



Digital Innovation Networks: Theory Building and Future Research

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Abstract. Properties such as convergence of digital innovation that change the relationships, structures, and modes of interaction between innovation agents have initiated challenges to existing innovation network theories and have led to thinking about digital innovation networks. This paper classifies digital innovation networks into two representations (digital innovation networking and digital of innovation networks) to better illustrate what is relevant to digital innovation networks. Digital innovation networking aims to facilitate the initiation, development, and application of digital innovation, and this innovation network, formed around the digital subject, continues the basic characteristics of convergence, generativity, and modularity of digital innovation. Innovation network digitalization is the result of the embedding of digital connectivity and digital convergence among innovation agents, which leads to the digital transformation of subjects, structures, etc. within innovation networks. The two forms of performance penetrate and promote each other, which changes the way in which the value of the innovation subject is created and promotes the overall enhancement of innovation effectiveness. Finally, the paper presents the main research findings.

Keywords: Digital Innovation Networks · Innovation Networks · Digital Networks · Digital Innovation · Digital Economy

1 Introduction

With the advent of the digital economy, digital resources have gradually become the core resource of innovation, which is comprehensively affecting the organizational innovation model and triggering a complete change in the connection and interaction between individuals, organizations, and the entire society [1], promoting the expansion and improvement of traditional innovation network theory [2]. Digital resources include digital technology, data, etc. [3], the reproducible and manipulable characteristics of digital resources reshape the connection and interaction forms between innovation subjects [4, 5], expand the existing innovation network theory, and trigger thinking about building digital innovation networks. An innovation network is considered a basic institutional arrangement for systemic innovation, emphasizing that the collaborative relationship between network subjects is the main network mechanism [6]. Digitization introduces

data, a new factor of production, into the innovation network, which not only helps to reduce the cost of inter-organizational relationship maintenance and communication, but also enhances the efficiency of inter-organizational communication, and helps to expand the scope of organizational interaction and promotes the cooperation and coordination of heterogeneous innovation subjects [7]. Correctly defining the connotation and mechanism of digital innovation networks not only helps to guide the practice of digital innovation in enterprises but also helps to promote the expansion and reconstruction of innovation network theory, which has important practical and theoretical significance. Despite this, there are very few studies focusing on digital innovation networks at home and abroad, and there is still a lot of research space to explore the new connotation and new characteristics of innovation networks in the context of digitalization.

Therefore, this paper believes that the digital innovation network has two basic manifestations: one is the networking of digital innovation, that is, the digital innovation network composed of heterogeneous dynamic innovation subjects, which is committed to promoting the digital innovation process, namely, the starting, development, and application of digital innovation networks. The second is the digitalization of the innovation network, that is, the deep integration of the digital innovation process and innovation subject information, resource sharing, and other behaviors. The innovation network has begun to have the attribute of digital innovation.

2 Materials and Methods

The main research method of this paper is theoretical deduction, which is to study the impact of digital technology on traditional innovation network theory. This paper focuses on the integration of digital innovation theory and innovation network theory by combing the existing literature, making up the research gap of innovation networks in the context of digital innovation, and expanding the digital innovation theory and innovation network theory.

3 Networking of Digital Innovation

The digital innovation network is an innovation network composed of digital representations of digital resources (digital technology, data, etc.), digital resource providers, digital resource users, and other heterogeneous network subjects through digital connection and digital fusion [8]. The purpose of the digital innovation network is to solve the outstanding contradiction between the limited innovation resources of a single enterprise and the uncertainty of technological innovation in the network environment. Based on the common goal of technological innovation, it is a form of network organization established by related enterprises or organizations at different levels [9]. Digital innovation networking is a digital innovation network to promote the initiation, development, and application of digital innovation. Therefore, the network of digital innovation continues the basic characteristics of convergence, generativity, and modularity of digital innovation.

3.1 Convergence

The Data homogenization and reprogrammable functionality Reprogrammable functionality of digital resources can promote the recombination of the original production factors [3, 10]. With the deep integration of traditional entities and digital entities, industrial boundaries, organizational boundaries, departmental boundaries and even product boundaries become blurred and less important, which reflects the convergence of digital innovation. For example, intelligent products integrating digital technology and traditional physical products have broken through the scope of use of the original products, and the boundaries of new digital products are no longer clear. The application of digital resources blurs industry boundaries, organizational boundaries, departmental boundaries, and even product boundaries, increasing the uncertainty of innovation and reflecting the convergence of digital innovation networks [4]. The networking of digital innovation is also convergent. On the one hand, the convergence of digital innovation networking helps to reduce the maintenance cost of strong relationships and improve innovation efficiency; on the other hand, it normalizes weak relationships and increases heterogeneous resources.

3.2 Generativity

Generative refers to the combination of useful information about innovation, the innovation environment, or the network connected by innovation to stimulate the co-generation of new ideas [8]. For example, digital products such as APP can conduct real-time iterative innovation based on user feedback and various problems in the operation process. The homogeneity, programmability, intangibility, and self-referential attributes of digital resources promote the interaction of heterogeneous digital innovation subjects [7], enabling innovation subjects to effectively identify the needs of potential and unrecognized digital users [11], in turn, it becomes possible to carry out innovation and mass customization centered on consumer or user needs [2].

3.3 Modularity

The characteristics of digital resources endow them with modular characteristics, which makes the digital innovation network have the characteristics of hierarchical modularity [10], which promotes more and more heterogeneous participants to connect across multiple boundaries to create new use value [12]. The innovation elements in the network can be decomposed into basic modules that are both independent and inter-dependent, driving the vertical loose coupling and horizontal integration of the product or service production architecture, and promoting the coordination and flexibility of the entire network [7]. Therefore, the networking of digital innovation is also modular. Modularization strongly calls on technical modules and design rules to reorganize industrial technology systems, in which rapid response and continuous innovation are the core concepts of modularity. Modularization provides enterprises with the opportunity of “competition trial and error” learning, and enables enterprises to integrate knowledge vertically and horizontally, thus forming a networked innovation system.

4 Digitalization of Innovation Networks

Digitalization realizes the transformation of social and technological structure and relationship through the migration from non-digital artifacts to digital artifacts, and enterprises can integrate their (relationship) resources across traditional industry boundaries in a unique way [1, 10]. By blurring the innovation boundary and improving connectivity and uncertainty, digitalization enriches the element composition of the innovation network, destroys the traditional innovation network boundary, improves the looseness of the innovation network, and changes the flowing resources and integration forms in the network [2, 4, 5, 10, 13]. Digitalization shapes the innovation network through digital connection and digital integration, promotes changes in the innovation network, forms the digitalization of the innovation network, embeds digital resources such as digital technology and data elements into the innovation network, and further deepens the theory and practical application of the innovation network [10].

4.1 Changes in Innovation Networks Under the Background of Digitalization

The innovation network is composed of interconnected innovation subjects. It emphasizes that the collaboration between enterprises is the main network mechanism, and is a basic institutional arrangement to deal with systematic innovation [6]. The innovation network emphasizes that the network subjects can share and complement resources and information by establishing a cooperative relationship [5]. In the digitalization of innovation networks, digital connection and digital fusion change the structure and relationship between network subjects, thus promoting the evolution of innovation networks under the digital background [2, 10].

From the perspective of technological innovation, the formation of the innovation network is to solve the outstanding contradictions brought about by the uncertainty brought about by technological innovation and the limited innovation resources of enterprises. Based on this perspective, this paper explores the changes in innovation networks under the background of digitalization from five dimensions, subject, structure, institution, function, and evolution. (As shown in Table 1).

In the digital context, new changes have taken place in the innovation network. Digitalization breaks the barriers between industries and between industries, making the scope of innovation cooperation more extensive. Specifically, it turns to the crowd [1]. Digitalization takes “consumers” or “customers” as the main body of the innovation network to participate in the innovation process [2]. It is possible to conduct mass customization and interactive innovation centered on consumers. In the new organizational context, digital technology, as an objective resource, has expanded the scope of interaction, reduced the cost of interaction, and improved the speed of interaction through digital connection [10, 13]. In addition, As operational resources, digital technology increases the heterogeneity and composability of knowledge through digital fusion and combines resources in a unique way to better meet the needs of users/consumers [7]. Therefore, with the popularization of digitalization, the boundaries of innovation are blurred. The innovation network in the digital context is a flexible group formed spontaneously based on similar goals and is not controlled by contractual relationships [5]. For example, Douban, etc., to achieve similar goals, network members spontaneously share

Table 1. Innovation network changes under the background of digitalization

Analysis Dimension	Basic Viewpoint of Innovation Network	Challenges of innovation networks in the context of digitalization
Subject	Universities, research institutes, local governments, intermediary agencies, financial institutions, etc. [6].	“Customers” or “consumers” have become one of the network subjects, and their contributions even surpass those of enterprises, universities, and research institutes [2, 14].
Structure	The network subjects are satisfied that the network they are in can well adapt their own capabilities to their needs, and achieve Pareto equilibrium [2].	It highlights the state of weak links, the network structure is more loose, its scale and heterogeneity are expanding, resource mobility is strong, and relationship maintenance costs are reduced [2–4, 12].
Institution	The external cooperation network formed by contractual relations such as cooperation and alliance agreements, and the internal cooperation network formed by contractual relations [5].	A new type of cooperative innovation network led by core enterprises and spontaneously formed by external stakeholders [7].
Function	Information sharing, resource sharing, operational rationalization, and collective strength [13].	Network effect, social interaction [5].
Evolution	Promoted by network subjects and network mechanisms [2].	Digitization promotes the application of innovative networks.

information and knowledge with the help of this Internet platform. Digitalization will promote the deep evolution of innovation networks and realize the digital transformation of network subjects [2].

4.2 Changes in Innovation Network Mechanisms under the Background of Digitalization

Innovation networks emphasize the collaborative relationship among network subjects as a key network mechanism [6]. With the continuous improvement of the speed and scope of digitalization, digitalization has significantly changed the innovation network mechanism [2], that is, digitalization changes the relationship between network subjects and the value creation process through digital connection and digital convergence, making the internal interaction of innovation networks more and more dynamic and complex [5, 8]. Digitalization is an operand resource of connection, that is, digital connectivity.

Table 2. The theoretical analysis framework of digital innovation network

	Convergence	Generativity	Modularity
Subject	Individual self-organization	Digital production factors	Digital platform
Structure	Blurring Innovation Boundaries	Promote coordination and integration of heterogeneous resources	Hierarchical Modularity
Institution	Digital Governance	Orchestration	Mechanism Platform Construction and Governance
Function	Promote openness and collaboration	Scenario blending, continuous iteration	Scenario blending, continuous iteration
Evolution	Deep evolution	Transformation and Upgrading	business model innovation

An object resource is a resource (usually tangible and static) used by network subjects to obtain support for performing tasks [11]. Operational resources are different from object resources and are resources that produce effects by acting on other resources (usually intangible and dynamic) [11]. Both forms of digitization offer a wide range of opportunities for interaction, creative recombination of resources of network subjects that may have originally been created for different purposes [1], change resource flow patterns, and influence traditional innovation network mechanisms.

4.3 Further Deepening of Innovation Network in the Context of Digitalization

An innovation network refers to the networking behavior of enterprises in the innovation process [13], and it is a basic institutional arrangement to deal with systemic innovation [6]. The innovation network has been widely used in academia and practice. With the development of digital technology, many basic views of innovation networks have been challenged, while their applications have been further deepened in practice.

Through the two characteristics of digital connection and digital integration, digital innovation can not only promote the interaction efficiency of network subjects but also provide a new environment for the evolution of innovation networks and improve the innovation efficiency of innovation networks [8]. The impact of digital innovation on innovation networks is mainly reflected in three aspects: First, changes in network subjects, that is, digitalization and diversification of network subjects. The digitalization of innovation subjects refers to the use of digital resources or digitally empowered network subjects [10], the diversification of network subjects is because digital connection and digital integration break the boundaries of organizations, improve the heterogeneity of innovation, and interact with other subjects more openly, especially “consumers” become one of the network subjects [2, 5]; the second is the interaction of network subjects across time and space [5, 8]; the third is to form a digital innovation network environment [13].

5 Digital Innovation Networks: A Framework for Theoretical Analysis

The intervention of data elements and the application of digital technology are two basic characteristics of digitalization, that is, digital resources (data and digital technology) are the basis for understanding digital innovation networks. Based on these two basic characteristics, digital innovation can be divided into two meanings: one is innovation related to digital; the other is innovation using digital technology. Based on this, this paper considers the digital innovation network to be a complex network in which the networking of digital innovation and the digitization of the innovation network are integrated (as shown in Table 2).

5.1 The Main Body of the Digital Innovation Network

The digital context enriches the diversity of network subjects [2]. The convergence of the digital innovation network makes individuals or teams the main body [5], especially a large number of consumers can spontaneously gather and disperse to form a flexible community to participate in innovation activities [14], network subjects are not bound by contractual relationships, and they are in a state of continuous flow in the digital innovation network. The digital innovation network further highlights the weak connection between network subjects, and the state [2, 5]. Digitization transforms a large amount of heterogeneous information into digital production factors in a unified digital format [10], which is conducive to promoting the integration of heterogeneous resources and connecting previously unrelated resources in a way that can be operated and analyzed while changing the traditional innovation model. Playing on the modular nature of digital innovation networks, the digital platforms spawned by digital infrastructures become the center of corporate innovation activities [7], and these digital platforms seek to creatively coordinate the interaction or exchange of services among distributed and heterogeneous enterprises.

5.2 Digital Innovation Network Structure

The digital context affects the innovation network structure [2]. Innovation is a bounded phenomenon, but the convergence of digital innovation networks breaks the boundaries of innovation networks and blurs the time, space, and industry boundaries of innovation [3, 4]. The generative nature of the digital innovation network is to integrate useful information in the network to stimulate the generation of new ideas [8], promote the coordination and integration of heterogeneous resources [7], and strengthen the network structure of the digital innovation network. The modularity of digital innovation has changed the traditional innovation network structure, making it present a hierarchical modular form [7, 12], the organizational logic of hierarchical modular architecture is described as dual distribution, that is, the control of key components or special components is distributed in multiple companies, and knowledge is distributed in different disciplines and communities [10].

5.3 Digital Innovation Network System

The integration of the networking of digital innovation and the digitization of the innovation network has brought major challenges to the innovation network system [2, 5]. First of all, the emergence of individual self-organization and the increase of heterogeneous subjects have increased the degree of decentralization and fragmentation of network forms [7, 12]. Therefore, convergence has significantly increased the governance difficulty of digital innovation networks [3, 5]. Secondly, the generative characteristic of the digital innovation network promotes the coordination and integration of resources among the network subjects, thus improving the resource processing ability of the core enterprise of the innovation network, that is, the orchestration mechanism. Finally, the digital platform has become the activity center of the main body of the network, and platform construction and governance issues have become one of important systems of the digital innovation network [3].

5.4 Digital Innovation Network Functions

The innovation network is the basic institutional arrangement for systematic innovation [6], and it has certain functions. The convergence of the digital innovation network promotes the openness and cooperation of the network [2, 8], in particular, the introduction of “consumers” into the digital innovation network can enable network subjects to innovate centered on consumer needs. Generative can not only promote the cycle and iteration of innovation but also better meet customer needs and improve customer experience by combining digital technology with its usage scenarios [3, 4, 7], generative endows the digital innovation network with the functions of scene integration and continuous iteration. Finally, the modularity of digital innovation networks leads to the emergence of hierarchical modular structures, the main goal of modularization is to reduce complexity and increase flexibility.

5.5 Evolution of Digital Innovation Network

Digitalization can promote the continuous evolution, iteration, and upgrading of innovation networks through digital connection and digital integration, and enable the continuous evolution of innovation networks with value co-creation [8, 11]. With the convergence of enriching network subjects and the cooperative relationship between network subjects, the digital innovation network is also constantly improving and further deepening [2]. Generative can make innovation continuously improve and change, and promote the transformation and upgrading of innovation networks. For example, digital products such as applets and APPs can iteratively innovate in real-time in combination with user feedback and problems in operation [3]. Finally, the networking of digital innovation and the digitalization of innovation networks penetrate each other, deep integration promotes network subjects to obtain more heterogeneous resources, improves the resource flow rate and resource integration efficiency among network subjects [2, 5, 12], and makes digital innovation network develop and evolve in a positive direction.

6 Main Research Conclusions

This paper defines the concept of “digital innovation network”, and constructs a theoretical analysis framework of digital innovation network by proposing the concepts of “digital innovation network” and “innovation network digitization”.

6.1 Theoretical Contributions

First of all, this paper defines the concepts of “digital innovation network” and “digital innovation network”, which provides a theoretical basis for the research on the concept of the digital innovation network. Based on the relevant literature on digital innovation and innovation networks, this paper proposes: (1) “Digital innovation networking” is a complex network composed of heterogeneous digital innovation subjects through digital connection and digital integration, to promote the initiation, development, and application of digital innovation. (2) “Digitalization of innovation network” refers to the deep integration of digital resources such as digital technology and data elements with the innovation network, aiming at realizing the digital transformation of the innovation network.

Secondly, this paper constructs a preliminary theoretical framework of digital innovation networks to reveal the changes in innovation networks in the context of digitalization. This paper believes that the integration and interaction of digital innovation networks and innovation network digitalization will help improve the interaction efficiency of network subjects and promote the improvement of innovation efficiency. By integrating the concepts of “digital innovation network” and “innovation network digitization”, the theoretical analysis framework of a digital innovation network is constructed, from the five dimensions of subject, structure, system, function, and evolution, and the three characteristics of convergence, generativity, and modularity, the construction of innovation network in the digital environment is expounded. The theoretical framework of the digital innovation network proposed in this paper not only helps to guide the practice of innovation networks in the context of digitalization but also helps to guide the construction of digital innovation networks.

6.2 Research Findings

(1) The network of digital innovation is formed by the interconnection of digital innovation subjects, so it also has the basic characteristics of digital innovation convergence, generativity, and modularity. (2) Digitalization enriches the innovation elements of the innovation network through digital connection and digital integration, improves the interaction efficiency between innovation elements, promotes the digital transformation of the innovation network, and forms the digitalization of the innovation network. (3) The digital innovation network improves innovation efficiency through the interaction and penetration of digital innovation network and innovation network digitalization. The former affects the internal mechanism of the latter, while the latter promotes the development of the former, therefore, the two co-evolve.

The research in this paper not only expands the theory of digital innovation and innovation networks but also expands the application of innovation networks in the context of digitalization, which has important theoretical significance for subsequent related research.

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