowing organizations to extend their boundaries and opportunity spaces for co-innovation and value co-creation. The embedding of digital technology into physical artifacts enhances usage scenarios, fostering more user innovations and expanding the co-innovation opportunity space [32,62]. Furthermore, the homogeneity of data and reprogrammability inherent in digital technologies facilitates a rapid, interactive, and iterative improvement process for existing products or tools, resulting in continuously incremental distributed innovation with collaboration at a relatively low cost [32,62,80]. Thus, we propose that:

**Hypothesis 1 (H1):** *Ceteris paribus, value chain digitalization is positively associated with distributed innovation in value chains.*

### *3.3. Value Chain Digitalization and GVC Embeddedness*

The digitally encapsulated artifact serves as a repository for the corresponding physical object's information describing how it should be created, akin to genes [65]. These genes dictate the artifact's interactions with its environment, and how its digitally encapsulated information manifests in the physical world. The distinctive feature of information ownership and control reduces the cost of knowledge flow and collaboration. Thus, distributed design and the manufacturing of products are facilitated, propelling digital encapsulation beyond the traditional application of modularity, which is the fundamental characteristic of GVCs [71,72,81]. In digital value chains, where digitally encapsulated artifacts interface with connected design–production–distribution control systems, real-time access to information is available. This empowers firms to dynamically visualize changes in demand, recognize bottlenecks and resource availability, and manage process variability in ways previously impossible. Consequently, digital value chains can facilitate more agile and cost-effective production and operation, thus promoting engagement in GVCs and maintaining GVC resilience in the complex and fast-changing context [65,82].

The convergence of digital technology applied in value chains not only blurs traditional boundaries between products, entities, and industries but also promotes connections and interactions among various innovation entities efficiently [32,33]. The digitalization of elements within value chains including the product, production, and communication systems allows for the convenient distribution of processes, decisions, and knowledge to respective partners [65]. Even tacit knowledge can be shared and integrated in intimate interaction through digital mediations. Thus, the digitalization of the value chain becomes a catalyst for knowledge and information sharing, a critical component for effective GVC engagement and coproduction in GVCs.

Moreover, this transformative digitalization of the value chain enables lead firms to efficiently orchestrate suppliers, service providers, distributors, and users at a lower cost. Previous vertical, singular, chainlike connection structure can be transformed into a multidimensional, interactive network, where diverse innovation groups collaboratively create value in GVCs through value chain digitalization. In summary, we posit that:

**Hypothesis 2 (H2):** *Value chain digitalization is positively associated with GVC embeddedness*.

### *3.4. GVC Embeddedness and Distributed Innovation in Value Chains*

Distributed innovation has become the dominant innovation mode in contemporary GVCs. The geographical dispersion of value chain stages, particularly of pre- and production activities, is especially significant within the context of GVCs, where these stages are inherently distributed around the globe. GVC actors are distributed globally, while knowledge remains dispersed and sticky with individual entities. Furthermore, the fine-sliced and modular nature of GVCs allows innovation activities to be geographically distributed and decoupled from other tangible operations. This results in innovation processes being finely sliced and distributed among diverse GVC firms globally [83,84].

A GVC is a semiopen hybrid organizational structure, typically featuring with lead firms' orchestration and participants' collaboration. As architects and strategic leaders in GVCs, lead firms coordinate the internal and external knowledge flow, consolidate dispersed resources, create value, and set rules for the entire value chain. Distributed innovation relies on recombining knowledge that is available beyond firm boundaries. Furthermore, to maintain distributed innovations in order in value chains, lead firms can orchestrate diverse partners' dispersed operations and activities around the final product [73,74]. Engaging in GVCs and orchestrating by lead firms facilitate collaboration for distributed innovation and value co-creation in value chains.

GVC is characterized by collaboration and co-creation, interdependence and interconnection, free knowledge flow, and sharing that enable successful outcomes [11,13,25]. GVCs serving as a channel for knowledge flow can enable knowledge transfer and sharing among GVC participants. The strategic engagement in GVCs allows firms to leverage the distributed pools of knowledge inherent in GVCs. It is crucial not only to possess knowledge or ideas, but also to have access to them, improving the combinative process essential for co-creating innovation. In particular, through engaging in GVCs, participants gain access to new or complementary knowledge critical for final new products or services. Additionally, diverse and cutting-edge global knowledge not only enriches the knowledge base but also expands the opportunity space of new ideas for distributed innovation. In a nutshell, we suggest that

**Hypothesis 3 (H3):** *GVC embeddedness is positively associated with distributed innovation in value chains*.

### *3.5. The Moderating Roles of Product Diversification*

Product diversification signifies the extent to which an organization is charged with providing a broad, diverse range of products [85]. Firms managing diverse product portfolios deal with a multitude of products consisting of different components, setups, and technologies. These firms are exposed to various customers with dissimilar product experiences. The richness of variety in this context is crucial for learning, as organizations with diverse portfolios should find it easier to expand their knowledge and conduct analogical reasoning [86,87]. If all customers report similar experiences, knowledge sourcing fails to broaden the knowledge base, restricting the potential of new ideas for improvement. The diverse service is particularly beneficial to generating new insights.

When adopting product diversification strategy, firms engage with various products, markets, buyers, and suppliers, providing more application scenarios for digitalization and opportunities for co-creating new value. Through DVC, firms can encapsulate and assemble a broader array of products, enabling real-time iterative updates to digitally encapsulated products and components. Therefore, digital encapsulation and convergence effects within value chains are enhanced. Despite the challenges associated with diversification, such as complexity and information asymmetry, digital encapsulation can simplify a product module's information [65]. The convergence of digitalization can facilitate interconnectedness and thus improve efficient linkages and interactions between diverse innovation entities, making communications within GVCs become more transparent and effective, enhancing organizational synergy and coordination, ultimately strengthening distributed innovation within value chains.

The value chain digitalization amplifies the acquisition and diffusion of diverse knowledge among value chain participants. The cross-implementation of knowledge accrued from diverse firms in digital value chains becomes mutually beneficial and enriches firms' knowledge bases and structures [88,89]. This lays the foundation for distributed innovation. In particular, research and development (R&D) for product diversification design activities become more complex. It is necessary to distribute and coordinate R&D activities with value chain actors. The utilization of digitalization enhances the efficiency of allocating R&D efforts. Therefore, within the context of product diversification, digitalization is more effective for distributed innovation in value chains.

**Hypothesis 4 (H4):** *Product diversification positively moderates the relationship between value chain digitalization and distributed innovation in value chains.*

For firms exposed to diverse markets with varied knowledge, participation in GVCs offers a dual advantage. On one hand, engaging in GVCs facilitates the diffusion of diverse knowledge to partners, the construction of knowledge base and structure, and establishing collective knowledge. Collective knowledge promotes orchestration and collaboration, thus strengthening distributed innovation in value chains. On the other hand, within product diversification contexts, there is a need to acquire new and complementary knowledge for technological innovation [4]. Distributed innovation involves the recombination of complementary knowledge that typically extends beyond the boundaries of individual organizations. Firms engaging in GVCs connect with international stakeholders to acquire diverse, new, and complementary knowledge, thereby enhancing distributed innovation in value chains. GVC participation enables the further diffusion of these innovation outcomes.

Within the context of diversification, which involves complex R&D and manufacturing processes, firms engage in close collaboration with relevant partners [87]. Distributed innovation relies on combining knowledge accessible to diverse external stakeholders beyond the boundaries of individual firms. Firms within GVCs collaborate to bring the final product or service to international market. In GVCs, firms are more inclined to engage with a broader spectrum of international external companies, acquiring innovation externally and disseminating innovation to external entities, thereby enhancing distributed innovation in value chains.

**Hypothesis 5 (H5):** *Product diversification positively moderates the relationship between GVC embeddedness and distributed innovation in value chains.*

## 4. Research Methodology

### *4.1. Data and Sample*

To test these hypotheses, we employed manufacturing firm data from the World Bank Enterprise Survey (WBES) in China. The dataset covers 25 metropolitan cities, and 2848 firms (including 2700 private firms and 148 state-owned firms). The data collection spanned from December 2011 to February 2013 through face-to-face interviews with firm managers or owners. The dataset is the most comprehensive and representative to explore Chinese manufacturing firms [90]. It provides a thorough and accurate reflection of the overall business environment of Chinese firms. The World Bank maintained a tight control over the sample selection process, utilizing a stratified random sampling technique based on location, size, and sector with a replacement technique. The strict design and substantial sample size were beneficial for increasing the accuracy of this study.

Despite the convenience of large-sample databases for research, some indicators contain missing or illogical sample data. To address this, observations with responses such as "not applicable" or "unable to answer" were screened out during the data filtering process. Firms lacking information on innovation and sales were also excluded. Consequently, our final sample included a total of 862 observations.

### *4.2. Measurements*

#### 4.2.1. Dependent Variable

In our analytical framework, the primary variable of interest was the distributed innovation in value chains (DIVC). Distributed innovation signifies a collaborative endeavor among pivotal actors including not only buyers and suppliers but also users and even rivals [11,25]. Given that suppliers, buyers, or clients are primary participants in value chains, a firm's distributed innovation in value chains implies co-innovation with suppliers, buyers, or clients. Utilizing data derived from the WBES, we took the value of the DIVC variable as 1 if new products or service were developed in cooperation with suppliers, buyers, or clients, and 0 otherwise. Therefore, DIVC was a binary variable.

#### 4.2.2. Independent Variables

Value chain digitalization. A firm's value chain is an interdependent system consisting of design, manufacturing, marketing, delivery, and other strategic activities [1]. Value chain digitalization refers to the embedding and application of digital technology in a firm's value chain segments, such as design, production, management and operation, and market service and sales. We regarded value chain digitalization as the scope of digital technology's application to a firm's five key segments of value chain: partnership (including suppliers, contractors, etc.), product and service enhancement, production and operation, marketing and sales, and customer relationship. The value of chain digitalization was measured as the number of segments employing digital technology, which was divided into 6 levels ranging from 0 to 5.

GVC embeddedness. Following Baldwin and Lopez-Gonzalez [91], we regarded GVC firms as those engaged in import and export activities simultaneously, known as two-way traders. Given the fragmented nature of the production process, firms are likely to be involved in these complex activities, aligning with the concept of GVC. The successful integration and sustained embeddedness into GVCs necessitate compliance with global quality standards [92,93]. Therefore, GVC embeddedness was measured as 1 if a firm exclusively engaged in import and export with quality certification, and 0 otherwise. Therefore, GVC embeddedness was a binary variable.

Product diversification (PD). The typical approach of measuring product diversification is an entropy measure constructed on the basis of Palepu's [94] method [95,96]. Assignment to a product category is based on the proportion of a firm's total sales attributed to the largest discrete area. However, due to data limitations of the WBES, we followed Chen et al. [97] and measured the value of product diversification as 1 minus the percentage of sales represented by the main product.

#### 4.2.3. Control Variables

We included several firm-specific control variables in the models.

Firm age. The influence of firm age on innovation is well established in the literature [98]. Older firms tend to focus on innovation and can derive more value from appropriability strategies related to new products and services. Moreover, older firms encounter lower sunk costs and financial constraints compared to their younger counterparts [92]. We used "the length of operation time of a company since its founding year" to measure firm age and took its natural logarithm (Ln) to eliminate bias.

Firm size. According to previous analyses [99,100], firm size may influence co-innovation due to financial capital or social capital. This paper chose firm size as a control variable, used sales revenues to measure it, and took its natural logarithm (Ln) in order to lower skewness.

Research and development (R&D). Research and development play a pivotal role in a firm's absorptive capacity, fostering learning and innovation [101]. We thus included R&D to control for financial and resource impact and measured it as 1 if a firm allocated resource on research and development activities. Therefore, R&D was a binary variable.

Financial constraints (FC). Many studies indicate that firms faced with severe financial constraints are less inclined to make R&D investment [102]. We controlled the perception-based financial constraint, which was a dummy variable measured as 1 if the firm perceived access to finance as its biggest obstacle, and 0 otherwise.

Political connections. Prior research suggests that the influence of business–government relations on innovation exists but conclusions are not consistent [103]. We controlled political connections and used the question of "what percentage of total senior management's time was spent on dealing with requirements imposed by government regulations" to measure the political connections of firms with a natural logarithm (Ln).

Information sharing. Information sharing affects interfirm collaboration and cooperation, and thus interfirm innovation. We measured information sharing as 2 if firms shared demand forecast with raw material supplier and shared production and replenishment plans with clients, 1 if firms shared demand forecast with raw material supplier or share production and replenishment plans with clients, and 0 otherwise. Therefore, information sharing was a categorical variable.

Additionally, we controlled for the managerial experience of the top managers, measured by the number of years they had worked in the sector. Given the potential impact of industry-specific factors, we incorporated a sub-sector industry fixed effect in our models. Despite all firms in our sample being manufacturers, the WBES offered a nuanced sub-sector classification with the 2-digit ISIC code.

### *4.3. Analysis Method*

Given the binary nature of DIVC and GVC embeddedness variables, we employed a probit regression model with robust standard errors. A probit model is a typical binary choice model belonging to generalized linear models, which expands general linear models so that the dependent variable is linearly related to the factors and covariates via a specified link function. Moreover, the model allows for the dependent variable to have a non-normal distribution. It is appropriate to examine the impact of value chain digitalization on distributed innovation in value chains and GVC embeddedness, as well as the influence of GVC embeddedness on distributed innovation in value chains. Our approach involved estimating five sets of equations to comprehensively analyze these relationships.

First, the model estimated the effect of value chain digitalization on distributed innovation in value chains.

$$\mathrm{DIVC_i} = \beta_0 + \beta_1 \text{ value chain digitalization}_\mathrm{i} + \beta_2 \text{Product diversification}_\mathrm{i} + \beta_3 \mathrm{X_{i1}} + \ldots + \beta_n \mathrm{X_{ij}} + \delta + \varepsilon \quad (1)$$

Second, the model evaluated the effect of value chain digitalization on GVC embeddedness.

$$\text{GVC embeddedness}_i = \beta_0 + \beta_1\text{Value chain digitalization}_i + \beta_2 \text{ Product diversification}_i + \beta_3 X_{i1} + \ldots + \beta_n X_{ij} + \delta + \varepsilon \quad (2)$$

Third, the model examined the effect of GVC embeddedness on distributed innovation in value chains.

$$\text{DIVC}_i = \beta_0 + \beta_1\text{GVC embeddedness}_i + \beta_2\text{Product diversification}_i + \beta_3 X_{i1} + \ldots + \beta_n X_{ij} + \delta + \varepsilon \quad (3)$$

Fourth, the analysis focused on the case of a firm adopting a product diversification strategy and digitalizing its value chain. The model estimating this interaction effect on distributed innovation in value chains was as follows:

$$\text{DIVC}_i = \beta_0 + \beta_1\text{Value chain digitalization}_i + \beta_2\text{Product diversification}_i + \beta_3\text{Value chain digitalization}_i \times \text{Product diversification}_i + \beta_4\text{GVC embeddedness}_i + \beta_5 X_{i1} + \ldots + \beta_n X_{ij} + \delta + \varepsilon \quad (4)$$

Finally, the estimation provided a comprehensive understanding of the interactive effect of a product diversification strategy and GVC embeddedness on distributed innovation in value chains.

$$\text{DIVC}_i = \beta_0 + \beta_1\text{GVC embeddedness}_i + \beta_2\text{Product diversification}_i + \beta_3\text{GVC embeddedness}_i \times \text{Product diversification}_i + \beta_4\text{Value chain digitalization}_i + \beta_5 X_{i1} + \ldots + \beta_n X_{ij} + \delta + \varepsilon \quad (5)$$

where i refers to firm i; $X_{ij}$ represents all control variables in the models.

## 5. Findings

### *5.1. Main Results*

Descriptive statistics and bivariate correlations between variables in the sample are summarized in Table 1. The results of the model analysis are displayed in Table 2. Model 1 in Table 2 is the base model, including all control variables and the moderating variable. To alleviate the possible impact of multicollinearity in the analysis, we also computed the variance inflation factor (VIF). The results showed that no variable was higher than the threshold of 10, thus indicating that multicollinearity was not a big concern in our analysis.

Hypothesis 1 proposes that the value chain digitalization of a firm has a positive influence on distributed innovation in value chain. We examined the effect of value chain digitalization on distributed innovation in value chains in model 2 of Table 2. The coefficient for value chain digitalization was positive and statistically significant (β = 0.374, $p < 0.001$). Thus, Hypothesis 1 was strongly supported.

**Table 1.** Descriptive statistics and correlations.

| Variables | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) DIVC | 1.000 | | | | | | | | | | | |
| (2) Value chain digitalization | 0.331 * | 1.000 | | | | | | | | | | |
| (3) GVC embeddedness | 0.104 * | 0.075 | 1.000 | | | | | | | | | |
| (4) Product diversification | −0.016 | −0.179 * | −0.035 | 1.000 | | | | | | | | |
| (5) Firm age | −0.002 | 0.019 | −0.014 | 0.002 | 1.000 | | | | | | | |
| (6) Firm size | 0.130 * | 0.149 * | 0.216 * | −0.039 | 0.104 * | 1.000 | | | | | | |
| (7) R&D | 0.139 * | 0.277 * | 0.086 | −0.079 | 0.019 | 0.307 * | 1.000 | | | | | |
| (8) Financial constraints | 0.012 | 0.125 * | −0.076 | 0.020 | 0.007 | −0.019 | 0.024 | 1.000 | | | | |
| (9) Political connections | 0.075 | 0.030 | 0.009 | 0.001 | −0.032 | −0.019 | 0.015 | 0.021 | 1.000 | | | |
| (10) Information sharing | 0.261 * | 0.164 * | 0.017 | −0.037 | −0.018 | 0.119 * | 0.089 * | 0.059 | −0.039 | 1.000 | | |
| (11) Manager experience | 0.003 | 0.210 * | 0.087 | −0.081 | 0.386 * | 0.179 * | 0.172 * | 0.028 | −0.016 | 0.060 | 1.000 | |
| (12) Subindustry | 0.059 | 0.030 | 0.058 | −0.042 | −0.019 | 0.109 * | 0.061 | 0.019 | −0.041 | 0.009 | −0.040 | 1.000 |
| Mean | 0.427 | 4.246 | 0.050 | 95.288 | 2.522 | 16.82 | 0.397 | 0.233 | 0.262 | 0.961 | 16.797 | 6.267 |
| SD | 0.495 | 1.444 | 0.218 | 8.801 | 0.484 | 1.617 | 0.490 | 0.423 | 1.641 | 0.839 | 7.62 | 3.359 |

* shows significance at the 0.01 level.

**Table 2.** Probit model analyses for DIVC and GVC embeddedness.

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | DIVC | DIVC | GVC Embeddedness | DIVC | DIVC | DIVC |
| Value chain digitalization | | 0.374 *** | 0.143 * | 0.373 *** | −1.488 * | −1.529 * |
| | | (0.050) | (0.069) | (0.051) | (0.709) | (0.703) |
| GVC embeddedness | | | | 0.471 * | 0.432 + | −3.244 |
| | | | | (0.231) | (0.229) | (2.144) |
| Value chain digitalization × Product diversification | | | | | 0.019 ** | 0.020 ** |
| | | | | | (0.007) | (0.007) |
| GVC embeddedness × Product diversification | | | | | | 0.039 + |
| | | | | | | (0.023) |
| Product diversification | 0.000 | 0.006 | −0.005 | 0.006 | −0.085 * | −0.089 ** |
| | (0.006) | (0.006) | (0.008) | (0.006) | (0.034) | (0.034) |
| Firm age | 0.023 | 0.072 | −0.137 | 0.086 | 0.066 | 0.071 |
| | (0.100) | (0.105) | (0.143) | (0.106) | (0.106) | (0.106) |
| Firm size | 0.065 * | 0.059 + | 0.257 *** | 0.045 | 0.048 | 0.051 |
| | (0.031) | (0.032) | (0.047) | (0.033) | (0.033) | (0.033) |
| R&D | 0.265 ** | 0.086 | −0.034 | 0.089 | 0.081 | 0.079 |
| | (0.098) | (0.103) | (0.180) | (0.104) | (0.103) | (0.104) |
| Financial constraints | −0.020 | −0.119 | −0.472 * | −0.101 | −0.104 | −0.104 |
| | (0.106) | (0.112) | (0.240) | (0.112) | (0.113) | (0.113) |
| Political connections | 0.070 * | 0.068 * | 0.019 | 0.067 * | 0.064 * | 0.066 * |
| | (0.034) | (0.032) | (0.035) | (0.032) | (0.032) | (0.032) |
| Information sharing | 0.412 *** | 0.385 *** | −0.048 | 0.391 *** | 0.397 *** | 0.401 *** |
| | (0.054) | (0.056) | (0.103) | (0.056) | (0.057) | (0.057) |
| Manager experience | −0.007 | −0.017 * | 0.012 | −0.018 ** | −0.018 * | −0.018 * |
| | (0.007) | (0.007) | (0.011) | (0.007) | (0.007) | (0.007) |
| Subindustry | Controlled | Controlled | Controlled | Controlled | Controlled | Controlled |
| Constant | −1.892 * | −3.876 *** | −5.970 *** | −3.701 *** | 5.104 | 5.427 |
| | (0.771) | (0.861) | (1.133) | (0.866) | (3.374) | (3.362) |
| *N* | 862 | 862 | 734 | 862 | 862 | 862 |

Standard errors in parentheses: + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Hypothesis 2 suggests that there exists a positive relationship between value chain digitalization and GVC embeddedness. In model 3, we tested the influence of value chain digitalization on GVC embeddedness. The coefficient for value chain digitalization was positive and statistically significant (β = 0.143, $p < 0.05$), providing robust support for Hypothesis 2.

Hypothesis 3 posits that GVC embeddedness is positively associated with distributed innovation in value chains. In model 4, we examined the influence of GVC embeddedness on distributed innovation in value chains. The coefficient for GVC embeddedness was positive and statistically significant (β = 0.471, $p < 0.05$), providing empirical support for Hypothesis 3.

Hypothesis 4 contends that product diversification positively moderates the relationship between value chain digitalization and distributed innovation in value chain. We added the interaction term of value chain digitalization and product diversification in model 5. The coefficient for the interaction term was positive and statistically significant (β = 0.019, $p < 0.01$). Therefore, these findings supported Hypothesis 4.

Hypothesis 5 supposes that product diversification positively moderates the relationship between GVC embeddedness and distributed innovation in value chains. We introduced the interaction term of GVC embeddedness and product diversification in model 6. The coefficient for the interaction term was positive and significant (β = 0.039, $p < 0.1$). Therefore, Hypothesis 5 was empirically supported.

### *5.2. Post Hoc Robustness Tests*

Considering potential endogenous issues caused by reverse causality, omitted variables, sample selection bias, etc., we implemented the following post hoc tests. Firstly, the endogeneity problem may result from the reverse causality problems: the first is between value chain digitalization and distributed innovation in value chains, the second is between GVC embeddedness and distributed innovation in value chains, and the third is between value chain digitalization and GVC embeddedness. A nonlinear extended probit model is the best fit to deal with endogenous issues caused by these variables. This model provides several advantages: (1) it allows the inclusion of multiple endogenous variables such as value chain digitalization and GVC embeddedness; (2) the use of binary endogenous regressors like GVC embeddedness is available; (3) the function to handle the use of endogenous covariates in the interaction. According to Elshaarawy and Ezzat [102] and Li and Zhang [104], the instrumental variable for GVC embeddedness can be a dummy variable with the value one if the firm perceives customs and trade regulations as the biggest obstacle, and zero otherwise. The instrument for value chain digitalization is the average value of value chain digitalization in the same subindustry within the same city. Results from the extended probit model were largely consistent and are reported in models 7–11 of Table 3. However, the moderating effect of product diversification on the relationship between GVC embeddedness and distributed innovation was positive but insignificant, as shown in model 11 of Table 3.

**Table 3.** Extended probit model analyses for DIVC and GVC embeddedness.

| | (7) | (8) | (9) | (10) | (11) |
|---|---|---|---|---|---|
| | **DIVC** | **GVC Embeddedness** | **DIVC** | **DIVC** | **DIVC** |
| Value chain digitalization | 0.448 *** | 0.191 * | 0.363 *** | −1.368 * | −1.414 * |
| | (0.058) | (0.091) | (0.049) | (0.685) | (0.682) |
| GVC embeddedness | | | 1.576 *** | 1.550 *** | −1.132 |
| | | | (0.287) | (0.279) | (1.854) |
| Value chain digitalization × Product diversification | | | | 0.019 ** | 0.019 ** |
| | | | | (0.007) | (0.007) |
| GVC embeddedness × Product diversification | | | | | 0.028 |
| | | | | | (0.019) |
| Product diversification | 0.006 | −0.005 | 0.006 | −0.082 * | −0.086 ** |
| | (0.006) | (0.008) | (0.006) | (0.033) | (0.033) |
| Firm age | 0.076 | −0.144 | 0.078 | 0.054 | 0.059 |
| | (0.104) | (0.141) | (0.103) | (0.101) | (0.102) |
| Firm size | 0.046 | 0.258 *** | 0.044 | 0.044 | 0.047 |
| | (0.032) | (0.047) | (0.032) | (0.031) | (0.031) |
| R&D | 0.079 | −0.034 | 0.086 | 0.071 | 0.068 |
| | (0.102) | (0.180) | (0.100) | (0.098) | (0.099) |
| Financial constraints | −0.087 | −0.465 + | −0.092 | −0.074 | −0.076 |
| | (0.110) | (0.237) | (0.109) | (0.108) | (0.108) |
| Political connections | 0.066 * | 0.020 | 0.064 * | 0.059 * | 0.061 * |
| | (0.030) | (0.035) | (0.030) | (0.029) | (0.029) |
| Information sharing | 0.391 *** | −0.049 | 0.374 *** | 0.382 *** | 0.387 *** |
| | (0.056) | (0.104) | (0.056) | (0.057) | (0.057) |
| Manager experience | −0.017 * | 0.013 | −0.017 * | −0.017 * | −0.017 * |
| | (0.007) | (0.011) | (0.007) | (0.007) | (0.007) |
| Subindustry | Controlled | Controlled | Controlled | Controlled | 0.000 |
| Constant | −4.056 *** | −6.180 *** | −3.638 *** | 4.589 | 4.921 |
| | (0.863) | (1.151) | (0.834) | (3.260) | (3.263) |
| corr(e.GVC embeddedness, e.DIVC) | 0.145 | | −0.559 *** | −0.579 *** | −0.567 *** |
| | (0.103) | | (0.142) | (0.135) | (0.144) |
| corr(e.Value chain digitalization, e.DIVC) | −0.160 ** | | | −0.167 ** | −0.161 ** |
| | (0.062) | | | (0.063) | (0.062) |
| corr(e.DVC, e.GVC embeddedness) | 0.099 | −0.093 | | 0.103 | 0.103 |
| | (0.069) | (0.110) | | (0.067) | (0.067) |
| *N* | 862 | 862 | 862 | 862 | 862 |

Standard errors in parentheses: + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Secondly, we included some individual manager-level, firm-level and industry-level covariates to reduce concerns about a possible endogeneity from omitted variables. Furthermore, in accordance with prior literature, we employed an alternative measure for GVC embeddedness as a robustness check. The alternative measure for GVC embeddedness was a binary variable taking the value of one if the firm obtained a minimum of 1 percent of its annual sales from direct exports, had a minimum of 1 percent of material inputs or supplies sourced from foreign origin, and held international quality certification, and zero otherwise. The results shown in models 12–15 in Table 4 remained consistent with our original tests.

**Table 4.** Probit model analyses with alternative measures of GVC embeddedness.

| | (12) | (13) | (14) | (15) |
|---|---|---|---|---|
| | DIVC | Alternative GVC | DIVC | DIVC |
| Value chain digitalization | 0.368 *** | 0.140 * | −1.483 * | −1.505 * |
| | (0.051) | (0.065) | (0.710) | (0.703) |
| Alternative GVC | 0.519 * | | 0.493 * | −3.910 * |
| | (0.207) | | (0.205) | (1.953) |
| Value chain digitalization × | | | 0.019 ** | 0.019 ** |
| Product diversification | | | (0.007) | (0.007) |
| Alternative GVC × | | | | 0.047 * |
| Product diversification | | | | (0.021) |
| Product diversification | 0.006 | −0.005 | −0.084 * | −0.089 ** |
| | (0.006) | (0.008) | (0.034) | (0.034) |
| Firm age | 0.081 | −0.082 | 0.060 | 0.067 |
| | (0.107) | (0.149) | (0.107) | (0.108) |
| Firm size | 0.039 | 0.280 *** | 0.042 | 0.046 |
| | (0.033) | (0.047) | (0.033) | (0.033) |
| R&D | 0.077 | 0.181 | 0.069 | 0.067 |
| | (0.104) | (0.166) | (0.104) | (0.105) |
| Financial constraints | −0.075 | −0.596 * | −0.077 | −0.074 |
| | (0.113) | (0.235) | (0.113) | (0.114) |
| Political connections | 0.066 * | 0.053 | 0.063 * | 0.064 * |
| | (0.031) | (0.035) | (0.031) | (0.032) |
| Information sharing | 0.381 *** | 0.042 | 0.387 *** | 0.396 *** |
| | (0.057) | (0.097) | (0.058) | (0.058) |
| Manager experience | −0.017 * | 0.009 | −0.017 * | −0.017 * |
| | (0.007) | (0.011) | (0.007) | (0.007) |
| Subindustry | Controlled | Controlled | Controlled | Controlled |
| Constant | −3.582 *** | −6.482 *** | 5.164 | 5.480 |
| | (0.875) | (1.160) | (3.375) | (3.364) |
| *N* | 850 | 850 | 850 | 850 |

Standard errors in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Finally, self-selection implies that only firms with distributed innovation can afford the costs of participating in GVCs; therefore, firms may self-select to participate in GVCs. To address the potential self-selection problem, we applied the Heckman two-stage procedure [105]. In the first stage, we estimated a probit model to analyze a firm's engagement in GVCs. We then computed the inverse Mill's ratio (IMR), which is included as a control variable in the second stage of the Heckman correction model. In Table 5, we can see the IMR is insignificant across all models, suggesting that the potential selection bias was not a big concern.

**Table 5.** Two-step probit selection model for sample selection bias.

| | (16) | (17) | (18) | (19) | (20) |
|---|---|---|---|---|---|
| | DIVC | DIVC | GVC Embeddedness | DIVC | DIVC |
| Value chain digitalization | 0.352 *** | 0.351 *** | 0.138 * | −1.477 * | −1.510 * |
| | (0.053) | (0.054) | (0.068) | (0.716) | (0.709) |
| GVC embeddedness | | 0.466 * | | 0.426 + | −3.421 |
| | | (0.232) | | (0.230) | (2.215) |
| Value chain digitalization × Product diversification | | | | 0.019 * | 0.019 ** |
| | | | | (0.007) | (0.007) |
| GVC embeddedness × Product diversification | | | | | 0.041 + |
| | | | | | (0.023) |
| Product diversification | 0.004 | 0.007 | 0.015 | −0.083 * | −0.091 * |
| | (0.015) | (0.016) | (0.018) | (0.037) | (0.037) |
| Firm age | 0.073 | 0.156 | 0.367 | 0.103 | 0.015 |
| | (0.368) | (0.381) | (0.418) | (0.382) | (0.360) |
| Firm size | 0.076 | −0.048 | −0.568 | 0.008 | 0.165 |
| | (0.558) | (0.579) | (0.653) | (0.583) | (0.547) |
| R&D | 0.163 | 0.150 | −0.156 | 0.149 | 0.168 |
| | (0.136) | (0.138) | (0.210) | (0.138) | (0.136) |
| Financial constraints | −0.095 | 0.127 | 1.074 | 0.028 | −0.256 |
| | (1.030) | (1.068) | (1.212) | (1.074) | (1.012) |
| Political connections | 0.043 | 0.032 | −0.048 | 0.034 | 0.049 |
| | (0.058) | (0.060) | (0.065) | (0.060) | (0.057) |
| Information sharing | 0.383 *** | 0.397 *** | 0.018 | 0.401 *** | 0.393 *** |
| | (0.076) | (0.077) | (0.113) | (0.078) | (0.077) |
| Manager experience | −0.017 | −0.025 | −0.040 | −0.022 | −0.012 |
| | (0.036) | (0.037) | (0.043) | (0.037) | (0.035) |
| Subindustry | Controlled | Controlled | Controlled | Controlled | Controlled |
| IMR | 0.036 | −0.473 | −4.051 | −0.228 | 0.491 |
| | (2.596) | (2.689) | (3.182) | (2.706) | (2.545) |
| Constant | −4.028 | −1.270 | 13.968 | 6.076 | 2.755 |
| | (13.175) | (13.652) | (15.826) | (14.065) | (13.218) |
| *N* | 734 | 734 | 734 | 734 | 734 |

Standard errors in parentheses: + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

## 6. Discussion

### *6.1. Theoretical Contributions*

Theoretically, our study not only deepens the understanding of distributed innovation in value chains but also extends the research on value chain digitalization, GVC embeddedness, and diversification strategy. First, this paper understands innovation activities in value chains from a unique distributed innovation perspective, which have been largely underemphasized in the literature [9,10]. Recent research has highlighted the importance of using value chains to enhance innovation [2,36,37]. However, these studies fail to conceptualize and theorize innovation in value chains with a more complete framework. To address this gap, we proposed the mode of innovation in value chains be featured by distributed innovation. Innovation in value chains is decentralized and distributed among diverse interconnected and interdependent value chain participants, such as suppliers, buyers, or users. Lead firms play orchestrating roles in knowledge creation, development, and diffusion. Value chain participants provide complementary technologies and collaborate to co-create new knowledge and value. Distributed innovation in value chains is characterized by modulization, orchestration of lead firms, collaboration, and value co-creation among value chain participants.

Second, based on the technology affordance theory, we explored influencers of distributed innovation in value chains by focusing on a key digital driver, value chain digitalization. Though value chain digitalization has already been studied recently, most discussions are conceptual, lacking constructing and empirically testing a systematic mechanisms and outcomes [45,47,65]. We proposed three mechanisms through which value chain digitalization influenced distributed innovation in value chains: digital encapsulation, convergence, and generativity. Through linking the three digital mechanisms of value chain digitalization to modulization, orchestration of lead firms, collaboration, and value co-creation of distributed innovation in value chains, we elaborated on how value chain digitalization drove innovation in value chains. Moreover, our empirical results showed the positive effect mechanism of value chain digitalization on distributed innovation in value chains. Therefore, we contributed to research on digitalization, distributed innovation, and innovation in value chains.

In addition, we deepened GVC research by exploring how digital value chains affect GVC embeddedness and GVC's role in distributed innovation. Previous research on GVCs predominantly explored the influence of firm digitalization on GVCs, with limited attention given to the role of digital value chains on GVCs. GVC is highlighted by the interconnection and co-creation which can be enhanced by value chain digitalization. Furthermore, GVCs expand the regional scale of partners and knowledge synergies, providing opportunities for distributed innovation. Though there is research on distributed innovation in value chains, empirical tests are scarce. We empirically examined the relationship among digital value chains, GVCs, and distributed innovation in value chains using data from the WBES. Furthermore, our findings suggest the facilitating effect of value chain digitalization on GVC embeddedness, and GVC's improving role in distributed innovation. Therefore, this study makes contributions to GVCs, digital value chains, and distributed innovation research.

Finally, this article extended research on diversification strategy by exploring its moderating role in the effects of value chain digitalization and GVC embeddedness on distributed innovation. Digital value chains and GVCs cannot provide a complete picture, and the paper explored the contingent role of diversification strategy. A diversification strategy can provide interdivisional knowledge for orchestration and collaboration for distributed innovation [87,89]. Using data from the WBES, our empirical analyses revealed that diversification positively moderated the effects of value chain digitalization and GVC embeddedness on distributed innovation in value chains. In other words, with high diversification, digital value chains and GVCs both appeared to be the stronger drivers of distributed innovation. Therefore, we provided more nuanced and complicated mechanisms of distributed innovation in value chains.

### *6.2. Managerial Implications*

These results carry important implications for managerial practices and policy considerations.

For firms in a complex, global business context characterized by disperse and sticky knowledge, innovation becomes a challenging task for individual firms. Innovation, especially within value chains, can be distributed to strategic partners, such as diverse suppliers [9]. Distributed innovation in value chain in essence requires orchestration by lead firms, and collaboration and value co-creation among partners. Our results suggest an effective way to improve distributed innovation is to take full advantage of digital value chains. Digital value chains are beneficial for digital encapsulation, orchestration and collaboration among value chain partners. Liu, Dong, Mei, and Shen [62] suggest that manufacturing firms should give considerable importance to integrating digital technologies into their innovation process and products. Therefore, managers could develop digitalization strategy and take steps to digitalize value chains especially in currently turbulent and uncertain environments.

Furthermore, our research demonstrates that value chain digitalization helps firms to engage in GVCs. Participating in GVCs offers firms with an opportunity for large market and global frontier knowledge. Our findings also suggest the positive impact of GVC embeddedness on distributed innovation in value chains. Thus, firms are advised not only to emphasize digitalization strategies but also to incorporate GVC strategies. Concurrently, policymakers are encouraged to implement supportive measures to incentivize firms' participation in GVCs.

In addition, firms should pay attention to their diversification strategy. A product diversification strategy can build up interdivisional knowledge resources, expand product market, and spread risks [87]. Interdivisional knowledge constructs the foundation for collective knowledge, which is critical for orchestration and collaboration for distributed innovation in value chains. Our findings shows that the driving forces of digital value chains and GVCs on distributed innovation in value chains can be enhanced by a product diversification strategy. Firm thus can exploit the synergies arising from digital value chains combined with a product diversification strategy, as well as GVCs combined with a product diversification strategy to improve distributed innovation in value chains.

Finally, our research could bring inspirations to government institutions' policymaking. Distributed innovation in value chains is critical for the sustainable growth and competitiveness of firms and GVCs [9,10]. To bolster this aspect of economic development, governments can enact measures to improve the efficiency of firms' value chain digitalization. This may involve initiatives such as investing in digital infrastructures and implementing supportive policies conducive to digital transformation. Moreover, the interaction effect of value chain digitalization, GVC embeddedness, and diversification strategy on distributed innovation should also be noticed for more effective and efficient policy interventions.

### *6.3. Limitations and Further Research*

Some limitations of our research could be explored and addressed in a future study. Firstly, this paper only explored a singular industry within the specific national context of China for the sake of accuracy and simplicity. A future study is necessary to generalize our findings to other industries and countries. For objectivity and strictness of data source, we used the survey data from WBES in 2012, nearly a decade ago. In order to accurately capture the inherence and evolving nature of digitalization, it is recommended to develop a large, new cross-time sample in recent years.

Secondly, our measurement of value chain digitalization primarily focused on the application breadth of digital technologies while neglecting the application depth of digital technologies. To what extent can this measure reflect traits of value chain digitalization? Our current measure, while useful, may not capture a complete picture of value chain digitalization. Prior studies often use word frequency of digitalization by text analyses method to measure the degree or depth of a firm's digitalization [77,106,107]. Future research could explore nuanced measures on value chain digitalization by a combination of application depth and breadth of digital technologies with mixed methods.

Thirdly, our results show product diversification may moderate the relationship between value chain digitalization and distributed innovation, and the relationship between GVC embeddedness and distributed innovation. However, other diversification strategies such as technology diversification and employee diversification, as well as contextual factors such as environment turbulence and culture, merit exploration as potential moderators. Existing studies have argued that innovation is also contingent on various variables, such as knowledge traits, culture, or environment [108–111]. Additionally, the mediating mechanisms could also be explored by incorporating other digital-attributed features on the basis of the current theoretical model.

## 7. Conclusions

This paper explored how firms' value chain digitalization affects distributed innovation in value chains. Using survey data of Chinese manufacturing firms from the WBES, we empirically examined the effect of value chain digitalization, GVC embeddedness, and product diversification on distributed innovation in value chains. The results indicated that value chain digitalization significantly promotes distributed innovation in value chains and GVC embeddedness; GVC embeddedness enhances the likelihood of distributed innovation in value chains. Further research also revealed that product diversification act as a positive moderator, strengthening the effects of value chain digitalization and GVC embeddedness on distributed innovation in value chains. The findings highlight that the interaction of value chain digitalization and product diversification strategy, as well as the interaction of GVC embeddedness and product diversification strategy can effectively improve distributed innovation activities. Therefore, DVC enables agile and cost-effective operation, collaboration, and thus GVC embeddedness and distributed innovation for sustainable development in value chains. As researchers and practitioners increasingly focus on digitalization and innovation for sustainable development, we expect the intricate interplay between digital value chains, GVC embeddedness, firm diversification strategy, and distributed innovation activities to garner attention in future studies.

**Author Contributions:** Conceptualization, L.Q. and W.X.; methodology, L.Q. and P.J.; software, L.Q. and P.J.; formal analysis, L.Q. and W.X.; writing— original draft preparation, L.Q.; writing—review and editing, L.Q., W.X. and P.J. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by Major Program of the National Social Science Foundation of China (No. 23&ZD090), National Natural Science Foundation of China (No. 72274041), and China Postdoctoral Science Foundation (No. 2022M720836).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author.

**Acknowledgments:** The authors thank the editor and anonymous reviewers for their useful comments and suggestions.

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

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