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SMU Classification: Restricted

Research on the Relationship between Service-oriented Manufacturing Platforms and Customer Enterprise Innovation

—Evidence from the 3D Printing Industry

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Singapore Management University (SMU)
2023

Research on the Relationship between Service-oriented Manufacturing Platforms and Customer Enterprise Innovation —Evidence from the 3D Printing Industry

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Singapore Management University (SMU)
2023

Declaration

I hereby declare that this thesis is my original work and has been written entirely by me.

I have appropriately noted all sources of information used in this thesis.

Previously, the thesis has never been used to obtain a degree at any university.

Zhao Dong Lai

Zhao D L

13th April, 2023

Abstract

Micro, small and medium-sized enterprises (MSMEs) are highly flexible and creative and play a significant role in the national economy and in employment, innovation, and entrepreneurship. However, due to their relatively small size, low technical level, lack of funds and talent, and backward management, they generally face development predicaments, such as the pressure to survive and weak anti-risk abilities. Therefore, in addition to leveraging their initiative to develop their competitive strength, making full use of external public service resources has become one approach MSMEs can take to find a way out of such predicaments.

Various service-oriented manufacturing platform enterprises have recently emerged in China, under the policy guidance of central and local governments. These apply next-generation information technologies, such as the industrial internet, to empower new manufacturing and promote new services. The development of new business types and new service-oriented manufacturing models is essential to enhance the quality and efficiency of the manufacturing industry and facilitate its transformation and upgrading.

This paper focuses on Bering3D Technology, a Chinese 3D printing technology service platform company, as the case study. Bering3D Technology represents a typical service manufacturing platform enterprise. An analysis of the specific service path of the enterprise reveals three main empowerment mechanisms: technology, information, and product empowerment. The influence of these three mechanisms on MSME innovation performance is examined and a questionnaire survey is conducted. This study extends the relevant literature on platform empowerment and

MSME innovation.

Keywords: Service-oriented Manufacturing Platform; Platform Empowerment; MSME Innovation; Bering3D Technology

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Acknowledgments

Life is a journey on which we should both read books and be well-traveled to attain wisdom and enrich our lives. During this journey, we may make several stops, climb high mountains, get acquainted with interesting people, and leave wonderful stories. As spring is approaching, we will graduate soon. Time flies. My feelings regarding this 4-year academic study are mixed, and include my expectations for admission, excitement at the opening ceremony, frustration and joy in class, and confusion, loneliness, and sense of accomplishment. I encountered difficulties in my independent research, hardships in preparing the thesis proposal, fun with my classmates, and warmth through my supervisors' patient instructions. I would therefore like to extend my heartfelt thanks to my supervisors and classmates for their academic help, to my family and friends for their strong support, to the Singapore Management University (SMU) and Zhejiang University for creating warm and precious memories, and also to myself, as I never remain still or stop moving forward, even in my middle age. This is a special life experience informing my growth and joy that I will remember forever.

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deeply impressed me. My thesis writing was not smooth and repeated revisions were necessary. They spent much time instructing me about my revisions. What I learned from them during the process will benefit me throughout my life. In addition, I have developed a broader outlook, learned methods for interacting with people, and experienced the spirit of striving for perfection. This will be valuable throughout my work and life and will encourage and inspire me when I face challenges.

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I am particularly thankful to my family. My parents have offered me the most selfless encouragement and support in both study and work. They are proud of me, which makes me confident and motivates me to move forward. I would like to thank my wife Ma Huihui for her company and support in managing our family affairs, enabling me to keep my mind on work and study. I would also like to thank my daughter Zhao Ruoqi. Her self-discipline and self-improving outlook also urge me to keep studying. She is talented, wise, and hardworking. I believe she will have a bright future.

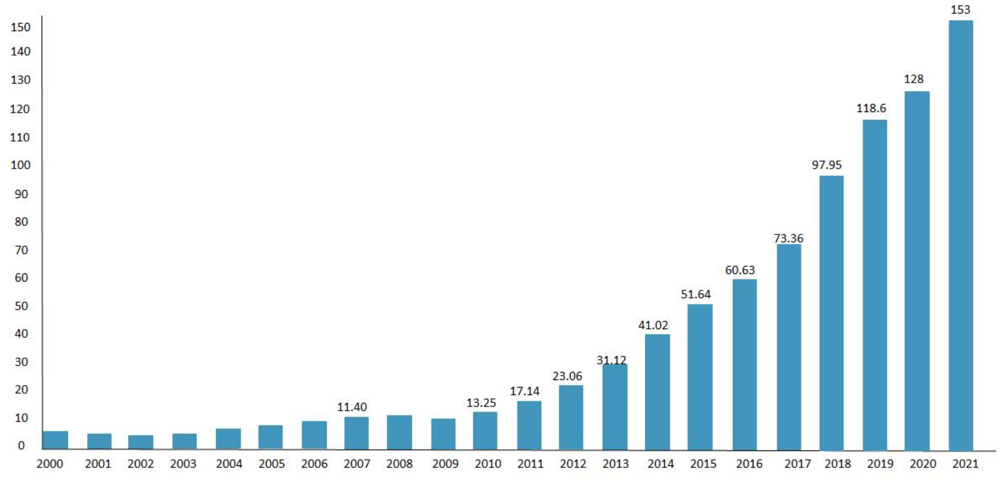
Finally, I hope that the COVID-19 pandemic has finally passed, that the global economy will steadily improve, that my friends and family will be healthy, and that I will cherish the good and live up to my life's potential in the future!

1. Introduction

1.1. Research background

Micro, small, and medium-sized enterprises (MSMEs) are the foundation of China's economy. Statistics from the Ministry of Industry and Information Technology (MIIT) of the People's Republic of China show that MSMEs accounted for over 99% of Chinese enterprises by the end of 2021. These highly flexible and innovative enterprises play a critical role in the national economy, employment, innovation, and entrepreneurship. However, due to their small size, low technical level, lack of funds and talent, and backward management, they generally face development predicaments, such as high survival pressure and weak risk management. Therefore, in addition to leveraging their initiative to develop competitive strength, making full use of external public service resources has become a potential way out for MSMEs. Similarly, local governments must acknowledge and effectively address the key problem of supporting and empowering MSMEs within their regions.

In the past decade, a government-supported comprehensive public service platform has been developed to promote the innovative development of the regional economy. This platform has various roles, including popularizing science, displays, publicity, promotion, education, R&D, and services. Vandermerwe and Rada (1988) viewed this as a new service-oriented business model that can provide customers with all-round services and add value by offering technical innovations and extended services, thus finally satisfying the specific demands of diverse customers. In this paper, the 3D printing industry is taken as an example. In 2012, the U.S. founded its first center for innovation in additive manufacturing (3D printing), thus providing significant support for the country's new manufacturing strategy. This formally marks the center for innovation as a vital force to promote the innovative development of the regional economy. This innovative model has been introduced and applied in many countries worldwide. In May 2014, Singapore made a significant investment by building a service center for 3D printing innovation. In June 2015, the European Union (EU) developed a master plan for the 3D industry. In line with Germany's Industry 4.0 Policy, the EU published the 3D Printing Standardization Roadmap under the 7th Framework Programme (FP7) to define the position and orientation of 3D printing in its development strategy. This action was named the "Support Action for Standardization in Additive Manufacturing (SASAM)." Countries such as Japan, South Korea, the U.K., and France have established various policies and centers or institutes for innovation in 3D printing. They have engaged in the application, R&D, and marketing of 3D printing in various areas, such as defense-related science and technology, military, medical treatment, education, and consumption. In terms of the technical advantages of the global 3D printing industry, the U.S. and Germany take the lead. The U.S. ranks first in this market, contributing to more than one third of the world's total investment. China is a latecomer in this sector but is now rapidly developing. At present, its market scale ranks second to that of the U.S. Figure 1.1 shows the global output trend of 3D printing over the past 20 years.



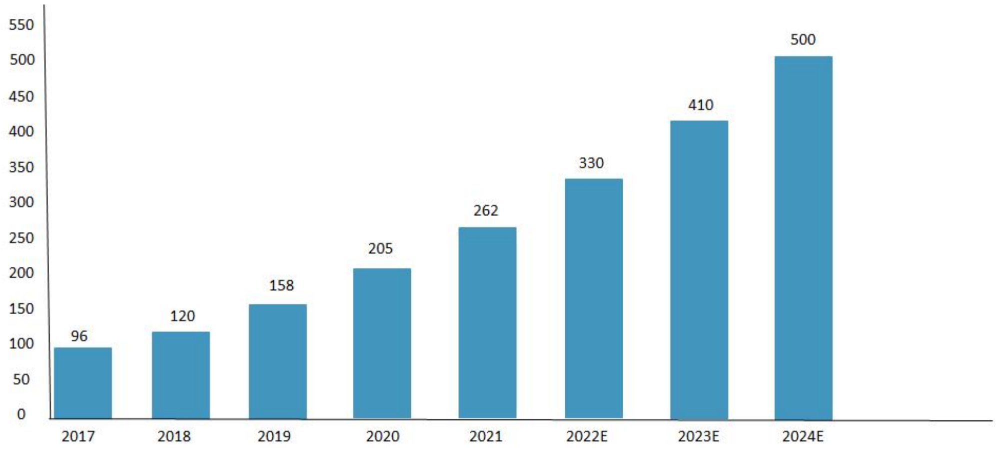
Unit: 100 million U.S. dollars

Data source: *Wohlers Report 2022*

Figure 1.1 Global market output value of 3D printing

On May 19, 2015, the State Council issued a document entitled *Made in China 2025*, indicating that efforts should be made to develop new internet-based manufacturing models, such as personalized customization, crowdsourcing design, and cloud manufacturing. These were aimed at promoting the development of R&D, manufacturing, and industrial organization patterns based on the dynamic perceptions of consumer demand. These are all important characteristics of service-oriented manufacturing. On July 15, 2020, 15 authorities jointly published guidelines for further advancing service-oriented manufacturing. These clarified that following the main task of supply-side structural reform, China will ensure that market forces have a decisive role in resource allocation, ensuring the government's input is effective, reinforcing the positions of manufacturing enterprises, improving the policy and business environment, strengthening leading roles, enhancing the service-oriented manufacturing ecosystem, and actively leveraging new-generation information technologies such as the industrial internet. This can then empower new manufacturing, enable new services, accelerate the development of new types of service-oriented manufacturing, and promote increased efficiency and quality. This transformation of manufacturing will enable China to become a manufacturing powerhouse. Under the support and policy guidance of the central and local governments, various service-oriented manufacturing platform enterprises have sprung up. However, many of these platform enterprises are still in their initial stages, and have yet to establish a mature development pattern. The core competitiveness of these platforms remains underexplored. In addition, these platforms have different understandings of customers' empowerment mechanisms. Some appear to be unsure about how to proceed or act in a way that defeats their purposes. Therefore, examining how to better empower MSMEs and improve customers' innovation performance is worthwhile.

The Chinese government has attached great importance to the R&D, application, and promotion of 3D printing. Chinese President Xi Jinping has stressed the importance of 3D printing on various occasions. Premier Li Keqiang has convened meetings to discuss issues concerning advanced manufacturing and 3D printing, among many others. In February 2015, the MIIT, the National Development and Reform Commission (NDRC), and the Ministry of Finance (MOF) jointly issued the *Additive Manufacturing Industry Development Action Plan (2015–2016)*, setting the course for the development of China's 3D printing industry. In November 2017, 12 authorities published the *Additive Manufacturing Industry Development Action Plan (2017–2020)*, which identified four fields, five goals, five missions, and six safeguards of 3D printing. These policies have provided guidance for local governments to accelerate the development of 3D printing. Figure 1.2 shows the market size and forecasts for 3D printing in China in recent years.



Unit: 100 million yuan

Data source: CCID, Qianzhan Industry Institute, and AskCI Consulting Co., Ltd.

Figure 1.2 Market output value of 3D printing in China

The development of 3D printing in China has major practical significance. First, 3D printing can help meet the demand for personalized consumer goods and industrial products. As a new manufacturing approach, 3D printing (or additive manufacturing) is distinct from subtractive manufacturing, which is characterized by cutting and polishing, and equivalent manufacturing, which involves forging and casting. Production in 3D printing is no longer restricted by scale, as every product can be customized without additional costs at a speed consistent with that of mass production. The layer-by-layer stacking principle makes it possible to manufacture products that could not previously be produced due to the limitations of the production process. Designers can imagine and brainstorm in an unrestrained manner. Thus, 3D printing has brought revolutionary new business opportunities to areas such as medicine, education, consumer products, and art. Many creative projects that cannot be easily mass produced due to high costs can be realized through 3D printing. Upstream enterprises can redefine their product processes and technical parameters in the R&D stage and directly print prototypes for rapid testing, resulting in small-scale production and customization. In addition, it is quicker to achieve. Designs can also be more easily and efficiently upgraded at a lower cost. As the production process is no longer an obstacle, end users can benefit from more creative product designs. The application of 3D printing can thus lead to more cost-effective products with higher performance.

Second, 3D printing can effectively help MSMEs in China achieve intelligent digital transformation. Local governments have rolled out various policies targeting local enterprises before offering incentives to promote and support the rapid development of MSMEs. Local public service platforms for 3D printing play a significant role in this process. These platforms are market-oriented enterprise entities. To promote their businesses, they must make themselves known to the market through publicity campaigns and frequently interact with their customer base. The platforms can inform MSMEs about 3D printing technology through activities such as science popularization, education, promotion, publicity, displays, and services. 3D printing is a form of digital technology and all 3D-printed products are made through 3D digitization. MSMEs also need more than word-of-mouth advertising and marketing to effectively develop, innovate, and adapt to megatrends in the market. Concrete and feasible approaches and measures are required that involve technical support and that can demonstrate successful cases, and that draw on the experiences of industry-leading enterprises. This is a long process that relies on policies, real transactions, technology, and product requirements. Chinese MSMEs cover a wide range of industries, including new energy, instruments, the arts, education, and medicine. They are on a fast track of industrial development. As they are small they have few employees, but they are flexible and quick learners that can adapt to market changes, understand market needs, and rapidly launch products. Therefore, in this study, we propose that 3D printing technology can offer MSMEs a way of “cutting corners” and improve their innovation performance.

Chinese 3D printing service enterprises are small-scale and face development bottlenecks. After more than a decade of rapid development, various 3D printing enterprises have been established, engaging in hardware, software, materials, and services, many of which have been listed on the STAR Market. These companies include the metal additive manufacturing solution provider Bright Laser Technologies (BLT), Farsoon Technologies, which just passed its IPO review for the STAR Market, and SHINING 3D and UnionTech, which are listed on the National Equities Exchange and Quotations (NEEQ). These small companies also focus on 3D printing hardware. No 3D printing service platforms have currently completed an IPO. Such enterprises are generally weak and uncompetitive. **First**, these businesses, and particularly MSMEs, typically form core teams with internet professionals, and thus are proficient in website building, traffic attraction, and promotion but lack industrial experience and an understanding of customer requirements. They do not know how to empower customers or build long-term, stable, and mutually beneficial partnerships with them.

Second, some enterprises simply follow traditional manufacturing approaches to building a platform by highlighting the scale and pursuing the low-cost dividends brought by mass production, rather than regarding 3D printing as a model for personalized, small-scale, and multiple types of production. They apply this state-of-the-art technology to the traditional model, and thus begin at the wrong end. **Third**, as service-oriented platforms, they encounter all kinds of customers. As these enterprises vary considerably in terms of scale, industrial position, learning capacity, relations with other platforms, and empowerment models, many 3D printing service platform enterprises find it difficult to succeed.

1.2 Research objectives and content

Through an exploratory case study and theoretical analysis, the focus of this study is on how service-oriented manufacturing platforms empower MSMEs to improve their innovation performance. The functional paths and impact mechanisms are also examined. The problem is addressed through case studies, a theoretical framework, and a questionnaire survey.

We focus on Bering3D Technology, a 3D printing service platform enterprise (Yin, 2009) that has service projects in several industries. Based on the analysis of the service paths, we find that this typical service-oriented manufacturing platform enterprise is empowered through technological, informational, and product-based mechanisms. These factors can influence MSMEs' innovation performance. In addition, the scale and industrial position of an enterprise can affect the impact of these empowerment mechanisms on innovation performance.

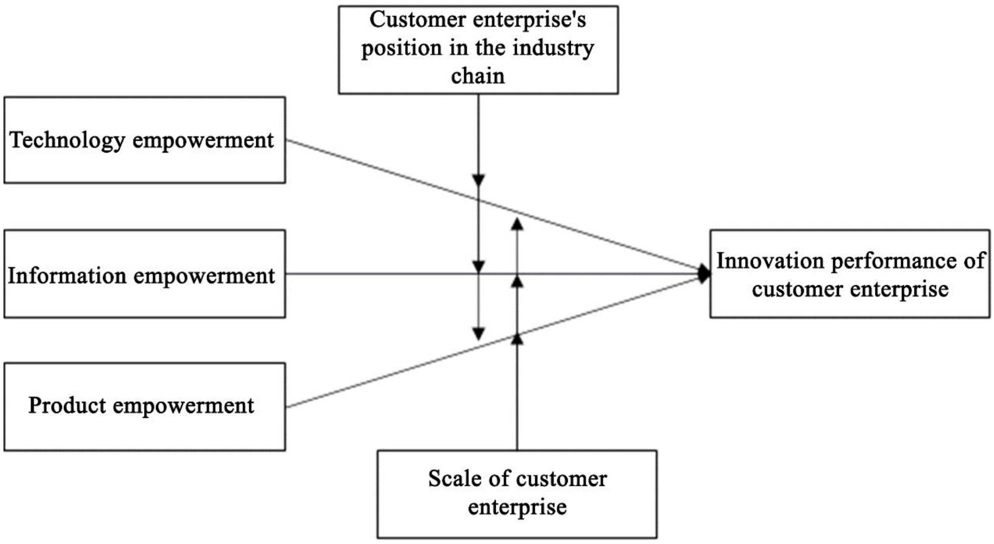


Figure 1.3 Framework of the study

This paper consists of the following six chapters:

Chapter I: Introduction. This chapter identifies the research topic and introduces the key terms, significance, objectives and content, methodology, and structure, based on both theory and practice. The technology roadmap and expected innovations are then proposed.

Chapter II: Literature Review. This chapter reviews and summarizes studies concerning service-oriented manufacturing platforms, in terms of theory, empowerment, and innovation performance. In addition, it identifies the specific research field, theory development, and the support this study provides for the theory, offering a theoretical foundation for the building of an analysis framework.

Chapter III: Single-Case Study. This chapter focuses on the case of Bering3D Technology. An exploratory case study was conducted from the perspective of a platform enterprise, to identify the approaches and impact mechanisms that platform enterprises can adopt to empower MSMEs and help them improve their innovation performance.

Chapter IV: Theoretical Framework Construction. Based on the outcomes of Chapter III, this chapter outlines the study's theoretical framework and proposes that empowerment mechanisms help to enhance the performance of MSMEs.

Chapter V: Empirical Analysis. We conducted a survey to collect basic information about the enterprises' mechanisms and to establish the control variables and other related data. SPSS and other statistical software was used to identify the main effects of the empowerment mechanisms, which were further discussed in combination with the results.

Chapter VI: Outcomes and Prospects. This chapter summarizes the demonstration process, main theory, theoretical and practical contributions, and limitations, which can provide suggestions for further study in the relevant fields.

1.3 Research methodology

Both qualitative and quantitative research methods are applied in this study, and a normative analysis is combined with empirical research to ensure the findings are as robust as possible, and to ensure the exploration and testing of the research problems are scientific and effective. The specific methods applied include a systematic literature review, an exploratory case study, and a large sample analysis.

1) Literature review. To provide a solid theoretical foundation for this study, I comprehensively and systematically assessed both the Chinese and foreign literature. I also retrieved studies from the college's database concerning service-oriented manufacturing platforms, platform theory, platform empowerment, and technological innovations of MSMEs. I then

analyzed this literature and summarized the ideas. Any research gaps were identified to provide theoretical support for this study. I then summarized any limitations in the theoretical research and further clarified the research perspective and content. In addition, a model for the service-oriented manufacturing platform empowering MSMEs was built, based on previous studies. The theoretical model was then analyzed and the hypotheses proposed.

2) Case study. I examined how Bering3D Technology empowers its customers. Through this exploratory case analysis, the collected qualitative data were coded and the main propositions and research framework proposed.

3) Questionnaire. Data were collected through a questionnaire to measure and test the effectiveness of the empowerment mechanisms of service-oriented manufacturing platforms, the innovation performance of MSMEs (as the dependent variable), and other constructs in the theoretical model. Statistical software was then used to analyze the descriptive statistics and to conduct reliability and validity tests, a correlation analysis, and a multiple regression analysis based on the questionnaire data. Finally, the theoretical hypotheses were tested.

4) Empirical research. Based on the case study and questionnaire data, the core constructs were quantitatively analyzed and tested, and specifically the platform empowerment mechanism, MSMEs' scale and industrial position, and innovation performance.

Due to the small number of service-oriented manufacturing platform enterprises in the 3D printing field, Bering3D Technology was selected as a single case. As a controller of Bering3D Technology, I have over 10 years' experience with 3D printing, so I am very familiar with the company's history and development. I have access to customer and other data, which ensure this case is accurate and reliable.

1.4 Research roadmap

This study focuses on how service-oriented manufacturing platforms empower MSMEs and improve their capabilities. Based on previous research into service-oriented manufacturing platforms, platform theory, platform empowerment, and the technological innovations of MSMEs, the study investigates the proposition that service-oriented manufacturing platforms empower MSMEs to improve their capabilities. We followed the problem-solving process of observing phenomena, identifying problems, analyzing them, and finally solving them. In this context, the actions and contingency factors related to the improvement of MSME capabilities through empowerment mechanisms were further analyzed. The technology roadmap is shown in Figure 1.4.

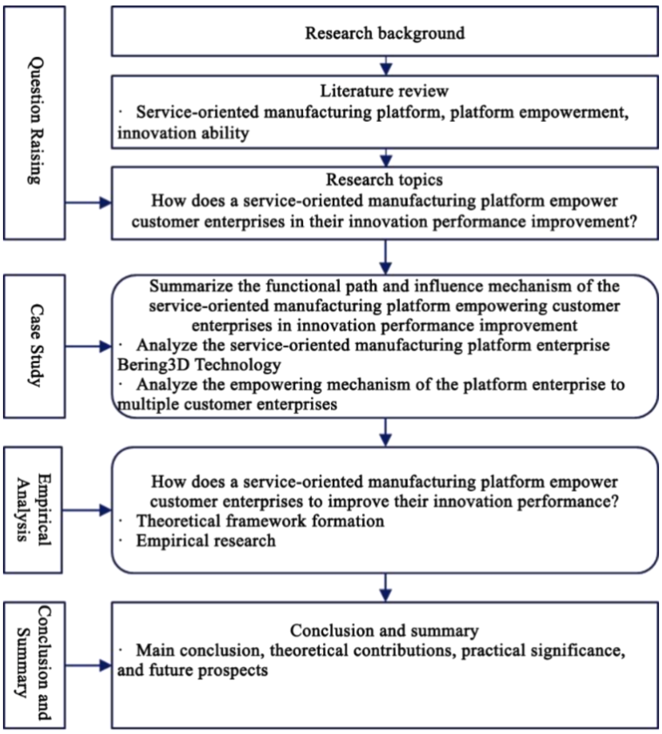


Figure 1.4 Technology roadmap

1.5 Research significance

China has implemented an innovation-driven strategy and supply-side reform and has encouraged the replacement of old with new drivers of growth. In this context, the incentives and resources made available by local governments for local manufacturing MSMEs to enhance their innovation performance should be considered. This study examines how enterprises achieve economic targets and empower MSMEs both upstream and downstream in the industrial chain by building 3D printing service platforms.

Service-oriented manufacturing platform enterprises have integrated the manufacturing processes of industrial enterprises and linked various production factors through platforms based on big data. Thus, they have become new industrial/organizational entities that are regarded as being of national importance. They play a vital role in promoting collaboration and trade and in guaranteeing service between upstream and downstream enterprises and between enterprises and users. Various empowerment mechanisms can encourage MSMEs to grow and realize “cutting corners” by seizing opportunities. External forms of empowerment can effectively make up for the constraining defects often apparent in MSMEs, such as poor foundations and motivation for technological innovation, by providing resource factor support and matching demand with supply. Successful service-oriented manufacturing platform enterprises illustrate that this approach has great potential for empowering design, R&D, and flexible manufacturing, and for improving the service capabilities of MSMEs. Thus, many mid-to-low-end MSMEs in China can obtain extensive opportunities to further align with the mainstream market and pursue high-end value.

In terms of theoretical research, the number of studies concerning platform empowerment is gradually increasing, with the main research focus being on operation management, information management, and innovative and strategic management. However, although the definition of platform empowerment and the mechanism through which a platform empowers the technological innovations of MSME have been discussed, further studies are required to clarify these issues. This study thus focuses on how service-oriented manufacturing platforms empower MSMEs to improve their innovation performance.

Based on big data architecture, industrial internet platforms empower industrial data elements through interconnections among people, machines, and things. This ubiquitous connectivity can enable flexible supply and dynamic and efficient configuration, thus promoting the building of digitized business ecosystems (Lyu et al., 2019). Leading industrial countries and enterprises worldwide have rolled out major strategies for building industrial internet platforms, to ensure their dominant positions in this new form of industrial revolution. Service-oriented manufacturing platforms have also been the focus of extensive academic attention. The definition of an industrial internet platform has been widely discussed (Wollschlaeger et al., 2017) along with its basic architecture (Guth et al., 2018) and evaluation system (Li et al., 2018). The enabling role of such platforms in the building of business ecosystems has also been explored (Cao, 2018; Sun et al., 2022). They can encourage the integration and circulation of industrial data at the equipment, platform, and network levels (Li et al., 2016), thus accelerating the construction of new data-centered business ecosystems. However, no research has been carried out to explore how industrial internet platform enterprises empower MSMEs to improve their innovation performance.

These service-oriented manufacturing platforms can include various participants from different industries or sectors (Cao, 2018). Powered by data-driven algorithms, the platforms can flexibly combine and allocate distributed resources (Arnold et al., 2016), invisibly transforming from service-oriented into tools for nurturing the business ecosystem. The ability to link and build platforms empowers MSMEs to share production resources and efficiently promote the flow of various factors (Sun et al., 2022). Platforms are likely to enable their customers to improve innovation performance (Gao et al., 2021) and develop new products (Soegoto et al., 2020). Therefore, as hubs, service-oriented manufacturing platforms integrate upstream and downstream resources and output customized services to MSMEs, enabling MSMEs to gain high-level abilities based on process reorganization and environmental changes, and the enhancement of innovation performance in the platform ecosystem.

This study makes various theoretical contributions. First, it explores improvements in the innovation performance of MSMEs from a research perspective in the context of digital platforms. Previous research has mainly focused on the efforts of a single enterprise to develop and improve its own innovation performance. From the new perspective of platform empowerment, this study highlights the overflow effect of service-oriented manufacturing platforms and the empowerment mechanism that helps MSMEs improve their innovation performance and demonstrates the logical path through which the supply side enables the MSMEs.

Second, by exploring platform empowerment, we extend assessments of empowerment to the context of the platform economy and digitization, and expand the research focus from internal employees to core organizations in the business ecosystem. The acting mechanism and path are obviously distinct, but new emerging practices provide a rich and diversified space in which to discuss this topic. Based on domestic and overseas research into industrial internet platforms, the servitization of manufacturing, and digital empowerment, we examine service-oriented manufacturing platforms and platform empowerment. We summarize the key paths through which MSMEs can improve their innovation performance via platform empowerment after studying the specific enterprise case.

This study is also of practical significance. First, it can provide direction for governments at the county and municipal levels, as the main public service providers, to establish 3D printing service platforms, which can link to various information and resources, which can promote the innovation performance of local MSMEs.

Second, in terms of market entities, this study assesses the path through which 3D printing service platforms help improve MSME innovation performance from multiple dimensions. This can inform the building and operations of effective platforms and help them empower customers in a targeted and efficient manner.

Third, this study can help MSMEs evaluate and select suitable service-oriented manufacturing platforms from the perspective of the supply chain and address any shortage of resources while pursuing enhanced innovation performance.

2. Literature Review

2.1 Service-oriented manufacturing platforms

2.1.1 Definition and classification

We consider three definitions of a platform. First, the engineering community regards product-based platforms as those enabling the innovative design and development of several products (Krishnan & Gupta, 2001). Meyer and Lehnerd (1997) defined a product platform as a set of parts, subsystems, interfaces, and manufacturing processes that are shared among a set of products. Tushman and Murmann (1998) argued that the fundamental architecture behind all platforms is essentially the same: the system is partitioned into a set of "core" components with low variety and a complementary set of "peripheral" components with high variety. The low-variety components constitute the fundamental architecture of the platform. By replacing high-variety components, enterprises can produce different products and develop a diversified product mix. In a broad engineering sense, a platform is a product-based technical architecture and platform enterprises are organizations that promote product development and innovation through this shared platform system and architecture. Such a product-based platform can flexibly adjust its characteristic elements according to changes in the external environment.

Second, platforms are defined as intermediaries from the perspective of industrial economics (Gawer, 2014), and are designed to bring together bilateral or multilateral groups of transactions. Armstrong (2006) examined two-sided markets and argued that these have two or more groups of agents interacting via intermediaries or platforms. The benefits enjoyed by members of one group depend on how effective the platform is at attracting customers from the other group.

Third, from the perspective of strategic management, scholars argue that two-sided or multi-sided platforms constitute an intermediary market that enables interactions between at least two groups of users, in which the decisions of one group will affect the value creation and acquisition of the other (Rochet & Tirole, 2004; Rysman, 2009). Brusoni and Prencipe (2005) proposed that platform enterprises, as the core of the platform, are modules that realize the essential functions of the platform or solve major problems, while complementary providers constitute the periphery of the platform, specifically the hardware, software, service modules, and the structure that combines them. Rong et al. (2013) pointed out that as an interaction interface, the platform can meet the increasingly personalized and diversified needs of consumers with the help of network externalities. Kim and Moon (2017) suggested that a platform is a pivotal axis that can organize resources and coordinate the interests of different partners (e.g., complementors) in many scenarios.

2.1.2 Manufacturing platform

From an engineering perspective, the manufacturing platform is a new type of product formed amid the transformation of manufacturing enterprises through the integration of informatization and industrialization in the new industrial revolution. This is also referred to as the “industrial internet platform.” This relies on big data architecture and empowers industrial data elements through the interconnections among people, machines, and things to realize ubiquitous connectivity, flexible supply, and dynamic and efficient configuration. This can then lead to a digitized business ecosystem (Lyu et al., 2019). Leading industrial countries and enterprises have rolled out major strategies for industrial internet platforms, to ensure they play a dominant role in this time of industrial transformation (Sun et al., 2022).

Scholars have widely discussed the definition of the industrial internet platform (Wollschlaeger et al., 2017), its basic architecture (Guth et al., 2018), and evaluation systems (Li et al., 2018). Some have explored the enabling role of such platforms in the building of a business ecosystem (Cao, 2018). These open, digital, and professional service platforms can meet the personalized, network-based, and intelligent development requirements of the manufacturing industry (Ciortea et al., 2018). They can enable numerous connections, flexible supply, and the efficient allocation of industrial elements (Fu et al., 2018) by fully integrating industry-based thinking, capabilities, methods, and models with new-generation information technologies, such as cloud computing, big data, and artificial intelligence (Menon et al., 2019).

Scholars have explored the characteristics of manufacturing and industrial internet platforms. Wang et al. (2018) identified infrastructure, platform, and application as the three layers, while Li et al. (2016) highlighted their integration and circulation of industrial data at the equipment, platform, and network levels, facilitating the construction of a new data-centered business ecosystem. In terms of functional value, within the application layer an industrial internet platform deploys edge solutions, accesses and gathers diverse and distributed industrial elements, and promotes the "datamation" and modeling of industrial resources, such as manpower, machines, materials, methods, and the environment (Mayer et al., 2017; Wang et al., 2018). At the platform layer, data-based and modeled industrial resources are processed, analyzed, combined, and optimized, thus providing services such as industrial resource management, dynamic scheduling, and optimal configuration for MSMEs (China Industrial Control Systems Cyber Emergency Response Team, 2017).

Scholars have also focused on the participants of service-oriented manufacturing platforms. These offer a stage for various participants from different industries or sectors (Cao, 2018). Informed by data-driven algorithms, these platforms can promote the free combination and allocation of distributed resources (Arnold et al., 2016), and are invisibly transformed into a tool for nurturing the business ecosystem. Industrial internet platforms have attracted many upstream and downstream partners from multiple industries. On the platform, partners can share real-time demands, which is conducive to addressing information asymmetry and further helps enterprises to quickly integrate the required resources (Arnold et al., 2016). These platforms move away from the traditional mode of "fighting alone" and can mine product or service ideas from the complex data on the platform, further motivating stakeholders in multiple industries to realize functional combinations and continuously creating new forms of scenario-based business (Cao, 2018).

2.1.3 Service-oriented manufacturing platforms

In the context of economic globalization and modern informatization, service-oriented manufacturing has become the latest business model, which effectively combines the service industry with the manufacturing industry to form a new industrial format. The *Guidelines for Special Actions to Develop*

Service-oriented Manufacturing jointly formulated and issued by the MIIT, NDRC, and the Chinese Academy of Engineering (CAE) clearly define service-oriented manufacturing as a new form that integrates manufacturing and services, and based on the actual development of China's manufacturing industry, helps to clarify its meaning. First, in terms of industry type, service-oriented manufacturing is defined as a new industrial form that integrates the development of manufacturing and services. Second, in terms of integration mode, in service-oriented manufacturing, service factors continuously increase their share in the manufacturing input and output. Third, from the perspective of development effectiveness, service-oriented manufacturing extends from both ends of the value chain to enhance its efficiency, and enterprises transform from simply providing products to providing "products + services" or total solutions.

One academic view suggests that service-oriented manufacturing platforms involve the "servitization" of manufacturing platform enterprises. Service-oriented manufacturing is distinct from production-based manufacturing. Vandermerwe and Rada (1988) first used the term servitization to describe the phenomenon of adding product value by adding services. This involved the transformation of manufacturing enterprises from providing products alone to providing product service packages, which cover product maintenance, technical support, process services, and knowledge (Neely, 2008). Servitization is viewed as a strategic alternative to product innovation and standardization (Baines et al., 2014), which can bring various competitive advantages and effectively avoid the problems of product commercialization (Zhang et al., 2020). Zhu (2017) pointed out that servitization marks a comprehensive change in the business strategies and models of manufacturing enterprises, as they adapt to the market environment and technological changes through the "service transformation of manufacturing enterprises." Some scholars believe that this transformation also involves the servitization of manufacturing enterprises, which then differ from traditional (Jammes & Smit, 2005) and pure service enterprises. Thus, services and products are integrated (He & Lai, 2012).

In addition, some scholars have described servitization from the perspective of the transformation of the manufacturing model, and have proposed concepts such as "manufacturer embedded-servicing" (Chadee & Mattsson, 1998) and "service-oriented manufacturing" (Jammes et al., 2005). The Chinese scholars Sun et al. (2008) proposed the term "service-oriented manufacturing," which they defined as a new industrial model in which services are added to products to add value, thus enhancing the strength and innovation of enterprises and providing better development spaces. Zhu (2017) suggested that service-oriented manufacturing enterprises take the lead in multi-entity participation, openness, and resource-sharing in this business model. Platforms make significant changes to the traditional industrial value chain. Digital, information-based, and intelligent approaches make it possible for platforms of service-oriented manufacturing enterprises to integrate the manufacturing links of all industrial enterprises. They can then monitor product production and related factors and the market dynamics of enterprises on the platform through big data. Therefore, a platform not only functions as an operational interface through which product manufacturers can conduct technical exchanges and realize remote intelligent manufacturing, but it also provides a virtual market. This can encompass the division of labor, cooperation, product transactions, and service guarantees between upstream and downstream enterprises and between enterprises and users. A platform involves enterprises from different industries and those producing the same product, other related enterprises in the industrial chain, end users of products and services, and various service-oriented organizations. The network effect makes industrial internet platforms become complex networks for organizing the allocation of various production factors and resources across society and the world. The platform-based structure breaks the boundaries of enterprises and pools global resources to increase both efficiency and transactions.

From the review of the literature, we can summarize the characteristics of three structural elements of the service-oriented manufacturing platform: organizational platformization, functional modularization, and business customization. These provide theoretical support for our subsequent research. The characteristics of the three structural elements are described below.

(1) Service-oriented manufacturing platform enterprises feature platform-based organization forms. Platforms bring significant changes to the traditional industrial value chain. Digital, information-based, and intelligent approaches make it possible for major platforms of service-oriented manufacturing enterprises to integrate the links of all manufacturing enterprises, monitor product production and related factors, and assess the market dynamics on the platform through big data. Thus, a platform not only functions as an operational interface through which manufacturers can conduct technical exchanges and conduct remote and intelligent manufacturing, but it also enables cooperation and provides a virtual market for labor, product transactions, and service guarantees between upstream and downstream enterprises and between enterprises and users. Platforms can include enterprises from different industries, those producing similar products, others in the industrial chain, end users of products and services, and other service-oriented organizations. The network effect means that industrial internet platforms can become complex networks in which various production factors and resources can be allocated at different levels.

(2) Service-oriented manufacturing platform enterprises provide modular service production functions. These platforms typically evolve from manufacturing enterprises, with services shifting from primary product supply to intermediate and advanced content related to products, processes, and industry. These service elements rely on the basic ability to manufacture products and on the professional integration of general functions and module components. Thus, service-oriented platforms enable these modular functions according to the manufacturing field. In addition, the individual needs and designs of upstream and downstream customers are combined, resulting in higher-order derivative services.

(3) Service-oriented manufacturing platform enterprises provide customized services for the upstream and downstream enterprises of the supply chain. A platform establishes links among upstream and downstream manufacturing enterprises in the industry, and an online platform is also accessible to customers. As shop windows, platforms encourage enterprises to fulfill the needs of consumers. They create a business system that is flexible, dynamic, innovative, and vibrant. A customer-centered mindset involves enterprises concentrating all of their resources to serve their customers and enhances their ability to avoid market risks.

2.2 Empowerment and platform empowerment

2.2.1 Definition of empowerment

The term “empowerment” in the field of human resource management emphasizes the distribution of rights within an organization (Banyard & Graham-Bermann, 1995). Empowerment has been examined in the fields of pedagogy, psychology, and management. For example, teachers can help students acquire certain abilities by imparting knowledge, or managers can improve subordinates’ working abilities by empowering them. Instead of the provision of rights, developing the abilities of employees or customers is the focus of empowerment. Empowering employees means that management increases the decision-making power of employees (Mainiero, 1986). This can occur in structural, psychological, and resource dimensions (Leong et al., 2015). Structural empowerment refers to facilitating the conditions that can give actions power. Conger and Kanungo (1988) first proposed “psychological empowerment,” which refers to the process of enabling employees. By enhancing their internal motivation and feelings of subjective empowerment, their sense of self-efficacy will be improved, further promoting the connotations and vertical structure of empowerment. Resource empowerment emphasizes the acquisition and control of resources and focuses on the ownership and control of resources (Leong et al., 2015).

The internet has led to improvements in customers' status, and enterprises focus more on dialogue and interactions with their customers (Acar & Puntoni, 2016). The internet reduces information asymmetry, transforms customers from passive receivers to active participants, and improves the status of customers in transactions. Thus, enterprises must establish a rapid, open, and continuous dialogue mechanism with their customers. Customer empowerment emphasizes giving customers more rights, to enable their initiative-taking and participation (Yukse et al., 2016). Customers' involvement in design, production, and marketing has an impact on enterprises' value creation process and results.

Chinese scholars have recently focused on empowerment in the business environment outside of the organization, with an emphasis on enabling or enhancing the ability to discover and exploit opportunities in a changing business environment (Zhou et al., 2018). Yukl and Becker (2006) suggested that organizational empowerment aims to enhance or renew the enterprise's ability to create value through the introduction of advanced technologies, concepts, or models. Cao (2018) proposed that structural empowerment involves promoting the interactive connection between upstream and downstream entities in the industry value chain through open and shared approaches, thus ensuring the accurate and efficient allocation of resources that rely on real-time cooperative relationships that vary with demand. Cao and Kong (2020) pointed out that field empowerment involves creating a value-generation space for cross-border participants from different industries and fields. Cooperative relationships can then be established and can evolve. Field empowerment breaks through traditional industry boundaries that involve value judgments and closely connects stakeholders who provide similar or related products and services (Zeng, 2018).

2.2.2 Research on platform empowerment

The rise of the digital economy and the formation of new types of industrial organizations containing multilateral markets means that platforms, suppliers, and consumers are the basic components, with platforms at the core (Lyu & Han, 2015). Enterprises join an internet platform as suppliers, and the mutual partnerships become more prominent as platforms provide enterprises in the ecosystem with commonly available resources (Suarez & Kirtley, 2012). During the process of platform empowerment, the participating enterprises can potentially create value through resource output, data support, marketing guidance, and model optimization, and participating enterprises can transform this potential into the actual ability to meet customer expectations through cognition, thinking, processing, and practice (Wang, 2017).

Many definitions of platform empowerment have been proposed. Zhou Liyong (2018) believed that core platforms rely on the shared output of the internet to "empower" participating enterprises in an energetic process, through which they gain new capabilities and added value. The internet platform initially empowers those using it. It determines the content and how capability develops according to the resources, information, and technological advantages. The empowerment process occurs simultaneously with the production process of the participating enterprises that provide goods/services. This process may be either proactive or passive. Internet platforms enable users to enhance their ability to create value by launching various empowering plans or building empowering infrastructure. They can also gradually learn and grow when using the platform functions. Zhu et al. (2019) drew on resource-based theory, enterprise ability theory, and the characteristics of digital empowerment to define platform empowerment as the ability of a platform to optimize the operation modes of its enterprises. This can be achieved as the platform acts as a hub providing unique information through digital technology, and has the ability to integrate resources, enable transaction-matching, and provide value-added services in the value chain. Enterprises can then gain high-level abilities based on process reorganization and environmental changes, and their implementation in the platform ecosystem can be enhanced. Thus, enterprises on the platform can be helped to obtain high-level abilities through platform empowerment. Wang (2021) defined platform empowerment as when a platform provides broad resource matching and various value-added services for enterprises through advanced digital technology and core value network location. This enhances the competitiveness of the enterprises in the platform ecosystem.

Platform empowerment has been examined by scholars such as Githinji (2014), who pointed out that internet platforms can act as development tools and empower MSMEs to obtain technical support. They participate in the knowledge economy by facilitating connectivity and create and deliver products and services on a global scale. The platform empowers MSMEs through its powerful resource integration ability, and this empowerment improves their efficiency, lowers the threshold of employment and transaction costs, and encourages growth (Ma, 2017). Wang and Zhang (2017) proposed a greenhouse management model of the seller on a platform, which includes the idea of platform empowerment. Wang (2017) discussed platform empowerment and proposed that it is realized by core enterprises that gain R&D abilities, production experience, and industrial resources. The platform users can be from both the supply and demand sides. Wang and Sheng (2017) suggested that the process of empowering producers through internet platforms includes various aspects, such as resource output, data support, marketing guidance, and model optimization, thus providing platform enterprises with the potential ability to create value. They can then meet customer expectations by transforming this potential into an actual ability through cognition, processing, and practice. Mazzei and Nobles (2017) proposed that big data enable platforms to turn any potential supply, cooperation, and demand into data resources through digitization and modeling, and then into output data through connections, interaction, and analysis. Zeng (2018) further pointed out that platform e-commerce enterprises can empower other enterprises operating on platforms through various dimensions, such as SaaS tools. Sun et al. (2018) pointed out that digital empowerment activities are the key to platform functionality, and only by designing smooth information, logistics, and capital flow channels can the business ecosystem structure be built. Zhou et al. (2018) explored the influence of platform enterprise data empowerment on the process of value co-creation and found that it can guarantee the success of this process. Value co-creation is a dynamic process that progresses through a pilot stage, replication, and expansion, and the integration of connectivity, intelligence, and analysis abilities can promote the interaction and cooperation between the platform and the bilateral market. Based on research into the decision-making mechanism between e-commerce platforms and multiple retailers, Xiao et al. (2020) showed that digital empowerment platforms can effectively help retailers improve operational efficiency, and the more retailers on the platform, the higher the profit each retailer will get. Mei et al. (2021) revealed how the mechanism of digital platform architecture design can empower the innovation of complementors based on the perspective of architecture design and the characteristics of digital technical data, such as homogeneity, editability, re-programmability, distribution, and self-reference. Wang (2021) explored the internal logic of cross-border e-commerce platforms that empower MSMEs by combining the idea of platform empowerment in the context of the digital economy with research into the internationalization of MSMEs. Miao et al. (2022) proposed a service-oriented digital platform based on digital infrastructure and explored the limitations of the single-dimensional approach to empowerment on the platform. This can provide traditional organizations with an all-round empowerment mechanism spanning internal and ecological resources and general and personalized abilities, by assessing the technical infrastructure through different dimensions.

2.3 Innovation of MSMEs

2.3.1 Factors influencing MSME innovation

MSME innovation is affected by many factors. We examine the influences of the macro-economic environment, meso-market characteristics, and micro-enterprise attributes.

National legal norms, institutional systems, macro policies, and financial environments differently affect the technological innovation abilities of MSMEs. Countries or regions with sound legal systems typically produce enterprises with high levels of technological innovation (Caprio et al., 2020). To promote its national innovation strategy, China has implemented reforms to its science and technology base and introduced various patent funding policies to facilitate the technological innovations of MSMEs (Zhang et al., 2018). Tian (2021) examined Japan's *Act on Temporary Measures for the Promotion of Machine Industry*, and his research results showed that such industrial policies could provide better support for MSME innovation. Li and Xiao (2020) based their data research on industrial enterprises and showed that despite posing challenges, environmental policies can encourage enterprises to innovate through green technology.

At the meso level, the technological innovations of MSMEs can be affected by factors such as the product market, banking competition, and regional technology incubators. Cao et al. (2009) found that rising labor costs and the falling external demand caused by market competition will hinder

SMEs in their technological innovation. Li et al. (2016) suggested that product market competition leads to market uncertainty and increased risk, resulting in risk-aversion behavior by MSMEs and impeding the sustainability of technological innovation. Other studies have indicated that increased competition in the banking industry can improve enterprises' technological innovation ability through addressing the financing constraints they face (Zhang, 2019). The excitation effect is particularly apparent in MSMEs and private enterprises, as shown by Wang et al. (2019). They conducted research on MSMEs in Haidian Science Park and revealed that technology incubators promote the technological innovation of MSMEs by improving human capital, easing financing constraints, and accelerating the transformation of scientific and technological achievements.

At the micro level, enterprise ownership and size, human resources, and digitization have a significant impact on the innovation performance of MSMEs. Yu et al. (2019) researched unlisted firms in the Chinese Industrial Enterprise Database, and revealed that the privatization of state-owned enterprises can hinder technological innovation. Cai (2019) found that enterprise size is positively related to technological innovation but negatively related to innovation policies. The negative correlation is not conducive to MSME development. Pei et al. (2006) indicated that MSMEs pay insufficient attention to human capital and do not recognize its innovative potential, which seriously hinders their technological innovation engagement. Shen and Yuan

(2021) found that the internet transformation of enterprises could improve their technological innovation capabilities, and significantly benefit MSMEs and other low-productivity enterprises.

2.3.2 Difficulties faced by MSMEs in terms of innovation

MSMEs have a great potential for technological innovation. However, in real economic environments, the problems of capital, technology, talent, and information present many challenges, so further stimuli of MSME technological innovation is required. Based on the literature, we summarize the main issues concerning MSME innovation.

Financing constraints. For MSMEs, innovation is an activity that requires high investment but involves great uncertainty. As MSMEs are vulnerable to financing channels and financing costs, innovation requires stable and abundant capital investment as the basis, and financing constraints are often a stumbling block for technological innovation. The particular treatment MSMEs receive in terms of financing channels, costs, and opportunities often discourages them from innovation (Brown et al., 2012). They may find it difficult to obtain initial loans and may encounter high financing costs and limited financing channels (Zhou, 2022).

Asymmetric information. MSMEs are often at a disadvantage due to the information asymmetry stemming from limited information channels and abilities to acquire information. This asymmetry may affect enterprises' technological innovation (Tan et al., 2016). MSMEs are unable to build information service platforms, and the few existing platforms and incubators for MSMEs are unevenly distributed. MSMEs often lack market-oriented approaches and effective targeted service capabilities, so they may find it difficult to engage in R&D consulting and information exchange, thus limiting how they can share services for innovation. In addition, information intermediary services are relatively underdeveloped, as are information consultation and disclosure services, legal aid, and other aspects. MSMEs thus find it difficult to locate suitable information services. The external markets and technical information available to MSMEs are thus often insufficient, and the internal exchange of R&D information is obstructed. This inhibits the technological innovations of MSMEs.

A lack of innovative talent. Technological innovation activities require the support of professional R&D talent and innovative teams, but access to talent is often limited, and only a few have innovative teams or platforms. This restricts their technological innovation (Zhou, 2022). Due to limited financial resources few MSMEs can offer competitive salaries and benefits, and thus they encounter the dilemma of struggling to attract, recruit, and retain high-level talent, experts, and scholars who can provide innovative input. In addition, the turnover rate of innovative talent in MSMEs is higher than that of larger enterprises, which further aggravates this problem. Many MSMEs have inadequate professional training systems and do not pay sufficient attention to training. Thus, they find it difficult to improve the quality of internal innovative talent and develop effective systems for passing on experience and skills to new generations. This shortage of innovative talent leads to a shortage of innovative technology and products, which seriously restricts the technological innovation ability of MSMEs.

2.3.3 Characteristics of innovation of MSMEs

I identified the characteristics of the innovation activities of MSMEs after consulting the literature and practice. The problems found include poor foundations, a lack of ability, and insufficient motivation. I discuss these in detail below.

(1) Lack of systems to promote technical accumulation and technological innovation. First, MSMEs rarely establish complete systems and have no time for self-inspection, due to intensified market competition. Second, they seldom have long-term strategies, especially in terms of technical development, which results in a lack of clear goals and implementation paths for the accumulation of technical skills and innovation. Third, they lack incentives due to the inadequate cultural atmosphere involving the encouragement of innovation. Finally, they lack effective knowledge management and technology management systems, which makes it difficult to sustain spontaneous innovation.

(2) Weak basic abilities. Technical accumulation and technological innovation need the support of corresponding basic abilities. Due to their lack of ability, funds, necessary facilities, and technical skills, MSMEs may not be able to fully digest and absorb advanced technology even if they have access to it. Ongoing investment in personnel training and knowledge management will overstretch them. These limit their initial accumulation and innovation of technologies.

(3) Technical accumulation can be insufficient to promote innovation. Technical skills and technological innovation require continuous investment but take time to generate benefits. This leads to a lack of motivation for MSMEs short of resources and who struggle to survive to accumulate and innovate technologically. MSMEs may be worried about the training costs caused by staff wastage and may overlook the long-term training and development of employees.

2.4 Platform empowerment and MSME innovation performance

Empowerment in manufacturing enterprises can provide value in terms of efficiency, novelty, and complementary resources (Zhang et al., 2022; Chen et al., 2021). In terms of efficiency value, a platform architecture approach based on information modules can help to coordinate the efficient development of standardized products and the inefficient development of customized products, thus improving the efficiency of the overall business model (Cenamor et al., 2017). Control innovations based on IoT and smart devices (Bjorkdahl & Holmen, 2019) can enable flexible manufacturing and mass customization, which is characterized by punctuality, dynamics, flexibility, and precision (Sun & Su, 2018). In terms of novel value, interpretation technology, or the ability to leverage big data analytics to gain insights and develop data-driven innovation (Coreynen et al., 2017), can help to establish a twin digital model based on both workshop big data analytics and debugging (Cagliano et al., 2019). Customer data can also be mined and more innovative products, remote services, and predictive services (Coreynen et al., 2017) can be developed. Manufacturers can integrate complementary external resources and enhance enterprise innovation through open platforms, such as Haier's open innovation platform and Volvo's digital service platform. In terms of complementary value, connection technologies, such as connected IoT, open information systems, wireless communication networks, and intelligent products, can connect participants in the ecosystem, strengthen the exchange of complementary resources and value co-creation, and then build business models centered around such complementarity (Saadatmand et al., 2019).

Novel value can be viewed as a reflection of improvements in innovation (Coreynen et al., 2017). However, the effects of these empowerment mechanisms on the innovation performance of MSMEs have rarely been theoretically or practically explored. Thus, we propose a positive relationship between platform empowerment and the innovation performance of MSMEs.

2.5 Inadequate existing research

Through a review of the literature, no single definition of platform empowerment has been established, but some consensus has been reached in terms of its characteristics. **First, in terms of the empowerment basis, a platform can perform the key functions of bridging resources, elements, products, and services in a bilateral framework, due to its core position and resource integration ability in the value network.** The platform can allocate supply and demand resources as it is a hub of network nodes, and the endogenous structure of platform-empowered sharing is at the network core of platform enterprises (Zhang & Lin, 2019). This hub position brings advantages in terms of control and information, supports its gathering, obtaining, and re-integration of internal and external resources, and allows users and enterprises to access complementary resources and services. Users of different network nodes can then better meet market demands. **Second, platform empowerment is a dynamic and purposeful process.** The co-creation of value for the platform and the enterprises is realized in the process of pursuing dynamic resources and the cultivation of common value goals and feedback. Platform empowerment facilitates the dynamic evolution of enterprise resources and abilities, drives the transformation of organizational orientation, and improves business co-creation capabilities. Enterprises are then encouraged to develop innovative business models (Ramaswamy & Ozcan, 2016; Kohtamaki et al., 2019). Innovation through collaboration and business model transformation then support the platform and realize its opposite advantages based on the demand side (Wang & Cai, 2018), thus enhancing the platform's capabilities.

In addition, the focus of empowerment research has shifted from intra-organization to inter-organization, and the research scope has also been expanded from the employee level to the organizational level and even the industry level. **However, the mechanism of service-oriented manufacturing platforms empowering customer enterprises has not been fully explored.** I suggest that the mechanism of platform empowerment is mainly reflected in production output factors and transaction matching, in which the former illustrates that manufacturing-oriented service platform enterprises are integrated production and service entities with interconnected attributes. This highlights that enterprises can pool the industrial resources required for diversified organizational development through the network hub aspect and the openness of resource links. Current industrial internet platforms integrate industrial thinking, capabilities, and models, and involve a combination of cloud computing, big data, and artificial intelligence. Empowerment through data has been extensively discussed in academia. Transaction matching suggests that manufacturing-oriented service platforms are bilateral trading platforms, which have an intermediary role in promoting the matching of supply-side and demand-side transactions. This role is typically realized through resource matching and transactions on online platforms for enterprises and through interactive customer interfaces.

Third, the characteristics of empowered enterprises should be

considered in more detail. These include the various services provided to customers by platforms, and the empowerment of MSMEs via platforms will be affected by the volume of customers, their positions in the industry, learning ability, and the relationship between customers and platforms. This study proposes that different customers have different needs, and thus the modes of empowerment will also differ.

3 Case Study of a Service-Oriented Manufacturing Platform that Empowers MSMEs

3.1 Case selection

The selection of a single case should meet both typical and heuristic requirements (Eisenhardt & Graebner, 2007). In this study, the company Bering3D Technology was selected as a representative service-oriented manufacturing platform enterprise through theoretical sampling. The company has the characteristics of typical cases, and its successful practice has significance in the current innovation ecosystem context.

Bering3D Technology is a platform enterprise dedicated to the application of 3D printing technology. Established at the end of 2019 with a registered capital of 17.255 million yuan, it completed Series A financing and developed a professional internet service platform for 3D printing technology (www.bering3d.com). In 2021, the company's sales of 3D printing services reached nearly 20 million yuan. In terms of its establishment time, development scale, financing stage, and team maturity, the company is considered to be at the median level of service-oriented manufacturing platforms for 3D printing technology in China. It thus offers a typical case.

As the founder and chairman of the company, I am responsible for its strategy formulation, investment and financing, senior talent recruitment, international ecological cooperation, resource integration, and key account project cooperation. Thus, I was able to obtain first-hand data and ensure its authenticity and accuracy, due to my long relationships with the interviewees and my close communication with the co-founders/executives (before the inception of Bering3D Technology, I worked alongside the other core members at SHINING 3D).

The extent to which platforms empower customer enterprises is also a key factor in case selection. Most of the numerous Chinese enterprises engaged in 3D printing services are in the initial stage, in which they are still exploring customer enterprise empowerment through trial and error, so they are not as representative. The core team of the case study enterprise has more than 10 years' experience in the application of 3D printing technology. They understand the 3D printing application needs of enterprises in different fields and locations and of different sizes, including hardware, software, and materials. Bering3D Technology operates under the concept of "flexible manufacturing, intelligent manufacturing, and shared manufacturing" to meet the needs of personalized services. Based on the platform technology of "3D printing + internet + IoT + AI," it combines an internet platform with the offline 3D printing supply chain to provide comprehensive solutions featuring "online and offline integration, AI and IoT, design-driven leadership, and national layout support." Headquartered in Weihai, Shandong Province, the company has branches in Guangzhou, Hangzhou, and Yuncheng. It has established strategic cooperation with most of the world's leading 3D printing suppliers to serve China's personalized customization market with advanced hardware equipment and application experience. Thus, it fully demonstrates its value support in the industrial ecology.

Bering3D Technology also has experience of cross-industry and regional innovation, which can inform its platform empowerment mechanism. Its core team has engaged in 3D printing for more than 10 years. When the team worked for SHINING 3D, they helped to develop multiple 3D printing technology innovation and application centers in Chongqing, Weihai, Hefei, Foshan, Wenzhou, Shaodong, Yangzhou, Pengzhou, Rizhao, Nanjing, and elsewhere. In terms of serving the industrial ecology, Bering3D Technology fully identifies the technical needs of various industries for 3D printing. It has also set up local operating companies, teams, and professional talent to make full use of its internet platform and empower local enterprises. For example, Bering3D Technology has long-term cooperative relationships with many universities, research institutes, and medical institutions in China, thus accumulating extensive links to the fields of education and medical care. In terms of supporting regional innovation, Bering3D Technology tailored the construction of its service center according to city-specific industrial structures and future development plans. The company has established long-term strategic partnerships with many well-known manufacturers in the global 3D printing field, such as HP, Materialise, SLM, and DSM, and thus has direct access to the world's most advanced 3D printing resources.

Finally, the demand faced by the enterprise in its present development stage also informs research. Bering3D Technology has gone through its initial founding process and serves an increasing number of large and small customers, including new "mom-and-pop" factories, small and medium-sized technology enterprises with about 20-200 employees, and large companies with 500, 1,000, or more employees in the fields of automobiles and home appliances. Its customers include upstream enterprises, downstream integrators, and end users. Thus, the levels of enterprise empowerment required vary widely. Through our communication with customer enterprises, we are aware that the provision of personalized 3D printing products and services is not currently sufficient, as customers seek empowerment through technology and information. Any empowerment Bering3D Technology offers customer enterprises is based on its internal system support and cost investment. What empowerment methods should be offered to different enterprises? How can close cooperation between platform enterprises and customers be developed, for their mutual development? What can be done to more effectively promote the innovation of customer enterprises? Addressing these questions can provide inspiration and guidance for the enterprise's future development.

3.2 Data collection

Since the company's inception, the founders have ensured that the team collects and organizes various forms of data, thus facilitating data collection for this study. I incorporated the perspectives of the company's administration and assistant team to ensure that the data collection was objective. The data were collected through in-depth semi-structured interviews, internal corporate documents, and immersive on-site participation.

When conducting the semi-structured interviews, my team and I used snowball sampling and finally selected 15 people for face-to-face or online video interviews. These included corporate co-founders, executives, and core participants, such as department and business heads. In addition, 12 project leaders of customer enterprises served by Bering3D Technology were selected for interviewing, to provide a third-party perspective to illustrate the process and outcomes of Bering3D Technology's service projects. The interviews focused on the goals of value support, the specific support process, and the final result of value creation. We compared third-party interview information with the first-hand interviews and secondary documents provided by Bering3D Technology for triangular verification. The case analysis data sources are shown in Table 3.1.

In addition to the interview data, which is the primary source, information was also collected from various in-house project records, including the minutes of meetings since the founding of the enterprise, my speeches at shareholder meetings, e-mails I sent as the founder of the company to the partners, partners' meetings, and corporate promotional presentations. These documents provided key information that was difficult to capture through interviews. After comparing and verifying the information from these sources, we conducted supplementary interviews to clarify any doubts or fuzzy information, which improved the entire data collection process incrementally.

As founder and manager, I have a broad understanding of the company's actual situation. I could identify whether the collected data were problematic and correct accordingly. My speeches and internal e-mails were included as first-hand material in the data collection.

Table 3.1 Data Collection

First-hand Information		**Interviewee**	**Interview Content**	**Interview Time**
	Bering3D Technology (case enterprise)	CEO(F1)	Development history, strategy changes, phased planning, business models, development bottlenecks, etc.	2020.11.23; 2022.05.16
		2 founding partners (F2)	Development history, enterprise development bottlenecks, future planning and outlook, business development situation, etc.	2020.11.24; 2022.05.16

		5 department executives (F3)	Enterprise department setting, rights and liabilities, current operational situation, and platform construction	2021.12.13; 2021.01.02
		8 business managers (F4)	Project development process, customer enterprise service content, difficulties in project implementation, etc.	2021.12.13
	External stakeholders	12 project leaders of customer enterprises (K1)	Project objective setting, cooperation content, supporting process, final delivery results, etc.	2021.12.13
		5 senior executives of partner enterprises in the industrial chain (C2)	Industrial chain cooperation mode, cooperation interaction process, cooperation results, etc.	2022.01.02
Other materials	24 external project introductions; 21 internal partners' meetings, strategy planning, and shareholders speeches; 33 educational training courses materials (D1)			

The data analysis process was iterative and focused mainly on specific behaviors and the characteristics of value support. When initially coding the case-related material, we first aggregated the sub-directories of the summary constructs in the literature and then coded and marked the new findings. We highlighted any uncertain items in the interviews, to determine the high-level coding structure to which they belonged. Throughout the coding process, we compared the classifications with those in the literature and adjusted the location and definition structure of our sub-items.

3.3 Case analysis

3.3.1 Background

Bering3D Technology's business model centers on the supply chain, platform operation, and sales. By integrating industrial resources, the supply chain provides solutions to customer enterprises in the form of platform products. The supply chain team then transmits product information to the platform operation team, which then converts the information into a "platform language" for online promotion and operation, to enhance brand visibility among target customers and attract them. The sales team then directly communicates with customer enterprises to learn about their needs and works with the operation and supply chain teams on providing comprehensive solutions. In this process, three teams work closely together, and the sales team is responsible for investigating and analyzing customer enterprises and for determining their short-, medium-, and long-term needs. Through products and services, personalized customization helps to establish trading relations, information exchanges that ensure frequent communication with customers and maintain customer stickiness, and technical support. Bering3D Technology has the trust and compliance of customer enterprises through talent training and technology output and thus maintains stable and long-term relationships with customers. Bering3D Technology's external value support business can be viewed through online and offline aspects.

Online business. Bering3D Technology's internet platform is a comprehensive and professional platform for 3D printing, which provides services such as product quotations, order payments, and order distribution to its customers. It also offers expertise in 3D printing technology, materials, and post-processing. The latest applications are updated for the industries its various customer enterprises are within, thus providing various types of learning resources. By integrating supply chain resources, Bering3D Technology creates strategic partners characterized by “single technology and single material.” Process- and material-related data (e.g., feature descriptions, case presentations, product pictures, production videos, etc.) are then collated and uploaded to its platform, and the operation staff edit these into other formats for whole-network promotion. The generated business opportunities can then be directly accessed by its sales team to take orders. The specifics of these orders (e.g., industry, customer, product, problem, etc.) determine how the customers are characterized, to understand their industries and needs. The platform operation team and the content department of Bering Academy collect, collate, and share the latest news, cases, and applications in the global 3D printing industry daily.

The business process of Bering3D Technology was analyzed from the perspective of the customer enterprises. When they require 3D printing services, they have two choices. They can directly communicate with Bering3D Technology’s business personnel if links have already been established, for example via telephone or WeChat, and obtain services offline.

They can otherwise visit Bering3D Technology's internet platform to request business services. In this process, they also face two situations. First, if they are familiar with 3D printing technology and have a complete standard 3D data model for product printing, they can directly obtain intelligent quotations and complete payments on the platform. The platform system will then automatically distribute the orders to specific factories for processing and production, and customer enterprises can monitor the process in real time through an app. Second, if no complete 3D model is available, design requirements can be established through the "Alliance of Designers" on the platform. In this process, the platform provides a trading location that can facilitate transactions between customer enterprises and designers registered for the Alliance. When the selected designers have completed the 3D product model design required by the enterprises, the process can proceed with an intelligent quotation, payment, order distribution, and production on the platform, following the above steps.

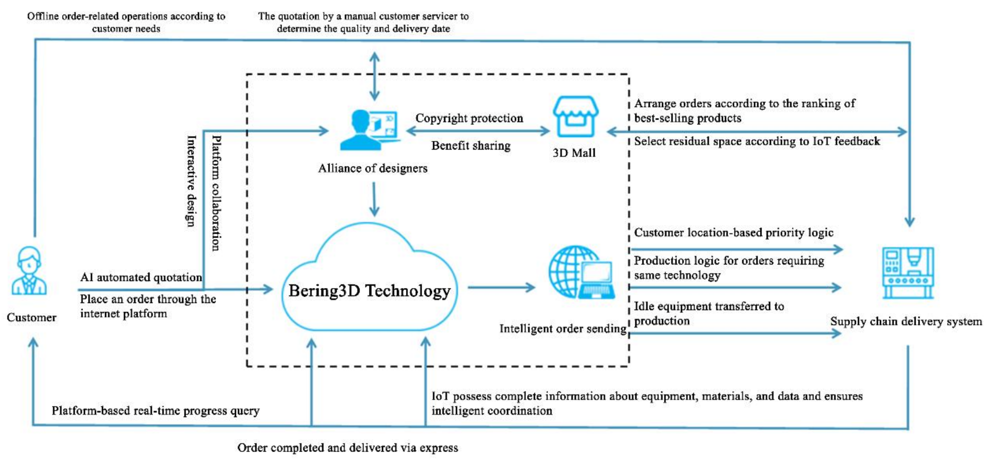


Figure 3.2 Bering3D Technology's Online Business

Two types of partnerships between designers and Bering3D Technology's platform can occur. First, after designers register for the Alliance of Designers, they can publish their personal information on the platform, including but not limited to personal resumes, works, and working tenure. When any customer enterprise on the platform needs a 3D model design, it can look for a suitable designer on the Alliance of Designers page. It is thus an order-receiving platform for designers, similar to that of an intermediary market, but it does not charge an intermediary fee. Second, in addition to accepting orders, designers can display and sell their creative works on the "3D Mall." If customers are interested in these products, they can place orders and pay online. The platform will then send the orders to the supply chain system to complete production and product delivery. They distribute the profits according to the agreement with the designers. According to the platform rules, the products that designers upload, display, and sell should mainly have lengths, widths, and heights of within 5 cm, such as jewelry, dolls, and small ornaments, because these are easy to produce by factories on the platform's supply chain alongside large-size industrial products. This approach can give full play to the technological advantages of 3D printing. The original processing time, manpower, and the consumption of water and electricity remain unchanged, and artistic and creative products can be produced for the same cost as industrial products, thus providing additional earnings.

This manufacturing of personalized products for the same costs as mass production is the key to profitability on the platform and illustrates the advantages of internet platforms. First, the platform's network-wide marketing has attracted many customer resources, so it receives more orders than traditional offline factories. When it has enough orders, the platform can distribute those that require the same technology and same materials to a single piece (type) of equipment for centralized production through the intelligent order-distribution system. In terms of 3D technology, such orders can be completed collectively, no matter what the product shape, size, quantity, and degree of individuation. Therefore, the intelligent order-distribution system assesses the extent to which the orders match the equipment in terms of technologies and materials. Second, the platform will as far as possible send orders to supply chains near the customer enterprises' locations to save logistics costs and time. Realistically, if an enterprise chooses to produce products using 3D technology, it is usually in urgent need of the product and thus the delivery time is very important, and the requirements increase accordingly.

In the supply chain, the full use of the equipment for any order is crucial to the profits of the factories. Thus, after a supply-chain enterprise and the platform establish a cooperative relationship, the enterprise will no longer assign its limited resources to manufacturing products that need specific technologies and materials, but use them for single-technology or single-material production. By streamlining the production process as far as possible, it can reduce the number of technicians and operators and improve its order-undertaking capacity for single-technology or single-material production. This promotes positive interactions between the enterprise and the platform and the process is more scientific, more effective, and cheaper.

Offline business. Bering3D Technology has built relationships with leading domestic and overseas enterprises and institutions involved in 3D-printing hardware, software, materials, application R&D, and other relevant fields through transactions, cooperation, and alliances. The company's business and technical teams also provide offline services, such as technology, publicity, application training, and experience-sharing, on regional service platforms or at customer enterprise gatherings, to offer them learning resources and opportunities. Since its establishment 2 years ago, Bering3D Technology has developed 105 supply-chain service providers in the Yangtze River Delta, Pearl River Delta, and core cities in central China, including Kanhoo, Xinsiwei, Zhanmeng, and Junchen. It therefore has achieved full coverage of core cities in China's central and eastern regions and provides conditions for the localized delivery of platform products. Bering3D Technology integrates resources in the government and education systems through "government-platform cooperation" and the "Bering Academy," respectively, and it has established a comprehensively open and collaborative mechanism that covers the government, industry, research institutions, schools, and enterprises in policy, talent training, and industrial development.

Its internet platform features openness and collaboration, which are reflected in the functional design and external cooperation of the platform enterprise. The main line in the platform's offline business chain is the "Customer-Business/Customer Service-Production Center-Supply Chain," which undertakes most of the daily communication, acceptance, distribution, and delivery of offline orders. All communication about orders is completed through the business/customer service team. When it can confirm an order independently, it can directly confirm the contract with the customer enterprise and send the order to the production center for subsequent distribution and production; when the team encounters any technical difficulties in the order, it can mobilize resources from the technical center for technical support.

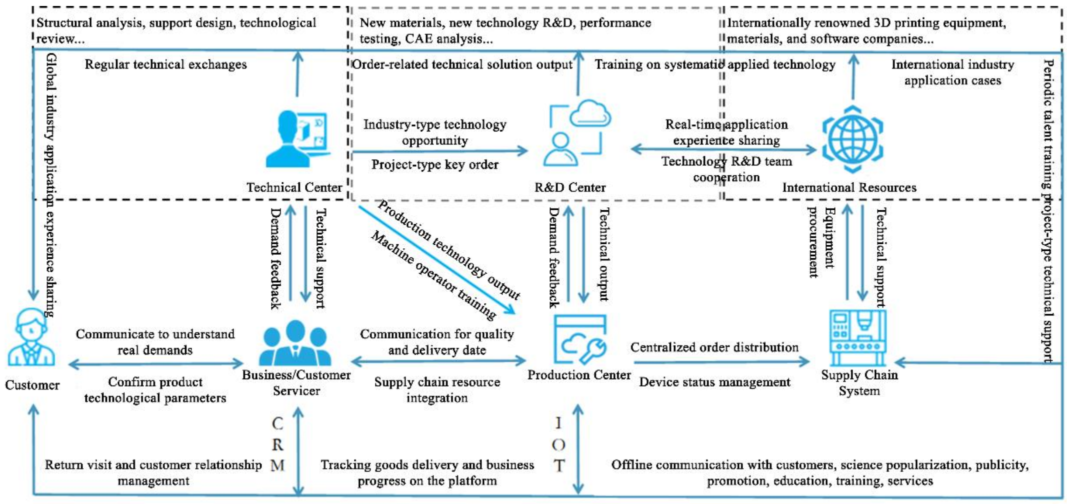


Figure 3.3 Bering3D Technology's Offline Business

The production center is responsible for the overall coordination of customers' orders. It accepts and distributes orders, schedules and coordinates production, follows up on production progress, responds to customer complaints, and undertakes other chain-related tasks. The production center organizes technical review meetings with the technology center and the R&D center from time to time. Frequently-occurring technical problems in previous order production are discussed in meetings and assigned to the technology center and the R&D center for research, to determine whether there is a need to organize technical training or set up key technical projects.

As a supporting department, the technology center undertakes technical support, transformation, and training work for the company's business and production. It is also responsible for the technology-related work of the company's R&D center, including establishing technical trends and opportunities and promoting key projects. The technology center's technical support and training are offered not only to the business/customer service department but also for the operators of the production center and even for customer and supply-chain enterprises, according to their business needs. Through the empowerment of the relevant personnel in customer enterprises and supply-chain enterprises, the technical capability of the ecosystem can be comprehensively improved, thus enhancing the efficiency of subsequent communication and identifying further business opportunities.

The R&D center focuses on the application and development of 3D printing technology. This does not involve the specific R&D of hardware, software, and materials, thus enhancing mutual and complementary approaches and promoting close strategic cooperation with ecological enterprises. The application and R&D of 3D printing mainly focuses on how customers in different industries use 3D printing technology to address unsolved problems and achieve greater efficiency with lower costs in specific realistic scenarios. Information is vital to the work of the R&D center. The technology center will pass on any technical information in the market it collects to the R&D center and the production center will regularly send information about trends in customer demands to the R&D center. The international resource department monitors hardware, software, materials, applications, and other information in the global 3D printing field. Based on the information received, the R&D center co-ordinates, analyzes, and arranges key R&D work. It offers comprehensive solutions that end with the final delivery of products according to the needs of specific industries. The solutions include the selection of hardware, materials, and printing technologies, the setting of technical parameters, the selection of post-processing technology, and in-process aspects that require attention. The R&D center analyzes and introduces any new technologies and processes to corresponding domestic customer enterprises, empowering them with both technologies and information and greatly improving their innovation performance.

The supply chain system is an important supporting aspect of the platform's production center, and mainly consists of numerous 3D printing service factories (including a few machining and post-processing factories) that the platform has signed strategic cooperative agreements with. These factories can provide 3D printing services for customer enterprises. They are both competitors and partners of the platform. Their main reasons for entering into strategic cooperation with the platform are as follows.

1. 3D printing features multiple technologies and the use of multiple materials, but customers often need one-stop services. 3D printing involves various technologies, such as SLA, SLS, MJF, and DLP, each of which requires a different type of machine. In addition, even single-technology or single-equipment production needs materials of different types and sizes. A specific 3D printing factory, however, can only use limited equipment at one time. Thus, with certain technologies and materials, the factory can only undertake specific orders. Ideally, the factory can realize full-load production using its own equipment, technologies, and materials and at its unit production capacity, so it can make the best use of its equipment and maximize its profits. However, this is usually difficult to realize. Although a factory can choose its equipment and materials, it cannot choose its orders, and the real needs of customers may not entirely be in line with its ideal processes. The needs of customer enterprises basically determine the technologies and materials to use, and these will not be changed according to the equipment and materials of the 3D printing service factory. Realistically, 3D printing service factories cannot undertake many orders from customer enterprises, and the enterprises are unwilling to (or will not) distribute their orders to different factories. In this situation, neither side knows what to do next. 3D printing internet platforms

such as Bering3D Technology can fix this problem. All of the needs of customer enterprises can be satisfied by the platform. After a platform receives an order, it can decompose the order by technical means and send different parts to different supply-chain factories according to the processes and materials. After the factories get their respective “decomposed” orders, they can quickly arrange the production and finally deliver all products with high quality. In the process, the platform’s cooperative 3D printing service factories do not need to dispatch business and technical staff members but only require one person to receive information from the platform and arrange the production. Thus, the whole production process can proceed smoothly, with each link taking its own responsibility and all links jointly providing services for the customer enterprises.

2. The aim is to reduce the number of technicians, improve the utilization rate of the equipment, and consider all of the costs involved in terms of the weight proportion of actual products to print through the printing cabin. After a 3D printing service factory establishes a long-term relationship with the platform, the platform will provide more than 70% of the factory’s orders. In addition, the platform can automatically distribute and arrange orders and check accounts, bringing greater convenience to the 3D printing service factory, and thus the factory can completes its daily production tasks with only one or two technicians and operators. With enough orders, the 3D printing service factory can gradually adjust its equipment technology and materials

for single-technology and -material production, and further standardize and streamline its production process to minimize costs. The factory can thus finalize customized orders through an industrialized and large-scale management approach, and gain high profits. In addition, the factory will no longer worry about losing customers if they do not meet all of their needs (orders from customers that require other technologies and materials will be allocated to other suitable factories by the platform). Every use of 3D printing production equipment involves fixed labor, water, electricity, and depreciation costs. The factory's profits often depend on the operation rate of the equipment and the weight proportion of actual products to print through the printing cabin. The factory can make substantial profits, as long as it increases the equipment operation rate as far as possible and maximizes production each time. Without the order distribution of the platform, the factory cannot obtain stable sources of single-technology and single-material orders.

3. This represents a virtuous circle and is an inevitable trend in terms of division of labor. Although 3D printing technology is powerful, the service factories cannot do everything. As the division of labor is increasingly specialized, it is obviously unscientific and unrealistic to expect all customer problems to be solved by a single factory. This would be like expecting a small general store to satisfy the shopping needs of a whole community. The strategic cooperation between service platforms and 3D printing factories can be compared to that between large supermarkets and supply chains. Orders

needing different technologies and materials are allocated to factories with corresponding production capacities, while the delivery cycle is shortened as much as possible according to the principle of proximity, to serve customer enterprises in a systematic manner. This forms a virtuous circle and maximizes social benefits.

3.3.2 Analysis of the service-oriented manufacturing platform of the case enterprise

As noted, Bering3D Technology's technical base features "3D printing + internet + AI + internet of things (IoT)." By aggregating and integrating resources, such as hardware, software, materials, and post-processing resources, in the 3D printing ecosystem, it empowers numerous MSMEs through the "service + product" mode. It realizes ubiquitous connections, a flexible supply, and the dynamic and efficient allocation of various production factors. It also promotes the construction of a digital business ecosystem and fulfills the functions of a manufacturing platform. Bering3D Technology has also attracted many upstream and downstream partners in the 3D printing industry, who have registered on its service platform where they can share needs in real-time. This, combined with the information empowerment of customer enterprises by the Bering3D Technology platform, can address information asymmetry and provide customer enterprises with the ability to quickly integrate industry-needed resources. The platform has also changed the traditional non-interconnected operational mode in the industry, realized the complementarity of the interests of different customers, and spawned new business models.

Through the “service + product” mode, Bering3D Technology provides comprehensive solutions for customer enterprises, fully demonstrating its service attributes. To expand its customer base and synchronously develop with its customer MSMEs in a sustainable and stable fashion, Bering3D Technology continues to integrate services into products. Unlike the offerings of traditional suppliers, this adds value to the products and enhances the competitiveness of its platform, while providing products for customer enterprises by meeting their needs. As the number and stability of customer enterprises increases, the customer repurchase rate and the per-customer transaction amount increases, which will in turn empower platform enterprises, increasing their industry influence and enhancing their ability for resource integration and collaboration, thus forming a positive cycle.

In terms of the structural elements of service-oriented manufacturing platforms, Bering3D Technology demonstrates numerous platform-based features in its organizational design. The comprehensive application of digital, information-based, and intelligent approaches provides the conditions for Bering3D Technology to integrate various 3D printing ecological resources. With the focus on 3D printing technology applications, the platform also creates room for interactions and cooperation with ecological enterprises engaging in hardware, software, materials, and post-processing. The long-term investment in content and customer operations attracts many customers to the platform. The comprehensive and long-term empowerment of customer enterprises stimulates business in the industry, and the resource scheduling and integration of the whole ecosystem are completed through business orders.

Bering3D Technology's service platform does not only focus on 3D printing technology. Its various 3D printing equipment factories offer a full range of technologies and materials in the supply chain system. In addition, it integrates numerous traditional machining factories engaging in turn-milling, planning, grinding, painting, and electroplating technologies. In terms of product processing, Bering3D Technology's ultimate goal is to solve customers' practical problems in an efficient and cost-effective manner. It selects appropriate approaches and provides comprehensive solutions according to customers' needs, in terms of technology, process, cost, delivery time, and other aspects. Thus, the industrial internet platform represents Bering3D Technology externally, while manufacturing is at the core. In addition to manufacturing, Bering3D Technology combines traditional production technologies and 3D printing technology to offer the best manufacturing solutions through the integration of technical features and functional advantages. The resulting information, technologies, and products will then serve customer enterprises, accelerate the development of the whole industry, and improve the innovation performance of the enterprises.

In terms of business customization, Bering3D Technology's service-oriented manufacturing platform has various significant structural elements. First, the characteristics of 3D printing technology are the foundation for Bering3D Technology's personalized and customized services. These services distinguish Bering3D technology from other manufacturing platforms. Second, in a broader sense, Bering3D Technology empowers customer enterprises in a customized manner, in addition to technological solutions. To provide comprehensive solutions, the company must first collect information, including customers' industry attributes, characteristics, scale, positions in industrial chains, and pain points. It can then create solutions that satisfy the actual needs of customers in aspects such as cost, efficiency, and experience. As all customer enterprises differ, the nature of Bering3D Technology's empowerment will also be different. Small-scale personalized products and services are offered, combined with the broader empowerment through information and technology. It can therefore fulfill the coordinated development with customer enterprises and enable them to enhance their innovation performance. Hence, Proposition 1 is proposed as follows:

Proposition 1: Bering3D Technology's 3D printing technology application service platform is a service-oriented manufacturing platform.

3.3.3 The mechanism through which the service-oriented manufacturing

platform empowers MSMEs leading to innovation performance improvement

This study's focus is on the mechanism through which service-oriented manufacturing platforms can empower MSMEs to improve their innovation performance. After examining the specific service paths of the case enterprise, we found that the core purpose of Bering3D Technology's empowerment of customer enterprises is to provide products and services for them (i.e., product empowerment). This is required for real business connections to be developed and for sales to be finalized. Only after the platform makes sales for customer enterprises can it obtain revenues from products and services. However, any sale is a full-link process, which requires much pre-sale work by the platform to attract more customers and improve the conversion rate of sales orders. In this process, the operational work including publicity, science popularization, display, promotion, training, and exchanges is of great importance. Platforms establish relations with customer enterprises and increase the likelihood of sales through information empowerment. Through technology empowerment, the customer enterprises recognize the value of the platform, and thus it gains sales and orders. Therefore, the platform must empower customer enterprises through information and technology so that the platform can complete sales orders and improve performance.

Platform enterprises want more than orders and aim for sustainable cooperative relations with customer enterprises, as only through this can platforms offset their initial customer acquisition costs and create additional benefits. Platform enterprises must therefore know how to effectively improve the stickiness of customer enterprises and raise their repurchase rates and average per-customer transaction amounts. To address this problem, the platform should take the perspective of the customer enterprises, be aware of their real needs, identify their pain points and establish strong complementary relations with them to ensure a win-win outcome. In the current Chinese market, many MSMEs are faced with the same problem: How can they improve their core competitiveness, innovate technologically, and enhance their innovation performance? By effectively improving the innovation performance of customer enterprises, platform enterprises can more easily establish long-term cooperative ties with their customers. In addition to considering their perspectives, they must understand the industries of customer enterprises, such as the status of 3D printing technology application at home and abroad, and gradually empower customer enterprises, according to their positions in their industries and their abilities to absorb knowledge. Information, technology, and product empowerment are often completed alternately or simultaneously. Platform enterprises establish business relations with customer enterprises through information and technology empowerment, acquire sales orders from them through technology and product empowerment, and maintain close ties and increase the possibility of longer and larger-scale business cooperation with them through continued information and technology empowerment. Thus, service-oriented manufacturing platform enterprises such as Bering3D Technology have three specific mechanisms for empowering customer enterprises: technology empowerment, information empowerment, and product empowerment. Thus, Proposition 2 is proposed as follows:

Proposition 2: The three empowerment mechanisms that service-oriented manufacturing platforms can offer customer enterprises are technology empowerment, information empowerment, and product empowerment.

In the following part, we introduce each mechanism through the specific practice of the case enterprise and its effect through the feedback of MSMEs.

（1） Technology empowerment

As a brand-new manufacturing technology, 3D printing has brought great changes to the R&D and production modes of customer enterprises. 3D printing is an intelligent and flexible distributed manufacturing technology that can provide customers with advanced production technology and more choices. Various combinations of hardware using different technologies, intelligent system software, and various materials can revolutionize the product design and development of customer enterprises from the source. 3D printing technology can also be applied in more fields to solve more problems according to user needs, as what supports the technology can be used to reconstruct the production flows, and can even extend to rethinking and improving the original design of products.

The technology empowerment offered to customer enterprises by Bering3D Technology is reflected in three aspects: technical translation, talent cultivation, and ecological supplies. First, Bering3D Technology acknowledges the bridging role of technical translation in conveying the technical needs of customers. The platform can identify the real needs of customer enterprises through interactions with them, translate these needs into the market demands of the industry chain, and convey them to the platform-built ecosystem. The head of the marketing center of Bering3D Technology agreed with numerous senior business executives and noted in the interview that “many customer enterprises only know their demands for the performance of final products, such as what scenarios the products should be used in, what the environment temperature should be, and how much pressure they can withstand, but they do not know the specific requirements for the technical parameters, for the production based on 3D printing technology (F3, F4).” No production unit can conduct production activities without clear technical parameters. Therefore, Bering3D Technology’s technicians serve as communicators and translators, who translate the real needs of customers into the specific technical parameters of the industry chain, such as the performance requirements for materials, the balance between printing speed and accuracy, and the printing size requirements of specific products. The head of an interviewed customer enterprise commented on this situation:

"They help us with technical communication on product performance, which is what we need" (K1). Second, during the in-depth technical empowerment of customer enterprises, the founder of the enterprise addressed the issue of feedback required in the process of solving specific practical problems, and reiterated in an internal meeting that "although most customers have been using this technology and have specific order needs, we still encounter a lot of technical problems, concerning data processing, material selection, technology selection (especially in multi-technology collaborative production), and post-processing details in handling specific orders." (F2, D1) To solve these problems, when communicating specific business orders, Bering3D Technology's business staff members "will give targeted technical explanations to customers and optimize schemes according to the demands and production situation of each order. Optimizing a scheme is often a complex process, which involves the selection of multiple technologies, the change of materials, and the application of post-processing technologies, among others, and its core purpose is to help customers better complete the production of products and achieve the best cost-effectiveness" (F4). An optimized product scheme can not only lower production costs but also better meet the actual needs of customer enterprises and improve the performance of products. Such improvements will directly enhance their innovation performance, particularly in the R&D of new products for customer enterprises.

Second, Bering3D Technology draws on its own talent base and cultivates technical talent for customers and the industry. Having worked in the 3D printing industry for more than a decade, the core members of Bering3D Technology are China's pioneers in the 3D printing service market and have rich industrial experience and knowledge. In addition, Bering3D Technology depends on its "technological base of 3D printing to cultivate professional and technical talent for the industrial ecosystem." When first recruiting employees, the company found that even graduates of the 3D printing major were sorely lacking in the general knowledge and operational skills required for the application of 3D printing technology. Thus, the company set up the Bering Academy internally, and has cooperated with multiple secondary and higher vocational schools to help develop the theoretical and practical abilities of students. In addition, outstanding students are recommended for internships and employment in the industry: "We have designed a systematic series of 3D printing training courses. We will achieve technology output in secondary and higher vocational schools through course output and industry-education integration (in secondary and higher vocational schools) to cultivate technical talent for the future development of the 3D printing industry" (F1, F2). Bering3D Technology also organizes training sessions for the internal employees of customer enterprises from time to time: "We have compiled training materials and made courseware based on successful 3D printing application cases. Our business staff members also visit customer enterprises from time to time to improve their technical capabilities through technical training, which is of great benefit to both sides in the long run" (F4). We interviewed the head of a supply-chain enterprise in Ningbo, who said, "In May 2020, Bering3D Technology recommended three student interns from vocational schools to us. They were young and without work experience, but they had a good knowledge of 3D printing, which made them different from our operators enrolled through social recruitment. "We used to train new employees for at least 6 months before we could formally employ them. However, some would ask for a pay raise after the 6-month training and would leave for another factory if their demands were not satisfied. The pay they got there was definitely higher because they had been trained by us to be experienced workers. So, our company was like a training school. In fact, we are willing to pay skilled workers well, as the long-term training was costly for us after all. When frequent mistakes lead to customer complaints, we cannot blame them at all. So Bering3D Technology welcomes recommended workers. Two of the three students recommended to us are now working here and they are doing very well" (C2).

Third, Bering3D Technology integrates resources across the whole industrial chain. As the platform positions itself only as a 3D printing service provider, it obviously complements premium hardware, software, and material manufacturers in the industry: "We have the same essential needs and hope that our customer enterprises can learn more about 3D printing technology and apply it more often" (F4, C2). Salesmen and eco-chain partner enterprise executives expressed similar views during the interviews. Therefore, platforms can activate technical resources across the whole industrial chain through strategic cooperation and resource-sharing to accumulate original technology. A head subordinate of the supply chain department mentioned in an interview that "… Most of the complaints arise from hardware performance issues, software bugs, material instability, etc. We feed back such information (or customer complaints) to the ecosystem (other complementary enterprises). This can urge enterprises in the ecosystem to make improvements and enhancements, and at the same time strengthen the connection between us and the ecosystem" (F3, C2). "Our cooperation with these internationally renowned enterprises has enhanced our company's influence and popularity. On the other hand, it has expanded our sources of information and technology—a capability that most customer enterprises do not have. Customer enterprises are keen to know the latest technical developments in the industry, what new equipment has been produced, how new materials perform, what new software can do, etc." (F3, F4). Similar views were expressed when we interviewed customer enterprises. A senior executive of an instrument and apparatus company said, "We also watch new technological developments, but after all, we are an enterprise that has to handle lots of matters. We have no way to make sure the new technologies and materials we see are real. Sometimes we cannot even tell whether a piece of news is up to date or obsolete. Since they started cooperating with Bering3D Technology, their business staff members and operation teams have sent us the latest technical information and cases through different channels. The face-to-face exchanges between us are enormously beneficial. This platform is a big vision. While receiving orders, they really care about our needs and will always find ways to help us and empower us to the best of its ability, which is of great help to our innovation" (K1).

（2） Information empowerment

Information empowerment is the process of providing free, enlightening, educational, and guiding content to customer enterprises and helping them acquire learning opportunities and resources. This includes case display, science popularization, and value proposition publicity.

First, in terms of display, Bering3D Technology provides customers with such content related to 3D printing technology in the form of text, video, and voice communication and helps them acquire learning opportunities and resources. For example, local government agencies can hold technical lectures and organize technical training for MSMEs in scientific innovation parks. The specific information displayed includes the sharing of cases through channels within the industrial chain and in the platform's production process. Bering3D Technology then collects and edits information from across the internet and updates industry information, annual industry reports, development trends, and application cases involving new equipment, new technologies, and new materials in the industry on the online platform in real time. It also translates and interprets important Chinese and foreign industry reports. In addition to tracking and forecasting developments in the industry to provide up-to-date information for (potential) 3D printing technology customer enterprises, Bering3D Technology dives deep into the potential capabilities of its customers. The founding partner advised business specialists in internal meetings as follows: “We should be able to discover customer needs through every order and stimulate customer needs ... We should have both lateral and vertical thinking” (F1, F2) to expand and strengthen the capabilities of customer enterprises. The core tasks of a company’s operation team are content and customer operations. “To put it more directly, its job is to collect the basic knowledge, application cases, and display scenarios related to the 3D printing industry as well as the information and news released every day about the 3D printing industry in China and foreign countries, and pass it on to customers through our own main site, applet, WeChat group, WeChat Moments, Zhihu, Douyin, 360.cn, and so on…(F3, F4) Customers normally do not immediately place orders on the platform the moment they receive such information. But over time, they will know that they can resort to Bering3D Technology if they have 3D printing needs. Then they will watch news and case applications on our website and follow our official WeChat account. This is a process of enhancing cognition and building trust. Once trust is built, they will definitely choose us over other companies with similar qualifications when they have order needs." (F2, F3)

Second, Bering3D Technology helps to popularize relevant knowledge. It promotes and publicizes 3D printing technology and organizes training for customers with various backgrounds through such channels as its website (through PCs and mobile phones), internet-wide information releases, its official WeChat account and WeChat group, one-on-one communication between its business teams and customers, and offline exchanges. As the head of the operation department concluded, "The ultimate goal is to tell customers what 3D printing technology can do and how to apply 3D printing technology" (F3). "We need our customers to understand 3D printing technology and apply it, regardless of their backgrounds. Therefore, we promoted, publicized, and popularized 3D printing technology extensively" (F3), added Bering3D Technology's senior sales executive. As part of its promotion campaign, Bering3D Technology routinely cooperates with local governments to collectively popularize 3D printing technology among regional enterprises. In this process, the company invites leading enterprises in the industry to attend training sessions on hardware, software, materials, and technology application. "For a hardware company like us, the sale of equipment takes time. Usually, we must track a customer for over 1 year before he places an order. So, we spend most of our time on brand promotion. To let more enterprises know about our company and equipment, we must start from scratch. It is a great choice for us to partner with Bering3D Technology. Our cooperation has enabled us to complement each other on the industrial chain and to jointly empower regional enterprises, and our business interests do not conflict with each other. This way of cooperation is highly cost effective" (C2).

Third, Bering3D Technology also conveys the message that enterprises can deliver to potential customers through the promotion of value propositions. Its founder emphasized this many times in internal meetings with business staff members: "Don't guess what customers care about but build an understanding of us in their minds. We must have a clear idea of what we are doing and what kind of company Bering3D Technology is. What should we persist in?" (F1). Using industry resources and 3D printing technology capabilities, Bering3D Technology drafts project proposals for customer enterprises and other eco-chain enterprises, and makes clear arrangements and enters into negotiations regarding the deliverables that customer enterprises can obtain, the landmark achievements, and the specific support terms and responsibilities provided. This approach can effectively enhance customer enterprises' understanding of 3D printing technology and their concept of its application. It can then help them explore digital application scenarios and build capabilities. A technical director of an auto parts factory said, "They are pragmatic. We are afraid of people who make false claims in publicity campaigns, who said they could do anything that we commissioned them to do, but it turned out that their work was very problematic and irritating. But Bering3D Technology does a very good job in this regard. Their business staff members and technicians came over and introduced to us the latest technical developments, what foreign enterprises could do, and what they could do at the present stage according to our actual demands during offline communications. They didn't exaggerate or downplay their capabilities. They basically managed to do what they said they could do. It is important to have such a channel for information exchanges, which is the key to building mutual trust. As a matter of fact, this company has its own persistence and is visionary. Most importantly, they are proficient in this technology, thanks to their long-time accumulation" (C2).

（3） Product empowerment

Product empowerment is the process through which platform enterprises deliver final (service) products to customer enterprises, according to their specific business orders. This process enhances the capabilities of the customer enterprises that obtain products and services. Product empowerment involves building digital functional modules, reconstructing production capacity, and cooperative development.

First, Bering3D Technology uses professional 3D modeling tools and a process knowledge-base to develop digital functional modules and capabilities and assist customer enterprises in building them. A senior executive of Bering3D Technology's applied technology R&D department said in an interview: "Some customer enterprises have only ideas or plane drawings" (F3). Thus, "Bering3D Technology can use professional 3D modeling software to help customer enterprises achieve product digitalization" (F3, K1). For many enterprises that have only products but no models, "We help them obtain 3D data models through 3D scanning so that they can do reverse engineering" (F3). Both senior executives and customer enterprises mentioned in interviews that the use of 3D modeling tools helps to build and improve customer enterprises' general digital capabilities, "When customer enterprises with specific physical models want further modifications, we obtain 3D model data through 3D scanning and then make data modifications (F3) based on the data according to their needs…In fact, we have 3D model data, which, however, can only be browsed online. So, we know the structure and shape of products, but cannot connect with 3D printers" (K1). 3D digitization is the basis for 3D printing technology applications. Without data models, nothing can be achieved. However, the reality is that most customer enterprises are still in the traditional 2D drawing stage. They know the specific requirements and have physical samples, but are not proficient in 3D modeling or digitalization. Thus, while providing 3D digital services for customer enterprises, Bering3D Technology also assists in their digital transformation process and helps them in their subsequent innovation performance improvement.

Second, Bering3D Technology helps customer enterprises optimize and reconstruct their production capacity from a technical perspective. A Bering3D Technology spokesperson said in an interview that "3D printing technology is not omnipotent…" (F1, F2). Furthermore, "If you combine 3D printing technology with the traditional subtractive manufacturing technology, you will get twice the result with half the effort and the order will be more cost effective" (F1). Customer enterprises should thus deconstruct their products' 3D data, distinguish between different technologies, and match demands through simulation. "Most customer enterprises are lacking in this ability" (F4). Bering3D Technology's supporting role lies in "understanding the real needs, essential needs, and potential needs of customer enterprises from different fields" (F4, D1) and in using 3D printing technology to reconstruct the production flow and processes according to the specific needs of customers. "It even rethinks and improves the original product design" (F4, K1). 3D printing is a revolutionary manufacturing technology. Compared with traditional subtractive manufacturing and equivalent manufacturing, the application of 3D printing (also known as additive manufacturing) technology will bring revolutionary changes to most industries. To ensure such changes happen, customer enterprises must first understand and apply the technology, particularly in the application process. It is not easy for any enterprise to replace its product processing technologies, as specific production costs, efficiency levels, and supply chain capabilities must be considered. Bering3D Technology's supply chain capability provides support for customer enterprises in this process. Whether for personalized small-batch orders or large-scale orders, Bering3D Technology's supply chain system can offer product empowerment to customer enterprises at a low cost and with high levels of efficiency. This effectively promotes customer enterprises' understanding and application of 3D printing technology and also further enhances their innovation ability and performance. "At the beginning, their business staff members came over often and made some good samples for us free of charge. When they said their products were low-priced and cost effective, we suspected they were doing marketing. Later, however, after we met often, mutual trust was built. We placed some trial orders, first for connectors and then for small batches of accessories. Their work was impressive. Now, we choose their 3D printing to make spare and accessory parts that number below 2,000. It is faster than opening the mold for production and has a lower overall cost" (C2).

Third, cooperative development can also empower customer enterprises by enhancing their capabilities and promote value co-creation with other MSMEs in the ecological chain. The founder of Bering3D Technology told us an interesting story: "A person in charge told us in our company that he had met a representative customer in the industry when communicating for an order. He thought the customer had great potential and reflected the technical advantages of 3D printing" (F1). After an internal project meeting, we agreed that this type of key customer was worth tapping into and that together we could overcome technical difficulties. "We will kick start the company's joint project team process and integrate our technical personnel with external industrial chain technical capabilities (if necessary) to jointly implement projects with our customers.” (F1, F2) In addition to meeting the technical needs of customer enterprises, Bering3D Technology has also upgraded and expanded its own technology and that of other complementary enterprises in the ecosystem. “We can also identify the needs and development direction of an industry through in-depth cooperation with a customer enterprise and then attract more customers in the industry” (F2, C2). Of the many enterprises on the platform, cooperative supply-chain enterprises also play the role of customer enterprises, as determined by their production capacity and equipment and technological type. Some supply chain enterprises gain their own customers when receiving orders from the platform. If customer orders exceed their production capacity, they will transfer such orders to the platform. The powerful supply capacity of the platform then empowers the supply-chain enterprises. The head of a platform supply chain enterprise in Kunshan said, “As a 3D printing service provider, we are happiest when seeing our equipment work at full capacity, because that means we have a cost advantage and will definitely be profitable. What we fear the most is that no orders come when the equipment is idle or many orders come when the equipment is busy because customers will not wait, and must turn to other suppliers if we cannot deliver the goods at the required time. Therefore, we really need to establish cooperation with platforms like Bering3D Technology. The orders they give to us can basically match our production capacity. Our production capacity can just meet the needs of nearby customers. Now, even if incoming orders exceed our production capacity, we won't worry, because we can upload them to the platform at one click and rest assured about the quality and delivery time" (K1, C2).

3.3.4 The relationship between the platform's three mechanisms of empowering MSMEs

1. The three enabling mechanisms are independent in the short term but dependent in the long term. As Bering3D Technology's 3D printing service platform is an internet platform, customer enterprises that fully understand and trust the platform can place orders, pay, and wait for products independently through the platform interface. In this process, the sales/customer service staff of the customer enterprises and the platform do not come into contact with each other, and the platform only empowers customer enterprises that have independent products. The relevant staff of customer enterprises can gain much information about 3D printing technology by browsing Bering3D Technology's website. No business transactions occur between customer enterprises and the platform in this process, so naturally no product empowerment takes place, but only information empowerment or technology empowerment. The platform's three empowerment mechanisms are therefore independent at a certain point in time or in a certain period. However, this independence is stage-specific and is not a long-term interaction. Customer enterprises can always find other ways to realize an

independent empowerment mechanism. Product empowerment can be realized by non-platform 3D printing service providers, technology empowerment can be realized by 3D printing research institutes, and information empowerment can be realized through 3D printing websites, official WeChat accounts, and WeChat video channels. However, it is precisely the integrated application of these three kinds of empowerment that has helped establish a long-term and stable cooperative relationship between the platform and customer enterprises. The head of a culture creation enterprise said in an interview, "In fact, there are quite a few 3D printing companies around us, which often offer much lower prices than Bering3D Technology, so we occasionally place some simple and small processing orders with these companies. However, this type of cooperation is not a long-term solution. We don't use 3D printing technology just for the price reason. What these companies can do for us is simply processing according to drawings and offering a favorable price, whereas Bering3D Technology can start from product design and our final needs to discuss the technical path with us and provide us with the latest application cases from across the world. Sometimes a casual remark of theirs can give us great inspiration and make our product innovative from the very beginning. This value is much greater than a discount on processing fees" (K1).

2. The integration of the three mechanisms is beneficial to the platform itself. This is determined by the platform's attributes and orientation. Product

empowerment is the basis for business transactions between the platform and customer enterprises. In the long run, the ultimate goal of both information empowerment and technology empowerment is to maintain a sustainable product empowerment relationship between the platform and customer enterprises. As the scale and architecture of platform enterprises are more complex than those of non-platform 3D printing service factories, the platform is at a disadvantage in terms of cost performance through single product empowerment (order processing). The adoption of traditional methods such as scale expansion and cost reduction in the competition will lead to a vicious cycle characterized by "low price, low quality, and poor service," and will also deviate from the characteristics and advantages of service-oriented manufacturing. As 3D printing is a disruptive manufacturing technology, the platform can integrate technologies and information in the ecosystem and deliver them to customer enterprises through product empowerment. Customer enterprises receive technical training, which will broaden their horizons, and they will be more open to innovative approaches so that better products can be designed and manufactured. Their own innovation will be enhanced, which is beneficial to their development. "Information empowerment is crucial for our business team/customer team to maintain a long-term relationship with customer enterprises. In the process of information empowerment, we should give equal attention to costs and benefits, roughly divide customer enterprises according to their attributes, scale, and positions in the industry, and carry out information empowerment in a pertinent way. But when there is no business opportunity, we should avoid one-on-one communication to save our labor costs. In principle, technology empowerment only targets customers with orders or major research projects. This process is not only for solving technical problems for customer enterprises, but also for improving our own technical team. We don't have to think too much about the immediate labor and time costs. Instead, we regard solving problems as the ultimate goal, win the trust of customers through technology empowerment, win orders for the company, and maintain long-term cooperative relations with customer enterprises. Product empowerment is the foundation for our survival. Although we don't emphasize price and delivery time, we must pursue high standards. We 'extract value out of machines' through intelligent order sharing and collective production using single technology and material and feed them back to customers. We will not only let customers appreciate the dividends of information and technology empowerment, but also enable them to enjoy optimal cost performance through product empowerment. In this way, customer enterprises will trust us, rely on us, and maintain long-term cooperative relations with us" (F1, D1).

3. MSMEs must balance short-term costs and long-term benefits according to their requirements. The demands in terms of platform empowerment differ according to the specific customer enterprises, in

addition to differences in their size, position in the industrial chain, and innovation abilities. "Some large-scale customer enterprises, especially their R&D departments, urgently need the information empowerment and technology empowerment by the platform. At present, however, we cannot define them as paid services but can only 'graft' them on product empowerment and earn benefits through real product and service orders" (F3, F4). An aviation researcher said in an interview, "From the perspective of product R&D, the supply chain end should preferably provide high-level technical support for information collection and analysis and the learning and discussion of new technologies, which is of great value for us. We don't worry about orders, although other suppliers may offer cheaper prices. However, it would be inappropriate if we discussed a technical scheme with Bering3D Technology but finally did not place the order with it, which would hamper future cooperation. As a company, it also pursues interests, and both sides should respect each other's business demands" (K1). For customer enterprises, service-oriented manufacturing platforms are only one of their many options. Unlike other suppliers, service-oriented manufacturing platforms can realize information, technology, and product empowerment and can enhance the innovation performances of customer enterprises from the very beginning. Therefore, customer enterprises must assess what they need to improve their innovation performance. In the stages of new product development, key project technical research, and small-batch new product trial production, platforms such as Bering3D Technology can play a very important supporting role as well as accelerate the iteration of product R&D and reduce the overall R&D and trial production costs. However, when products are finalized and enter the mass production stage, selecting such a platform would be inappropriate, as customer enterprises will then pursue product standardization and scalization while seeking to reduce costs and improve efficiency through large-scale production. The advantages of 3D printing technology in terms of personalization and small-batch customization are not evident in this stage. When products become stable, the demand for new technologies and information decrease, and the platform's empowerment mechanisms are no longer advantageous for customer enterprises in the short term.

4. The conceptual model of service-oriented manufacturing platforms empowering MSMEs

In this paper, we identify the mechanisms through which service-oriented manufacturing platforms enhance the innovation of MSMEs, based on resource-based and capability-based views and on the concepts of platform theory performance. These service-oriented manufacturing platform enterprises leverage their positions as hubs in the industrial chain and their unique advantages in digital information integration. They provide MSMEs with mechanisms to improve their high-level innovation performance through the provision of value-added services, in which they match the production and service transaction opportunities of the supply and demand sides.

4.1 Hypothesis deduction

4.1.1 Technology empowerment and the enhancement of MSMEs' innovation performance

Service-oriented manufacturing platforms have the ability to integrate hardware, software, materials, application R&D, and other resources. These integrated technical capabilities can help MSMEs achieve better innovation performance. First, the digital technologies deployed on service-oriented manufacturing platforms such as the industrial internet, big data, and 3D data modeling can significantly improve the basic digital capabilities of MSMEs (Soegoto et al., 2020) and provide them with an innovation foundation. The operational efficiency of MSMEs can be significantly improved through the application of digital technology (Xing, 2021). Traditional manual work can be conducted by artificial intelligence and industrial machinery, the efficiency and management of enterprise service and production can be enhanced, original production and management models can be updated, and MSMEs can shift to a refined intelligent digital production model. Research on digital empowerment has suggested that technology empowerment is a process in which new-generation digital technology (e.g., 3D printing technology) can be applied to activate and boost the system capabilities of enterprises (Gao et al., 2021).

Second, technology empowerment can significantly reduce the R&D and production costs of MSMEs and eventually improve the innovation performance of enterprises. Technology R&D is known to drive innovation in enterprises, but the high development costs and risks can be insurmountable obstacles for MSMEs. Service-oriented manufacturing platforms can fully integrate hardware, software, and materials, which can then be delivered at a lower cost to MSMEs through small orders and multiple iterations, thus considerably reducing the application cost of simulation software. Therefore, MSMEs can use advanced 3D printing technology to simulate product design, experimentation, and production in the R&D stage, which can drastically reduce R&D costs and time.

Finally, technology empowerment can help MSMEs and their employees boost their performance through innovation. Sun et al. (2020) suggested that empowerment helps to improve the abilities of the empowered, broadens their knowledge, and enhances their levels of innovation.

One example is of a solar energy production company that is one of the customer enterprises. It required finished products for the improvement and design of a solar panel outer frame. Bering3D Technology conducted a technical analysis according to the 3D data provided by the customer and decided to use a high-temperature resistant nylon material to optimize the structure of small parts on this outer frame. This solved the problem of high mold opening costs faced by the customer and reduced the R&D time significantly. "The whole R&D cycle is reduced. Now it takes only 37 hours to design and produce a solar panel" (D1). Bering3D Technology also received an order from a technical research institute of a university to print exoskeleton wearables. It came up with an integrated design according to the requirements, and conducted a simulated stress analysis from multiple angles, finally producing six generations of prototypes in 1 year. Each had an average production cycle of 3-5 days and the R&D cycle was significantly shortened. The institute also chose 3D printing for small-batch customized production in the sales stage.

A military research institute, another customer enterprise of Bering3D Technology, wanted to improve its microwave receiver. After numerous rounds of communication with Bering3D Technology's technical team, it replaced its traditional machining processes with brand-new 3D modeling and

3D printing technology. “As a result, production costs directly decreased by 30%, microwave reception efficiency increased by nearly 70%, and the production cycle accelerated significantly” (D1). The fourth generation of this product has since been rolled out, and the production costs are declining while the level of efficiency is increasing. The military research institute was impressed by this project. “We are affiliated with the military, so we must keep our product information confidential and rarely cooperate closely with external technical teams. This project has demonstrated the power of new technology. We now have all-new solutions to the problems that have been bothering us.” (C2) Based on the above, we propose the following hypothesis:

H1: Technology empowerment has a significant positive impact on MSMEs’ innovation performance.

4.1.2 Information empowerment and improvements in MSMEs’ innovation performance

Service-oriented manufacturing platforms serve the supply and demand sides in many ways, such as through transaction matching and information exchanges. The information gathered by these platforms online and offline can improve MSMEs’ innovation performance. First, this model is dramatically different from the traditional one in which partners in the upper, middle, and lower reaches of the supply chain are separate. Industry information can be shared on the platforms in real-time to tackle information asymmetry (Sun et al., 2022). Service-oriented manufacturing platforms as external networks enable MSMEs to find the information resources that match their services or production processes, and thus realize transaction matching (Armstrong, 2006). The information concerning case development, technology application, and logistics provided by service-oriented manufacturing platforms open up extensive possibilities for MSMEs to improve their innovation performance. They can draw on the numerous success stories and business cases from home and abroad to improve their technical routes and optimize their operations (Zhou, 2018), identify the essential changes required in terms of market demand and production, gain first-mover advantages and develop products that the market welcomes (Yi, 2020), and eventually improve their technology and product innovation performance.

Second, information empowerment through service-oriented manufacturing platforms can be multi-faceted. Industrial data can be integrated and circulated in the equipment layer, the platform layer, and the network layer (Li et al., 2016; Sun et al., 2022), thus allowing MSMEs to obtain business ecosystem-grade information resources. Lyu et al. (2019) noted that in the "new industrial revolution," informatization integrates with industrialization on industrial internet platforms. By connecting industrial data, this can dynamically and efficiently provide MSMEs with the resources necessary for production and innovation or share resources with them.

Finally, information empowerment can help MSMEs develop dynamic innovation performance. Teece (1997) defined dynamic capability as the ability of enterprises to integrate, establish, and reconstruct their internal and external approaches, and thus adapt to the rapidly changing environment. Service-oriented manufacturing platforms provide MSMEs with many examples of market application, industry information updates, annual reports, and trends in materials development that are related to 3D printing technology at home and abroad. MSMEs can make use of this huge volume of heterogeneous knowledge and resources and combine and upgrade them based on their current knowledge and ability levels (Ren et al., 2018). This is proven to be beneficial for identifying new market opportunities, reconstructing resources and activities (Zhang et al., 2022), and improving the dynamic innovation abilities of enterprises. The massive data provided by the platforms can also help enterprises efficiently obtain information regarding cooperation and follow up on the real-time, rapid product or technology solutions of their R&D partners (Wang et al., 2018).

For example, the long-term communication between Bering3D Technology's technicians and the chief physician team of an orthopedic hospital in Weihai, a customer enterprise, mastered how to customize skull operation guide plates using 3D printing technology. After repeated trials, the team applied it to actual operations and shortened the operation time to 1 hour and 20 minutes, and required substantially less blood than expected. "We heard of some precedents abroad before but going from understanding it to applying it in actual surgical procedures is not easy. Bering3D Technology's technical team gave us great support in this process—from early-stage technical communication to later scheme design, guide plate printing, and surgery simulation…We saw how technology drove development in the medical field. We can also use this technology to stimulate innovation in our field and benefit patients" (K1). As a new manufacturing technology, 3D printing is set to create value in all fields. This depends not only on 3D printing technology itself, but more importantly on how customers on the application side understand and apply this technology to enhance their levels of innovation and create greater value in their respective fields.

Bering3D Technology stresses the need to communicate with customers and retain them during the process, as a full understanding of customer needs and pain points is key to providing effective solutions and creating long-term value for customers. "We find in specific business practices that different customers respond differently to our invitation to interactions. Some customer enterprises communicate with us through their purchasing department, with a focus on the price, delivery date, and quality of orders; some customer enterprises communicate with our technical team through their purchasing and R&D departments, starting from the design of product solutions so they can fully understand and use 3D printing technology to meet their order needs; some customer enterprises open up communication channels from above down, regarding the communication with our platform as the 'most prioritized task.' Their CEOs built chat groups to maintain the flow of information. This not only fundamentally improves the efficiency of all but also closely follows the information gathered on the platform that concerns upstream and downstream industries, fully activating the internal innovation power" (F1, F4). The examples of two pen manufacturers illustrates this.

The two enterprises are referred to as enterprises A and B, and they are customer enterprises of Bering3D Technology, based in Wenzhou. They first participated in Bering3D Technology's platform in May and July 2020, respectively. Enterprise A communicated with the platform via its purchasing department concerning orders of small-batch printing tasks for newly designed sample pens. Bering3D Technology's business staff then entered into discussions with the purchasing department of Enterprise A, and found that it was simply following some transactional procedures and focused only on the price, delivery date, and quality requirements of the orders. In addition, they were obviously unwilling to communicate further with our business staff members. However, after this failed attempt, the platform's business staff did not give up on the business opportunities in the stationery market. They learned that a large-scale stationery exhibition is held every October, where pen manufacturers place large quantities of orders for the printing of new products. Thus, Enterprise B was identified through its online information and a partnership was successfully established. The size and business type of Enterprise B were similar to those of Enterprise A. Upon learning that we had already provided sample printing services for Enterprise A, the head of

Enterprise B instigated communication with us and visited Bering3D Technology's Hangzhou branch with its R&D and purchasing teams. "For an enterprise with a moderate scale like ours, investment in the R&D of new products is the most difficult part. Without new products launched, new business opportunities hardly emerge. However, the design, R&D, and sample making for every new product come at a cost. If we cannot win orders, we will have to bear the cost ourselves. In addition, it is very difficult for our design team to make a 'breakthrough' or come up with an innovation in this field" (K1). After gaining a thorough understanding of the needs of Enterprise B, the platform offered its creation and design resources, stimulating Enterprise B's innovation in terms of new product development. In August and September 2021, the orders placed by Enterprise B on the platform were 5.3 times those of Enterprise A. Our business staff member later learned that Enterprise B had far more new products than Enterprise A in the October stationery exhibition. Thus, we propose the following hypothesis:

H2: Information empowerment has a significant positive impact on MSMEs' innovation performance.

4.1.3 Product empowerment and improvement of MSMEs' innovation performance

Service-oriented manufacturing platforms can help MSMEs improve their innovation performance through intensive production and supply chain management. First, a traditional manufacturing enterprise that adopts the

Enterprise Resource Planning (ERP) platform can significantly improve the efficiency of internal production information circulation, reduce the production cost of services to MSMEs, and accelerate their R&D (Meijers et al., 2014).

Second, compared with ordinary manufacturing enterprises, service-oriented manufacturing platforms can produce a stronger "amplification effect on the internet" (Xing, 2021). This effect, derived from the intermediary role of the upstream suppliers and downstream complementors who are connected to platform enterprises, can lead to significant aggregation in the industrial chain. Service-oriented manufacturing platforms can therefore empower many MSMEs and promote high-quality manufacturing innovation while enhancing innovation performance and efficiency.

Finally, service-oriented manufacturing platforms can help increase the level of MSMEs' production standardization and ensure quality in the manufacturing industry. As platform enterprises can provide intensive, value-added production, marketing, and logistics services, they can further optimize the operation models of MSMEs (Zhu et al., 2019). This helps to both standardize the production process and reduce potential uncertainties, but also boosts MSMEs' competitive standing in terms of marketing networks and customer management.

An Australian architectural design company has had a long cooperative relationship with Bering3D Technology. It bids for large-scale architectural design projects for science and technology museums, opera houses, and art galleries on the Chinese mainland. The company's design director said in an interview, "We once had a long-time competitor. Their design philosophy and design standards were on par with ours. We often competed for the same project—sometimes they won, and sometimes we won. But since early 2021, we have no longer used albums and PowerPoint presentations to display our schemes. Instead, we printed out the 3D model we designed with 3D printing technology and put it on the customer's desktop (K1) after adding sound and light to the model. In this way, we overwhelmed our opponents in three projects and gave them a big surprise!" (K1). 3D printing technology was obviously not the only reason for this customer's consecutive victories over its former, evenly matched competitor. Extensive communication between Bering3D Technology and its customer took place concerning technical issues, such as the improvement of the 3D model (the virtual display and real printing set down different requirements for the model), the choice of printing materials, the audio, photic and electric interfaces, and the details when painting the finished products. This can be viewed as a new innovative journey in terms of using 3D printing technology for irregular building models. Thus, we propose the following hypothesis:

H3: Product empowerment has a significant positive impact on MSMEs' innovation performance.

4.1.4 Differences in innovation performance improvement of platform-empowered MSMEs due to customer enterprise scale

The innovation performance of MSMEs is also influenced by the size of the enterprise subject, in addition to the platform empowerment mechanism. From an organizational economics perspective, although large-scale enterprises have obvious advantages over SMEs in terms of resources, they do not require extensive external support and they may not be willing to increase their levels of innovation or apply innovative solutions. Their strategies for innovation are not as flexible as those of SMEs (Li, 2022). SMEs have unique advantages in terms of organization mechanisms and market response. They can increase their market shares and expand the business by developing more flexible strategies, making decisions faster, and adopting more efficient business models than large enterprises (Cenamor & Frishammar, 2021). Their technicians are more willing to seize opportunities to increase resources enabling innovation and make full use of the empowering resources provided by service-oriented manufacturing platforms. Thus, we propose the following hypothesis:

H4: The effect of platform empowerment on MSMEs is stronger than on large-scale enterprises.

4.1.5 Differences caused by customer enterprise positions in the industrial chain in the innovation performances of platform-empowered MSMEs

In addition, the platform's empowerment effect on the innovation performance of MSMEs is influenced by their positions in the industrial supply chain. This is generally regarded as consisting of upstream, middle-stream, and downstream components. The upstream businesses provide raw materials for production, conduct product R&D, and design and manufacture parts, and are interdependent with middle- and downstream businesses. Those downstream output the final products and deliver services (Shang & Gao, 2022). For example, customer enterprises in the new energy vehicle (NEV) industry may be located at different positions along the industrial chain and engage in concept NEV design, sample vehicle test-piece design and manufacturing, finished automobile assembly, points of sale, or 4S stores. Here, concept NEV design and sample vehicle test-piece design and manufacturing belong to the upstream industrial chain. Bering3D Technology, as a service provider in this industry, is in the middle of this industrial chain. Finished automobile assembly plants are integrators on the downstream industrial chain. NEVs' points of sale and 4S stores are downstream terminal enterprises. All of these customer enterprises are in the same industry but due to their different positions in the industrial chain their requirements differ. Thus, their interaction needs on the platform are obviously different.

Upstream NEV customer enterprises can benefit more from technology empowerment and information empowerment through Bering3D Technology. To solve a specific problem, for example, customer enterprises can invite

Bering3D Technology to participate in technology matchmaking or project implementation meetings. Showcasing the latest application cases or the integrated application of new materials and new technologies in the NEV field can be extremely beneficial to these types of customer enterprise. To feed back on specific technologies, they will regularly send print testing and small-batch customization orders to Bering3D Technology to maintain their long-term cooperative relationships. Such enterprises are often large in scale and impressive in terms of brand profile. In terms of economic value, dealing with this type of business is often a "thankless" task, and it can promote the corporate brand and provide industry information. The cooperation between downstream NEV assembly plants and Bering3D Technology mainly concerns the design and mass production of frock clamps. Here, the room for innovation for customer enterprises is relatively small; they make their production processes more efficient and reduce unit costs mainly by ensuring that personalized clamp and brace designs are scientifically planned and cost-effective. These enterprises benefit most from product empowerment, in terms of using new materials and specific application cases by their international peers. The platform does not need to put much effort into information or technology empowerment to win bulk product orders. The cooperative relations established are also relatively stable. These represent high-quality customers for platform enterprises. In the NEV field, end users often apply 3D printing technology to making personalized ornaments and headlights, modifying bumpers, and designing more powerful exhaust pipes, among other things. In this process, customer enterprises can benefit from all three empowerment mechanisms on the platform. They need to know about specific application cases and advanced technologies before they apply them to end-product improvement and optimization. The orders placed by such customers are sporadic, but they comprehensively apply 3D printing technology and the platform typically gets paid well, so the orders are conducive to case building and promotion.

The main effect reported in this paper suggests that the technology empowerment mechanism of service-oriented manufacturing platforms follows a distinct path. The basic digital capabilities of MSMEs are improved through accumulated digital technologies, such as the industrial internet, big data, and 3D modeling data (Soegoto et al., 2020), which supports innovation and improves enterprises' R&D efficiency. Upstream suppliers or R&D staff are involved in 3D printing design and R&D (Liu, 2022), which require high levels of skill and capital. These suppliers and staff therefore have the highest entry thresholds and restrictions (Han, 2020). Thus, external technology empowerment through service-oriented manufacturing platforms can benefit upstream MSMEs.

Through information empowerment mechanisms, service-oriented manufacturing platforms match the transaction and interaction needs of the supply and demand sides and transmit the information collected online and offline to MSMEs, thus improving their innovation performances. Both upstream enterprises and end users are dependent on industry information and the information feedback from every node on the industrial chain (Han, 2020). Service-oriented manufacturing platforms integrate this information, which informs new product development and leads to new product categories. On-platform matching can efficiently meet the 3D printing needs of end users. Thus, information empowerment by service-oriented manufacturing platforms can benefit upstream MSMEs and end users.

The product empowerment mechanism provides intensive, value-added production, marketing, and logistics services to MSMEs and increases the level of production line standardization, ensuring manufacturing quality and optimizing MSME operation models (Zhu et al., 2019). Downstream integrators are usually responsible for end-product integration, package testing, and providing industry solutions to end customers (Yin, 2019; Liu, 2022; Shang & Gao, 2022). They have the largest requirements for manufacturing and packaging technology. Thus, product empowerment through service-oriented manufacturing platforms can benefit downstream integrators. Thus, in complex scenarios, the influences of the empowerment mechanism of platforms and the positions of enterprises in the industrial chain on enterprise innovation are likely to be non-linear and varied.

The empowerment provided by the platform in terms of information and technology therefore has the most obvious positive effect on the innovation of upstream suppliers/R&D departments. These enterprises are already competent in R&D and innovation and invest heavily in the development of new technologies and new products. They naturally have stronger demands for 3D printing technology. They can, however, benefit greatly from the information and technology empowerment provided by the platform, particularly in new product surveying and experimental stages. In the trial production stage, product empowerment can be extremely useful, as illustrated by the NEV customer example. NEV customer enterprises place most of their orders on the platform in the first quarter of each year, as automobile exhibitions typically occur in April, and the enterprises need to be ready to launch their new products. However, very few concept cars are produced in the early stages of R&D, and the products have yet to be finalized. Mold opening for mass customization is thus not useful. Service-oriented 3D printing enterprises that are able to offer multiple technologies and materials are then the preferred partners of these customer enterprises. They require technical seminars and meetings for brainstorming, technical research, and discussing project progress coordination, with the technical team of the platform. These customers will have an open attitude toward new technologies and materials and are willing to pay for product tests. Here, information, technology, and product empowerment through service-oriented manufacturing platform enterprises can help increase the innovation performances of customer enterprises.

For downstream integrators, product empowerment generates more obvious positive effects on their innovation performances than technology or information empowerment. The auto parts used in NEV assembly plants are all derived through orders placed by the main automobile engine plants. The assembly plants cannot modify the order data but can consider how they can improve production efficiency and reduce costs. Any information or technology empowerment offered by the platform ultimately becomes product empowerment for these enterprises. The platform can only assist these enterprises by improving their production performance through product empowerment. Information and technology empowerment can encourage them to participate in 3D printing technology, which can then generate more opportunities and orders (i.e., product empowerment) and improve their innovation performance. An AI company in Shandong that engaged in medical device customization and customized services for hospitals, doctors, and medical institutions is also a customer enterprise of Bering3D Technology. It is dependent on its technical strength in medical engineering and as a medical integrator, sources product parts from other companies. Product shells and related structural parts are customized on the platform according to the requirements of each batch of products and the structures of the internal core hardware. In this process, product empowerment through the platform provides much support to the customer. A good product structure design that considers aesthetics and safety and that meets a series of functional indicators can bring extra benefits to customers and lead to the improvements in innovation. While product empowerment has the most direct effect on such enterprises, information and technology empowerment are also important in the early pre-sale communication stages and will have a direct effect on product ideas, designs, and test pieces.

The end users of platform services are typically those who use products. These customers are less concerned about technology than information and products. The effects of information and product empowerment will be higher than that of technology empowerment for such customers. Another customer is a medical device company in Suzhou that focuses on the R&D and production of medical ventilators. Its products are rapidly iterated, so it often uses 3D printing technology to customize the spare and accessory parts of its terminal products in small batches. As the added value of these products is high and the sales volume of each batch is limited, opening a mold and customizing the required parts in batches is not feasible. Using 3D printing technology to produce them in small batches is preferable and more economical. The gross margin of such products is relatively high. The enterprises are not concerned about slight differences in costs or in the materials, processes, or technologies used in production. They are mainly concerned about how their peers operate and whether there are better solutions available in global terms. They are eager to obtain such information through the platform and apply it to their products. They also have specific requirements regarding the end product, no matter what combination of technologies and materials the platform adopts. These enterprises need to have good quality products provided efficiently and in good time. Although all three types of empowerment provided by the platform are important for such end-user enterprises, they mainly focus on information and product empowerment. Thus, we propose the following hypothesis:

H5: The effect of platform empowerment on MSMEs' innovation performance improvement varies according to the position of customer enterprises in the industrial chain.

4.2 General empirical model

Based on the previous analysis, we propose an empirical model of service-oriented manufacturing platforms' empowerment of customer enterprises' innovation performance (see Figure 4.1). In this model, the dependent variable is the innovation performance of customer enterprises; the moderating variables are the scale of customer enterprises and the position of customer enterprises in the industrial chain; and the independent variable is the empowerment mechanism of platforms. This is divided into three constructs: technology empowerment, information empowerment, and product empowerment.

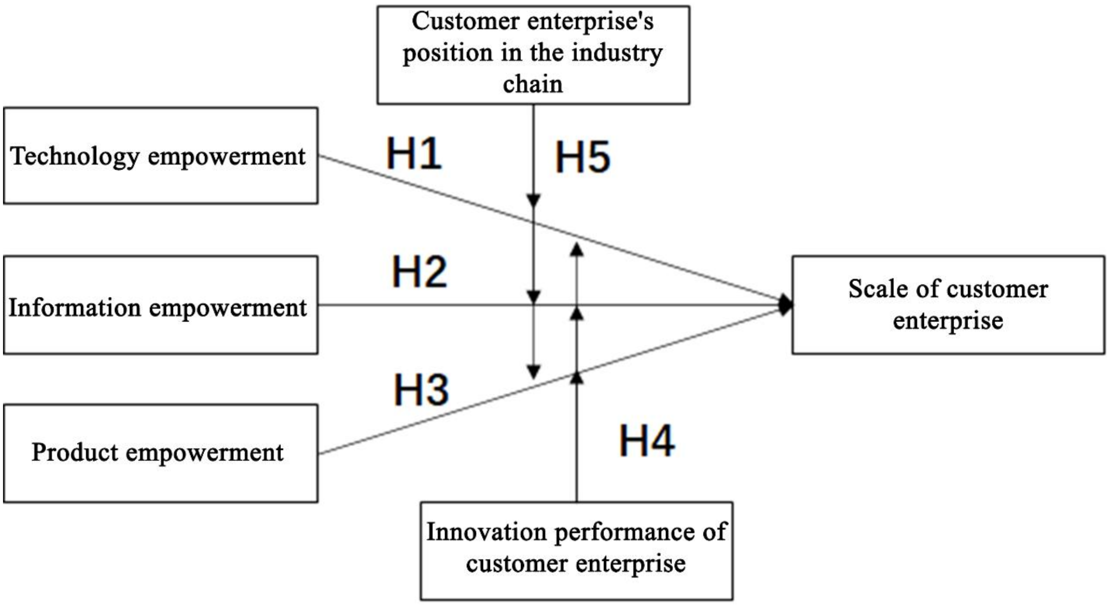


Figure 4.1 Model of the Empowerment Mechanism of Service-oriented Manufacturing Platforms

5 Empirical Test of Service-Oriented Manufacturing Platforms Empowering MSMEs

5.1 Variable measurement

The items for the scale used in this study were based on the content of the interviews and cases discussed in Chapter 3. Relevant research was consulted to generate the initial items of technology empowerment, information empowerment, product empowerment, and innovation performance. The main variables were measured using 5-point Likert scales. For the measurement of the sub-variables of the three constructs of platform empowerment, 1 = “completely disagree” and 5 = “completely agree.” For innovation performance, 1 = “significantly reduced,” 2 = “slightly reduced,” 3 = “same as before,” 4 = “slightly increased,” and 5 = “significantly increased.”

Platform empowerment. Based on previous research and the evaluation processes of platform empowerment (Wang, 2017), we propose that the empowerment mechanism of service-oriented manufacturing platforms can be measured from the three aspects of technology resource output, information data connection, and production logistics supply. We measured the effectiveness of platform empowerment based on whether a service-oriented manufacturing platform can help MSMEs improve their abilities in these three aspects. The coding results of the case analysis in Chapter 3 indicate that **technology empowerment** should reflect how the platform’s digital technologies help MSMEs improve their basic digital abilities and outputting, in terms of hardware, software, and materials, in a multi-dimensional and integrated manner. Based on this, eight items were generated:

1) The platform can help us convert the actual product demand into the technical language (parameters) of 3D printing.

2) The platform can help us analyze technology/product optimization plans.

3) The platform can develop and provide technical talent for the 3D printing industry.

4) The platform has launched systematic 3D printing training courses.

5) The experiences and customer application examples in the 3D printing industry offered by the platform can be helpful.

6) The platform can consolidate the supplier resources of the 3D printing industry (e.g., hardware, software, and material manufacturers).

7) The platform can meet our actual needs through ecological chain resources.

8) The platform can offer us access to 3D printing industrial clusters.

The coding results suggest that **information empowerment** reflects the role of service-oriented manufacturing platforms in sharing industry information, decreasing information asymmetry, and integrating industrial data from the equipment, platform, and network layers. Thus, eight items were generated:

1) The platform enables us to gain business information related to 3D printing (e.g., the latest technology/product R&D initiatives, the market environment, and user requirements).

2) The platform provides knowledge about the application of 3D printing technologies.

3) The platform provides knowledge about the development of 3D printing products.

4) The platform has done a lot to promote 3D printing (e.g., information-sharing sessions, training, and science popularization).

5) The platform updates/releases information and data related to 3D printing in a timely manner.

6) The platform summarizes application cases of advanced 3D printing technologies.

7) The platform provides knowledge about potential business opportunities for using 3D printing technologies.

8) The platform helps us explore potential scenarios in which 3D printing technologies can be used.

The coding results indicate that **product empowerment** reflects the role of service-oriented manufacturing platform enterprises in connecting upstream suppliers and downstream complementors and enabling MSMEs to benefit from the aggregation effect formed in the industrial chain. Thus, seven items were generated:

1) The platform can provide us with the required technology/product support/services (e.g., 3D modeling, scanning, and 3D modeling optimization).

2) The platform helps us choose appropriate production processes and materials to meet our final product requirements.

3) The platform has sufficient production capacity to receive relatively large orders.

4) The platform can solve transportation and logistics issues of 3D printed products and meet the requirement of timely delivery.

5) The technicians of the platform clearly communicate with us to ensure effective solutions immediately after quality or delivery problems arise.

6) The clerks (technicians) of the platform can provide us with timely and effective assistance by answering questions to ensure the quality and accurate delivery of final products.

7) The clerks of the platform actively respond to requests for irregular orders that cover diverse categories and come in small quantities.

Innovation performance. This measures improvements in MSMEs' product and technology innovation. Some maturity scales have been developed for this construct in overseas studies. We therefore applied a strict reverse translation process and translated these scales into Chinese for the item design. We followed Calantone, Cavusgil, and Zhao (2002), Liao, Fei, and Chen (2007), Zhan, Shao, and Tang (2018), and others for reference.

Based on this, five items were generated:

1) After using the services of the platform, our operational efficiency has improved.

2) Our R&D costs have reduced.

3) Our technical personnel's ability has improved.

4) Our R&D efficiency has improved.

5) Our ability to provide customers with personalized and small-batch products has improved.

5.2 Sample data

(1) Sample selection

Given the focus of this study on how service-oriented manufacturing platforms empower MSMEs to improve their innovation performance, the selected sample range covered enterprises, teams, and individuals using the services of such platforms, and the control group consisted of those who did not use the services, to ensure that our findings were robust. The sample selection followed two main criteria. First, the participants had to have used the services of service-oriented manufacturing platforms within the past 3 years to ensure that the observation data were in the valid range. Second, we screened them to establish their actual innovation or R&D activities, to ensure we selected organizations that were operational or that engaged in R&D, so we could measure the effectiveness of the empowerment mechanism.

(2) Data collection

The data were mainly collected through the online questionnaire. As the author is the founder and operator of Bering3D Technology (a typical service-oriented manufacturing platform enterprise), his partners participated in the survey through field visits, online questionnaires, and telephone calls, and information was also collected about those who had not used the services. One example screening item was, "Have you ever used a 3D printing service platform (such as Bering3D Technology)?"

The final questionnaire was distributed between August and September 2022. As strict COVID-19 containment measures were still in place in China, the questionnaire was mainly administered online. Real-name authentication and telephone and e-mail contact information were required in the questionnaire so that the respondents who failed to complete their questionnaires could be contacted. In total, 305 questionnaires were distributed and 226 were collected. Of these, 209 were valid, accounting for 68.5% of the total number distributed. Table 5.1 gives the structure of the sample.

Table 5.1 Distribution of Basic Characteristics of the Sample (N = 209)

Category	Characteristic	Frequency	Percentage (%)
Using 3D printing service platforms	Yes	145	69.38
	No	64	30.62
Frequency of using the	Less than 10 times	106	50.72

Category	Characteristic	Frequency	Percentage (%)
	11-30 times	29	13.88
	31-100 times	29	13.88
	More than 100 times	45	21.53
Position of the company in the industrial chain	Upstream supplier/R&D personnel	94	44.98
	Downstream integrator	38	18.18
	End customer/user	64	30.62
	Others	13	6.22
Administrative level of post	General staff	105	50.24
	First-line manager	32	15.31
	Middle-level manager	37	17.70
	Senior-level manager	20	9.57
	Business owner	15	7.18
Year(s) of establishment of the company	0-2 years	42	20.10
	3-5 years	45	21.53
	6-10 years	39	18.66
	More than 10 years	83	39.71
Number of employees	Less than 20	17	8.13
	20-200	130	62.20
	201-500	33	15.79
	More than 501	29	13.88
Industries of the company's main businesses	Computer, electronic, and communication equipment	25	11.96
	General and special equipment and transportation equipment	26	12.44
	Electrical machinery and equipment manufacturing	48	22.97

Category	Characteristic	Frequency	Percentage (%)
	Automobile manufacturing	16	7.66
	Bio-engineering and pharmaceutical manufacturing	8	3.83
	Manufacturing of articles for culture, education, arts, crafts,	4	1.91
	Furniture manufacturing	5	2.39
	Manufacturing of petrochemicals, chemical fiber, rubber, and	12	5.74
	Manufacturing of textiles, apparel, and clothing	5	2.39
	Metal manufacturing	29	13.88
	Food manufacturing	7	3.35
	Other industries	24	11.48
Nature of property right of the company	State-owned	15	7.18
	Privately-owned	165	78.95
	Foreign-invested	1	0.48
	Joint venture	19	9.09
	Others	9	4.31

In the sample, 106 (50.72%) respondents had used the services of 3D printing platforms fewer than 10 times, 29 (13.88%) had used them 11-30 times, 29 (13.88%) had used them 31-100 times, and 45 (21.53%) had used them more than 100 times. Of the respondents, 94 (44.98%) were from companies that belonged to upstream suppliers/R&D personnel and 38 (18.18%) were from downstream integrator companies. Those from companies that were end customers/users totaled 64 (30.62%), and 13 (6.22%) were from companies in other sectors. A total of 42 (20.10%) of the respondents were from companies established 0-2 years ago, 45 (21.53%)

were from companies established 3-5 years ago, 39 (18.66%) were from companies established 6-10 years ago, and 83 (39.71%) were from companies established more than 10 years ago.

We examined three independent variables and one dependent variable. Table 5.2 gives the Pearson correlation coefficients among the variables. Our analysis suggested that the dependent variable of innovation performance was associated with the three independent variables of technology empowerment, information empowerment, and product empowerment, with correlation coefficients of 0.578, 0.594, and 0.553, respectively. These values are all higher than zero, indicating that the correlations between innovation performance and the three forms of empowerment were positive.

Table 5.2 Descriptive Statistical Analysis of the Main Variables in the Study (N = 209)

	Technology empowerment	**Information empowerment**	**Product empowerment**	**Innovation Performance**
Technology empowerment	1			
Information empowerment	0.425**	1		
Product empowerment	0.539**	0.438**	1	
Innovation Performance	0.578**	0.594**	0.553**	1

Note: * $p < 0.05$; ** $p < 0.01$

5.3 Reliability and validity tests

Before the exploratory factor analysis (EFA), the author conducted a reliability test on the collected data to ensure the reliability and robustness of the scale of the questionnaire. In general, the study used the Cronbach's α coefficient and the corrected item-total correlation coefficient for the reliability test (Churchill & Peter, 1984). To infer causality between variables, the reliability coefficient should be 0.7 or above. As shown in Table 5.3, the Cronbach'α coefficients of all of the variables were greater than 0.870, and the corrected item-total correlation coefficient was greater than 0.693, indicating good internal consistency among the independent variables, moderating variables, and dependent variables and indicating that they could be used for further analysis.

Table 5.3 Reliability Statistics of the Main Variables of the Questionnaire (N = 209)

	Cronbach Reliability Analysis			
Variable	**Item**	**Corrected Item-total**	**Cronbach's Alpha if Item**	**Cronbach'α**
Technology empowerment	JS1	0.792	0.813	0.873
	JS2	0.693	0.852	
	JS5	0.696	0.851	
	JS6	0.735	0.835	
Information empowerment	XX1	0.776	0.881	0.905
	XX2	0.789	0.878	
	XX4	0.779	0.880	

	XX6	0.704	0.896	
	XX7	0.763	0.884	
Product empowerment	CP2	0.773	0.797	0.870
	CP3	0.768	0.801	
	CP6	0.714	0.850	
Innovation Performance	IC2	0.793	0.850	0.892
	IC4	0.773	0.857	
	IC6	0.732	0.872	
	IC8	0.751	0.865	

(2) Validity test

We combined the EFA and confirmatory factor analysis (CFA) methods to test the discriminant and convergence validity among the constructs. SPSS 26.0 statistical software was used to conduct further principal component factor analysis of the large sample data. First, the KMO and Bartlett's test of sphericity was conducted to assess whether the sample was suitable for EFA. EFA was then performed on the core variables, such as the independent and dependent variables.

1) EFA of independent variables

As shown in Table 5.4, the statistical analysis of the large-sample data revealed that the KMO value of the independent variable was 0.881 and the significance value of Bartlett's test of sphericity was 0.000, indicating that the items set in the questionnaire for the independent variables were suitable for

EFA.

Table 5.4 KMO and Bartlett's Test of Sphericity for Independent Variables in the Questionnaire (N = 209)

KMO and Bartlett's Test of Sphericity		
KMO Measure of Sampling Adequacy		0.881
Bartlett's Test of Sphericity	Approximation to Chi-Square	2361.558
	Degree of freedom	120
	Significance	0.000

After conducting the KMO and Bartlett's test of sphericity, a principal component factor analysis was performed. As Table 5.5 shows, the 16 items of the questionnaire were finally aggregated into four factors, corresponding to technology empowerment, information empowerment, product empowerment, and innovation performance. The total cumulative explained variance of all of the items was 75.365% and all of the loading coefficients were greater than 0.5. We found no cross-factor phenomenon and the EFA test was therefore passed. This indicates that the independent variable factors in this study had good convergent validity.

Table 5.5 EFA Results of the Independent Variables Measured in the Questionnaire (N = 209)

Item	Factor Loading Coefficient			
	Technology empowerment	Information empowerment	Product empowerment	Innovation Performance
JS1	0.146	**0.841**	0.233	0.183
JS2	0.106	**0.767**	0.340	0.097
JS5	0.343	**0.672**	0.214	0.288
JS6	0.236	**0.768**	0.165	0.262
XX1	**0.824**	0.124	0.173	0.172
XX2	**0.834**	0.149	0.140	0.149
XX4	**0.800**	0.146	0.268	0.125
XX6	**0.744**	0.171	0.235	0.090
XX7	**0.792**	0.213	0.181	0.154
CP2	0.199	0.196	0.178	**0.845**
CP3	0.098	0.186	0.216	**0.860**
CP6	0.249	0.265	0.244	**0.742**
IC2	0.256	0.204	**0.818**	0.189
IC4	0.274	0.267	**0.757**	0.219
IC6	0.187	0.265	**0.763**	0.235
IC8	0.380	0.317	**0.663**	0.197

Convergent validity is used to reflect how a latent variable can be measured by different manifest variables, and CFA is mainly used to test it. AMOS 21.0 software was used for structural equation modeling (SEM).

Before testing the convergent validity, it was necessary to test the fit indices of the SEM and evaluate whether the model fit passed the test. The results are shown in Figure 5.1 and Table 5.6. AMOS 21.0 software was again used for first-order CFA modeling of the variables.

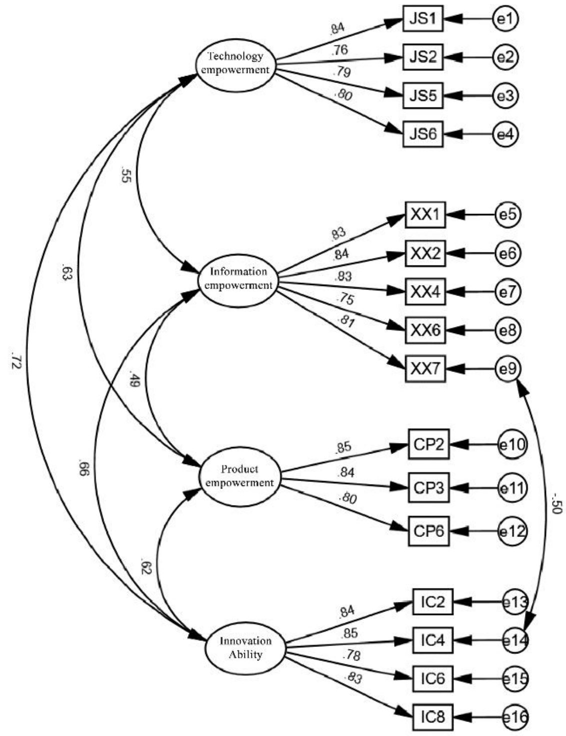


Figure 5.1 Measurement Model of First-order CFA for the Variables

In this study, various indicators were selected to analyze the indices of the first-order CFA model of each variable construct, and the results are summarized in Table 5.6. As shown in the table, χ^2/df = 2.718, NFI = 0.892, CFI = 0.928, TLI = 0.911, IFI = 0.929, RMSEA = 0.091, and SRMR = 0.05. All of the fit indices of the first-order CFA for the variables in the study passed the goodness of fit test. Therefore, a convergent validity analysis of the scale could be performed.

Table 5.6 Overall Fit Coefficient Table (N = 209)

Fit Index	Suggested Value	Measurement Result of the	Meet the Requirement
x^2/df	＜3	2.718	Yes

NFI	≥0.8	0.892	Yes
CFI	≥0.9	0.928	Yes
TLI	≥0.8	0.911	Yes
IFI	≥0.8	0.929	Yes
RMSEA	≤0.1	0.091	Yes
SRMR	≤0.08	0.05	Yes

Four factors and 16 analysis items were covered in the CFA. The valid sample size of 209 was 10 times greater than the number of analysis items and was therefore adequate.

Table 5.7 Factor Loading Coefficient Table

Factor (latent	Measurement Item	Unstandardized Loading	Standard Error	C.R.	*p*	Standardized
Technology	JS1	1.000	-	-	-	0.845
Technology	JS2	0.915	0.074	12.348	0.000	0.760
Technology	JS5	0.986	0.076	12.955	0.000	0.787
Technology	JS6	0.970	0.073	13.266	0.000	0.801
Information	XX1	1.000	-	-	-	0.833
Information	XX2	1.005	0.070	14.368	0.000	0.837
Information	XX4	1.059	0.074	14.331	0.000	0.835
Information	XX6	0.942	0.078	12.145	0.000	0.744
Information	XX7	0.944	0.070	13.569	0.000	0.805
Product empowerm	CP2	1.000	-	-	-	0.854
Product empowerm	CP3	0.944	0.068	13.785	0.000	0.839
Product empowerm	CP6	0.889	0.068	13.159	0.000	0.805
Innovation Performanc	IC2	1.000	-	-	-	0.839

Innovation Performanc	IC4	1.045	0.072	14.481	0.000	0.840
Innovation Performanc	IC6	0.927	0.071	13.079	0.000	0.783
Innovation Performanc	IC8	1.038	0.074	14.080	0.000	0.824

Four factors and 16 analysis items were covered in the CFA. Table 5.7 shows that the values of the average variance extracted (AVE) of the four factors were all greater than 0.5, and the CR values were higher than 0.7, indicating that the analyzed data had good convergent validity.

(3) Discriminant validity

Discriminant validity indicates the extent to which a variable is different from other variables. The judgment criterion is that the square root of the AVE of the items of a construct must be greater than its correlation coefficient with other variables (Fornell & Larcker, 1981). The correlation coefficients and AVE square root matrix results of the independent and dependent variables in this study were calculated; they are shown in Table 5.8. The comparison results reveal that the AVE square root value of each variable was greater than the correlation coefficient between this construct and other constructs, which indicates that the measurement in the study had good discriminant validity.

Table 5.8 AVE Square Root Matrix of the Variables Measured (N = 209)

	Technology empowermen	**Information empowermen**	**Product empowermen**	**Innovation Performanc**
Technology empowerme	**0.799**			
Information empowerme	0.503	**0.811**		
Product empowerme	0.555	0.443	**0.833**	
Innovation Performance	0.649	0.592	0.561	**0.822**

Note: The diagonal numbers are the AVE square root values, and the others are correlation coefficients.

A discriminant validity analysis was then performed. For technology empowerment, the AVE square root value was 0.799, which is greater than 0.649, the maximum absolute value of the correlation coefficient between factors, indicating that it had good discriminant validity. For information empowerment, the AVE square root value was 0.811, which is greater than 0.592, the maximum absolute value of the correlation coefficient between factors, indicating that this also had good discriminant validity. For product empowerment, the AVE square root value was 0.833, which is greater than 0.561, the maximum absolute value of the correlation coefficient between factors, indicating that this had good discriminant validity. For innovation performance, the AVE square root value was 0.822, which is greater than 0.649, the maximum absolute value of the correlation coefficient between factors, again indicating that this had good discriminant validity.

5.4 Common method bias

Given that the data for all of the variables in the study were derived from the same questionnaire completed by the same respondents, common method bias might be an issue (Campbell & Fiske, 1959). During the data validation process, SEM was used to check for common method bias and all items were assigned to a latent variable to build a one-factor fit model and compare it with the four-factor fit model. Any significant difference between the two models would indicate that there was no serious common method bias (Podsakoff & Organ, 1986). As shown in Table 5.9, Model 1 is a four-factor fit model, and Models 2, 3, and 4 are three-factor, two-factor, and one-factor fit comparison models, respectively. The chi-square test showed a significant difference between the two models (p < 0.001). Thus, based on both test methods, we could be confident that no serious common method bias occurred in the questionnaires collected, and further analyses could be conducted.

Table 5.9 Test of Common Method Bias

Model	Combination	χ^2/df	RMSEA	CFI	TLI	IFI	GFI	SRMR	NFI
1	JS, XX, CP, IC	2.718	0.091	0.928	0.911	0.929	0.874	0.05	0.892
2	JS+XX, CP, IC	5.905	0.154	0.787	0.747	0.789	0.695	0.101	0.756
3	JS+XX, CP+ IC	7.456	0.176	0.714	0.667	0.716	0.642	0.110	0.686
4	JS+XX +CP+ IC	8.609	0.191	0.660	0.607	0.662	0.610	0.107	0.634

Note: JS = technology empowerment, XX = information empowerment, CP = product empowerment, IC = innovation performance

5.5 Hypothesis testing

(1) Empowerment mechanism of platforms and innovation performance of customer enterprises

The scores for "position of the company in the industrial chain" and "number of employees" for different variables differed in their levels of significance, so they were converted into dummy variables as controls.

Once these items were converted, linear regression analyses were performed for “number of employees” (less than 20) and “position of the company in the industrial chain” (downstream integrator) as the referred items of the control variables, with technology empowerment, information empowerment, and product empowerment as the independent variables and innovation performance as the dependent variable. The R^2 value of the linear regression model was 0.551, indicating that “position of the company in the industrial chain” and “number of employees,” along with the three forms of empowerment, could explain 55.1% of the changes in innovation performance. An F-test was then performed on the model, and the result (F = 27.114, p = 0.000 < 0.05) showed that it passed the test. This indicated that “position of the company in the industrial chain” and/or “number of employees,” in addition to the empowerment types, can affect innovation performance. In addition, the multicollinearity test results revealed that all VIF values in the model were less than 5, indicating that collinearity was not a problem. The D-W value was also near 2, indicating that there was no autocorrelation in the model and no correlations between sample data. Therefore, the model was robust.

As shown in Table 5.10, the regression coefficient value of technology empowerment was 0.302 (t = 5.194, p = 0.000 < 0.01), indicating that it can have a significant positive impact on innovation performance. The regression coefficient value of information empowerment was 0.371 (t = 6.670, p = 0.000 < 0.01), indicating that it can have a significant positive impact on innovation performance. The regression coefficient value of product empowerment was 0.208 (t = 3.613, p = 0.000 < 0.01), indicating that it can have a significant positive impact on innovation performance. Thus, Hypotheses 1, 2, and 3 were all supported.

Table 5.10 Results of Linear Regression Analysis (N = 209)

	Unstandardized Coefficient		Standardized Coefficient	t	p	VIF	R^2	Adjusted R^2	F
	B	Standard Error	Beta						
Constant	0.136	0.261	-	0.522	0.602	-	0.551	0.531	27.114***
Number of employees (Less than 20)	Referred Item								
20-200	0.129	0.207	0.057	0.624	0.534	3.755			
201-500	0.441	0.228	0.148	1.931	0.055	2.588			
More than 501	0.331	0.240	0.105	1.378	0.170	2.564			
Position of the company in the industrial chain (Downstream integrator)	Referred Item								
Upstream supplier/R&D personnel	0.182	0.153	0.083	1.190	0.236	2.157			
End customer/user	0.054	0.164	0.023	0.326	0.745	2.140			
Others	-0.267	0.249	-0.059	-1.073	0.285	1.348			
Technology empowerment	0.302	0.058	0.309	5.194	0.000**	1.572			
Information empowerment	0.371	0.056	0.378	6.670	0.000**	1.422			
Product empowermen	0.208	0.058	0.222	3.613	0.000**	1.667			

t										
Dependent variable: innovation performance										
D-W value: 2.026										

Note: * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

(2) Analysis of differences in the role of the scale of customer enterprises in the platform empowerment mechanism

An independent-samples t-test was conducted to assess the differences resulting from the scale of customer enterprises (i.e., "number of employees") in technology empowerment, information empowerment, product empowerment, and innovation performance. Table 5.11 shows that when dividing the sample according to the number of employees, no significant difference ($p > 0.05$) was found for technology empowerment, product empowerment, or innovation performance, and thus the total sample appeared to be consistent. However, the different samples of "number of employees" showed significant differences in terms of information empowerment ($p < 0.05$). The details are as follows.

The sample of the "number of employees" showed a significance level of 0.05 (t=2.359, p=0.020) in terms of information empowerment, and a difference comparison analysis showed that the average number of employees (0-200) was 3.86, thus higher than 3.43, which was the average value of the "number of employees" (more than 201).

Table 5.11 Analysis of Differences in How Platforms Can Empower SMEs' Innovation Performance from the Scale of Customer Enterprises

	Number of Employees (Mean ± Standard Deviation)		*t*	*p*
	0-200 people (n = 147)	Over 201 people (n = 62)		
Technology empowerment	3.638±1.101	3.435±1.163	1.193	0.234
Information empowerment	3.856±1.025	3.429±1.260	2.359	0.020*
Product empowerment	3.689±1.105	3.441±1.283	1.331	0.186
Innovation Performance	3.626±1.071	3.633±1.150	-0.044	0.965

Note: * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

(3) The position in the industrial chain affects the promotion role of the platform empowerment mechanism

A one-way analysis of variance (ANOVA) was used to test the differences between "position of the company in the industrial chain" and technology empowerment, information empowerment, product empowerment, and innovation performance. Table 5.12 shows that the different samples of "position of the company in the industrial chain" were all significant ($p < 0.05$) in terms of technology empowerment, information empowerment, product empowerment, and innovation performance, and thus these different samples showed differences in all four aspects. The details are as follows.

The position of the company in the industrial chain had a significance level of 0.05 for technology empowerment (f = 2.909, p = 0.036). The outcome of the comparison of the average scores of the groups with obvious differences was "upstream suppliers/R&D personnel>downstream integrators; end customers/users>downstream integrators."

The position of the company in the industrial chain had a significance level of 0.01 for information empowerment (f = 5.744, *p* = 0.001). The outcome of the comparison of the average scores of the groups with obvious differences was "upstream suppliers/R&D personnel>downstream integrators; end customers/users>downstream integrators; others>downstream integrators."

The position of the company in the industrial chain had a significance level of 0.01 for product empowerment (f = 6.628, *p* = 0.000). The outcome of the comparison of the average scores of the groups with obvious differences was "upstream suppliers/R&D personnel>downstream integrators; end customers/users>downstream integrators; others>downstream integrators."

The position of the company in the industrial chain had a significance level of 0.01 for innovation performance (f = 5.533, *p* = 0.001. The outcome of the comparison of the average scores of the groups with obvious differences was "upstream suppliers/R&D personnel>downstream integrators; end customers/users>downstream integrators."

Table 5.12 Analysis of Differences in Innovation Performance of Platform-Empowered MSMEs from the Industrial Chain Position

	Position of the Company in the Industrial Chain (Mean ± Standard Deviation)			*F*	*p*
	Upstream supplier/R&D personnel (n = 94)	Downstream integrator (n = 38)	End customer/user (n = 64)		
Technology Empowerment	3.68±1.12	3.10±1.11	3.68±1.15	2.909	0.036*
Information Empowerment	3.89±1.03	3.08±1.18	3.82±1.09	5.744	0.001**

Product Empowerment	3.68±1.16	2.91±1.12	3.88±1.09	6.628	0.000***

Note: * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

(4) Difference analysis of platform empowerment mechanism by the times of using 3D printing platform services

A one-way analysis of variance (ANOVA) was used to assess the differences in technology empowerment, information empowerment, product empowerment, and innovation performance due to differences in the number of times 3D printing platform services were used. Table 5.13 shows that the correlation coefficient between different times of using 3D printing platform services and technology empowerment, information empowerment, product empowerment, and innovation performance was not significant ($p > 0.05$), indicating that there was a consistent correlation between the number of times 3D printing platform services were used and the four aspects.

Table 5.13 Analysis of Differences in Innovation Performance of Platform-Empowered MSMEs from the Frequency of Platform Use by Customer Enterprise

	Times of Using 3D Printing Platform Services (Mean ± Standard Deviation)				F	p
	Within 10 (n = 106)	11-30 (n = 29)	31-100 (n = 29)	More than 100 (n = 45)		
Technology Empowerment	3.58±1.14	3.52±0.97	3.40±1.25	3.73±1.09	0.546	0.651
Information Empowerment	3.71±1.12	3.60±1.04	3.79±1.12	3.82±1.17	0.268	0.848
Product Empowerment	3.58±1.19	3.62±1.06	3.59±1.21	3.73±1.16	0.181	0.909
Innovation Performance	3.64±1.14	3.47±1.05	3.64±1.10	3.71±1.04	0.289	0.833

Note: * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

5.6 Research findings

(1) Empowerment mechanism of service-oriented manufacturing platform and innovation performance of customer enterprise

The results of this study confirm the positive effect of the platform empowerment mechanism on the innovation performance of customer enterprises. The results of the hypothesis test of the multiple linear regression model show that technology empowerment, information empowerment, and product empowerment had significant positive effects on the innovation performance of customer enterprises. We also explored the scope of the three platform empowerment mechanisms, which are discussed in the sections below.

The scope of the technology empowerment mechanism. The mechanism is based on the basic digital abilities and composite technical ability output of the service-oriented manufacturing platform, and it was hypothesized to be more favorable among MSMEs, such as upstream suppliers/R&D personnel and end users. Relatively low scores were found for downstream integrators. One explanation is that the industrial internet, big data, 3D modeling data, and other digital technologies on the platform are only helpful to MSMEs with R&D and innovation needs. In addition, the case findings and questionnaire survey data suggest that these customer enterprises must also have the authority to make independent decisions and modify their requirements. For example, the integrator of the auto parts factory downstream in the industrial chain can only passively accept orders from the upstream main engine factory, and thus find it difficult to generate the modification and optimization requirements of their core components, Therefore, it is difficult for their innovation ability base to fundamentally change through the empowerment of external platforms.

The scope of the information empowerment mechanism. Like the technology empowerment mechanism, the mechanism of real-time information sharing and service or production information resource-matching based on the external network attributes of the platform is beneficial for MSMEs such as upstream suppliers/R&D personnel and end users, while relatively low scores were reported for downstream integrators. One explanation is that the cross-level information resources gathered by the platform are useful in the research and experimental stage of new products, which facilitates upstream enterprises with R&D requirements for new products. The resource elements at the business ecosystem level integrated by platform enterprises can also effectively meet end users' production and customization needs. Conversely, for downstream integrators who lack the ability to modify and customize designs, obtaining more industry information is invalid for them because they cannot modify. Their core value is to efficiently deliver products with high quality and in quantity, at a low cost.

The scope of the product empowerment mechanism. This mechanism is based on intensive production and standardized supply chain management, and also plays a vital role in MSMEs such as upstream suppliers/R&D personnel and end users, while relatively low scores were reported for downstream integrators. Thus, compared with ordinary manufacturing enterprises, the "network amplification effect" and the standardized production support of service-oriented manufacturing platforms are significant for upstream R&D institutions and end customers who engage in small-scale experiments. For downstream integrators, one explanation is that the benefits provided by product empowerment are conducive to the entity's business, so even if the service-oriented manufacturing platform provides extensive product production assistance, any improvement of their enterprise innovation performance will be small.

(2) Analysis of differences in innovation performance of platform-empowered MSMEs from the scale of customer enterprises

We assumed that platform-empowered MSMEs' innovation performance varies with the size of the customer enterprise. The effect for platform-enabled small- and medium-scale MSMEs is greater than that for large-scale MSMEs. The research data indicate that the information empowerment mechanism is most effective in promoting the innovation performance of small and medium-scale MSMEs (less than 200 employees) than in large-scale MSMEs (more than 201 employees). This may be due to the specific practices of the enterprises.

First, the platform empowerment mechanism plays a prominent role in promoting innovation performance in small- and medium-scale MSMEs. As mentioned, MSMEs are often at a disadvantage due to the information asymmetry resulting from limited information channels and insufficient information acquisition capacity. Their ability to build an information service platform within the enterprise is limited and their external resources are scarce. Therefore, for these enterprises benefitting from a platform for information empowerment it is undoubtedly timely. Such enterprises have a strong desire to pursue innovation efficiency and achieve transformation. Although they are of limited size, they have flexible decision-making mechanisms and efficient communication and cooperation among departments. The founders or senior managers of these enterprises can go deeper into the front line, have a strong perception of and sensitivity to industry information, and can use external resources to quickly feed back the information to enhance the innovation of the enterprises. Therefore, the information empowerment role of service-oriented manufacturing platforms fits them well, as it supports and improves their innovation performance.

Second, the role of the platform empowerment mechanism in promoting innovation performance in large-scale MSMEs (more than 201 people) is insignificant. These enterprises are typically limited by the traditional manufacturing and production approach. The R&D and production functions are separated, and are thus difficult to coordinate and make any higher-level changes. Platform empowerment can occur in terms of production, but has little direct contact with internal design and R&D departments. Thus, the platform empowerment mechanism can only help with printing production and has little effect on improving large-scale MSMEs' innovation performance. Although 3D printing technology has been developing rapidly in China for more than 10 years, such a technological revolution requires the efforts and practice of several generations, particularly at the application level. As the older generation of technicians is familiar with the traditional technology and operation system, they will find it almost impossible to quickly grasp, adapt to, and operate any new technology. Of course, the understanding and cognition of individuals and specific departments about 3D printing technology has a bearing on this. However, promoting the application of this technology horizontally and across departments in a traditional enterprise with a rigid organizational structure and operation process at an adequate scale is challenging.

(3) Analysis of differences in innovation performance of platform-empowered MSMEs from the customer enterprise's position in the industrial chain

We hypothesized that the position of different customer enterprises in the industrial chain will influence the effect of the platform empowerment mechanism in improving the innovation performance of customer enterprises. The test results show that the scores for empowerment differ according to enterprises' positions in the industrial chain. In terms of the industrial chain position, information, technology, and product empowerment will positively impact performance, as the scores for upstream suppliers/R&D personnel and end users in terms of innovation performance improvement are higher than those for downstream integrators. Thus, we discuss our specific analysis.

The impact on upstream suppliers/R&D personnel. The upstream industrial chain involves the initiation of product creativity, design, and R&D iteration. An enterprise's industry/position determines its sensitivity to information and technology. Various elements determine the future R&D and iteration direction of a factory/product. These include the understanding of the latest technology and the application of information in the industry, the activities of other more advanced enterprises in the same industry, the process developments brought by new technology, the performance improvement brought by new materials, and the optimization of functions through new software. Therefore, the platform's information and technology empowerment provided to upstream suppliers/R&D personnel is beneficial. Although the empowerment process does not bring substantive business transactions to either party, the possibility of subsequent cooperation encourages upstream suppliers/R&D personnel to place orders directly through the platform during new product design, prototyping, testing, and small batch production.

The impact on downstream integrators. These enterprises typically purchase software and hardware directly from external suppliers and are only responsible for designing internal structures and shapes. Downstream integrators therefore typically only connect and arrange the various parts, and have low technical requirements. The scale of such enterprises is generally relatively large, and their organizational structures are relatively stable and rigorous. Their departments only act according to the system and process. The R&D, production, and procurement departments all have separate responsibilities. Such companies are more concerned with reducing costs and improving efficiency. Due to their relatively limited demand and space for innovation, such customer enterprises are less responsive to platform empowerment than upstream suppliers/R&D personnel and end-user enterprises.

The impact on end users. These enterprises have direct user experience of all of the product attributes. They are concerned with product design, function, material, production technology, and improvement. The links between them and the platform are comprehensive. They consider the latest global application cases and the latest technologies and materials and will also use the production capacity of the platform to customize various personalized and small batch parts to improve and upgrade their products. Therefore, the enthusiasm of end-user customer enterprises for innovation can be enhanced by the information and technology empowerment provided by the platform. They will put forward ideas and suggestions for product improvement, identify the shortcomings in the product trial process, and find the product empowerment provided by the platform useful for testing and improvements, thus enhancing their innovation performance.

Chapter 6 Research Results and Prospects

6.1 Research results

Through the exploratory case study discussed in Chapter 3, this study analyzed and identified the technology, information, and product empowerment mechanisms that affect the innovation performance of customer enterprises. The mechanism through which the platform empowers MSMEs does not simply rely on the output of a single factor of production and the matching of transactions between the supplier and the customer. Service-oriented manufacturing platforms empower enterprises through a combination of various technologies, information, and products. However, no studies have explored the effect of different empowerment mechanisms on MSMEs' innovation performance, which represents an important research gap. Chapter 4 proposes the theoretical research model based on the case analysis in Chapter 3. From the data obtained through the questionnaire, Chapter 5 further analyzes the role of technology, information, and product empowerment mechanisms, and their differing effects on customer enterprises of different scales and industrial chain positions. This effectively addresses the current research gap.

6.1.1 The empowerment mechanism of service-oriented manufacturing

platforms and the innovation performance of customer enterprise

The results of this study confirm the positive effect of three platform empowerment mechanisms on the innovation performance of customer enterprises. The results also reveal that the levels of empowerment vary according to enterprises' positions in the industrial chain. Depending on the industrial chain position, information empowerment, technology empowerment, and product empowerment will positively impact performance. These three types of empowerment help upstream suppliers/R&D personnel and end users improve their innovation performance to a greater extent than downstream integrators. Section 5.6 provides the scope of these platform empowerment mechanisms.

6.1.2 Analysis of differences in the innovation performance of platform-empowered MSMEs in terms of the scale of customer enterprises

We examine the key situational factor of enterprise scale and test how this influences the effectiveness of the platform's empowerment mechanism. We propose that the platform empowerment mechanism affects the perception and behavior of different-sized MSMEs through technology empowerment, information empowerment, and product empowerment. The size of the enterprise can weaken or enhance these effects, and thus different levels of improvement in their innovation performance will be observed.

We further define the circumstances under which the effect of the platform empowerment mechanism will increase or decrease. The research data indicate that the information empowerment mechanism is most effective in enhancing the innovation performance of small- and medium-scale customer enterprises (less than 200 people). This suggests the following conclusions.

First, the platform information empowerment mechanism can effectively enhance the innovation performance of small- and medium-scale customer enterprises. These enterprises have the ability to innovate and an awareness of new approaches but are also flexible and efficient. These enterprises develop rapidly, and the communication among departments is smooth. The product demand of the R&D department can be quickly conveyed to the platform through the purchasing department, and the R&D department has the power to place orders directly, and thus it has great autonomy, thus making it open to the benefits of platform empowerment. Due to the small scale of the enterprise, its managers can go deeper into the front line, understand the requirements, implement processes, shorten the feedback chain, and even directly participate in specific R&D projects. They can directly mobilize the platform's capabilities in information, technology, and product empowerment for the enterprise, thus more effectively improving innovation performance.

Second, the role of the platform empowerment mechanism in promoting innovation performance in large-scale customer enterprises (more than 201 people) is insignificant. In such enterprises, the R&D and procurement departments have separate responsibilities and act according to established forms and processes. The clerks and operation personnel of the platform are rarely able to contact the R&D personnel. The purchasing personnel of the enterprise see no benefit in the information empowerment and technology empowerment provided by the platform in the early stages. Although such an enterprise may have a modest demand for 3D printing orders, it is more concerned about the product price and delivery date. As long as the products are delivered according to the contract, no additional in-depth communication is required. The R&D personnel can appreciate the value of the information and technology, but they do not have the ability or power to place orders and test pieces. The purchasing personnel are able to place orders but have no interest in information and technology. It is therefore natural to infer that for such enterprises, platform empowerment will not enhance their innovation performance.

6.2 Theoretical contributions

First, in the context of service-oriented manufacturing, this study defines the concept of platform empowerment and extends the research to service-oriented manufacturing platforms. Scholars have reached a consensus on the definition and process of empowerment (Ramaswamy & Ozcan, 2016; Kohtamaki et al., 2019; Zhang & Lin, 2019), but research on how MSMEs can be empowered by platform enterprises in the context of service-oriented manufacturing is limited. This study focuses on the case of

Bering3D Technology, a typical service-oriented manufacturing platform enterprise that aims to empower MSMEs so they can utilize 3D printing and intelligent manufacturing. By exploring the concept of platform empowerment, it extends the research on service-oriented manufacturing platforms.

Second, this study analyzes the micro mechanism of service-oriented manufacturing platforms that empower customer enterprises. Current empowerment research has shifted from a within-organization to a between-organization focus. The research level has also expanded from the employee to the organization and even the industry. However, the mechanism through which service-oriented manufacturing platforms empower customer enterprises is only roughly outlined. Through our exploratory case analysis, it is found that service-oriented manufacturing platform enterprises, as represented by Bering3D Technology, can improve the innovation performance of MSMEs through three mechanisms: technology empowerment, product empowerment, and information empowerment. This study thus addresses the lack of academic attention given to the micro mechanism of platform empowerment through a clear summary of a practical case.

Third, this study explores the functional boundary of the object characteristics that affect platform empowerment. The platform hosts many MSMEs, and their size and position in the industrial chain affect their levels of platform empowerment. Through case analysis and empirical tests, this study finds that different types of MSMEs absorb platform empowerment differently, providing more microscopic evidence of the functional boundary of the platform empowerment mechanism.

6.3 Management enlightenment

This study takes the service manufacturing platform and empowerment mechanism as the starting point and Bering3D Technology as the research sample. Cases of the company's 3D printing platform in actual operation were analyzed and the specific measures for empowering MSMEs summarized. Through factor analysis, the author conducted a questionnaire survey and data verification of the specific measures that can improve customer enterprises' innovation performance. Based on this, this study provides the following conclusions.

First, the empowerment mechanism of service-oriented manufacturing platforms can significantly promote the innovation performance of MSMEs. For local governments at the county and municipal levels, if the region has an industrial-based economic structure and many MSMEs, the development of service-oriented manufacturing platforms through policy guidance, encouragement, and support will help promote the healthy and rapid development of local MSMEs and improve their innovation performance.

Service manufacturing platforms vary their empowerment methods according to the sizes and industrial chain positions of their customer companies, resulting in different levels of innovation performance. Local governments at the county and municipal levels that already have service-oriented manufacturing platforms should make careful distinctions and considerations when formulating specific supporting policies. They cannot simply take product empowerment (e.g., service output value, tax, etc.) as the only assessment indicator. If the enterprises in a region are mainly small- and medium-scale customer enterprises (less than 200 people), the information empowerment of service-oriented manufacturing platforms in terms of their innovation performance will be more significant. Through the establishment of a platform by the government, more lectures, technology matchmaking meetings, talent training, and other forms can be encouraged to help local MSMEs obtain more industry information, such as on cutting-edge technology application experiences and industry cases, thus effectively promoting their innovation performance.

Local governments should also be aware that service-oriented manufacturing platforms such as those for 3D printing technology have a strong ability for resource integration and reconfiguration. With encouragement and support, they can better empower MSMEs to improve their innovation performance while driving the healthy development of 3D printing service factories that provide no platforms in the region. However, a limited number of service-oriented manufacturing platforms of the same type is preferable in a specific region. Otherwise, it will lead to redundant resource allocation and unfair competition. Local governments should implement measures according to the actual situation of the regional economy, and differentiate the allocation for different types of service-oriented manufacturing platforms, thus achieving mutual complementarity in terms of advantages of resources and regional balance.

Second, understanding the three types of empowerment mechanism can help service-oriented manufacturing platform enterprises improve their customer enterprises' innovation performance and develop a sense of self-worth and their sense of responsibility. These platform enterprises can adopt a more strategic and directional approach to expand their business, based on the results of this paper. In terms of small and medium-sized customer enterprises (less than 200 employees), service-oriented manufacturing platform enterprises should focus on providing information empowerment to improve the viscosity of customer enterprises, quickly bridge the distance, establish business relations, and provide services to improve their innovation performance. For large-scale enterprises (more than 201 employees), the platform should make timely judgments, learn about the industries the customer enterprises belong to, and be aware of the communication modes within the enterprises' R&D and procurement departments and their order processes, to empower them effectively.

In terms of customer analysis, the platforms must consider the position of customer enterprises in the industry chain. Both information and technology empowerment serve product empowerment, and only the realization of product empowerment can bring direct economic benefits. Relying only on product empowerment to establish a long-term cooperative relationship with customer enterprises and improve their viscosity is not sufficient, as the platforms need to provide product empowerment cost-effectively while integrating the necessary information and technology empowerment from the perspective of their customer enterprises. Therefore, platform enterprises should consider the marginal costs of the three types of empowerment, make trade-offs, and do everything possible to empower customer enterprises. They should not only maintain their own input–output ratio but also take into account customer viscosity and industry disruption.

Third, MSMEs should consider this study's results and their own scale and position in the industry chain, so they can work in cooperation with service-oriented manufacturing platforms following their priorities, to effectively obtain the platforms' empowerment.

Thus, the information, technology, and product empowerment provided by service-oriented manufacturing platforms can effectively improve the innovation performance of small and medium-sized customer enterprises. The senior managers should remove all impediments in their internal processes, allowing the employees of R&D and procurement departments to communicate smoothly and share information. Senior managers can lead key projects, establish a long-term communication mechanism with the platforms, and obtain the resources required for innovation and development, to complement the platforms in terms of information and technology, rather than simply offering products and services.

The information, technology, and product empowerment of service-oriented manufacturing platforms can also effectively improve the innovation performance of large-scale customer enterprises. Therefore, such customer enterprises should regard the platforms as having advantages in terms of information, technology, and products, and as their preferred partners within the industry chain. They should analyze how the platforms construct their own means of information and technology empowerment, and assess their comprehensive strength in the empowerment mechanism, rather than making decisions according to traditional procurement elements such as prices and delivery time.

6.4 Research limitations and prospects

This study obtained significant research results by using qualitative and quantitative research methods. However, due to the novelty and complexity of the research questions as well as the limited research methods and capabilities, this study can benefit from further improvement.

First, the selection of the case study samples and the universality of the research results are to some extent limited. This study selected a single case for analysis, which had its own specific requirements and limitations. A multi-case comparative analysis among service-based manufacturing platform enterprises could be conducted in future to reach more stable and universal conclusions.

Second, the measurements of variables and samples/common method bias can be problematic. The central constructs of this empirical study were based on an exploratory case analysis and all of the data came from the same set of questions, so common method bias might have occurred. The sample scope could be expanded in future research, or data could be collected in multiple batches across time intervals to obtain more useful information.

Third, this study focused on the innovation performance improvement of customer enterprises empowered by the platforms, and such improvements incur costs. Although performance improvement is important for enterprises, profitability is the key to their survival. Pursuing improvements in innovation performance at the expense of operating losses will not pay off in the long run. Thus, whether platform empowerment can increase the profits of customer enterprises while improving their innovation performance could be a future research direction, and it would yield results that are more instructive for customer enterprises.

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Appendix 1

Questionnaire

Dear Sir or Madam,

Greetings! First of all, thank you for taking your time to fill out the questionnaire! The purpose of this questionnaire is to explore the relationship between the empowerment of service-oriented manufacturing platforms and the capacity improvement of small and medium-sized enterprises. Your answers are of great significance to this research. I assure you that the data in this questionnaire will only be used for my DBA dissertation, and the information you provide will not be released to the public. You can answer these questions without worries based on your actual situation. Thank you for your participation and cooperation!

Instructions: The questionnaire consists of three parts: the first part is the basic information of individuals and enterprises; the second part is the evaluation carried out by individuals or enterprises on the 3D printing service platforms that they have used; the third part is to evaluate the impact of the 3D printing service platforms on the capacity improvement of enterprises.

I. Basic information of individuals and enterprises

1. Have you ever used a 3D printing service platform? (such as Bering3D Technology)

□ Yes □ No

2. How many times have you used 3D printing platform services over the past five years?

□ Less than 10 times □ 11-30 times □ 31-100 times □ More than 100 times

3. What's the position of your company in the industry chain?

□ Upstream supplier/R&D personnel □ Downstream integrator □ End customer/user □ Others, _______.

4. What's the administrative level of your position?

□ Ordinary staff □ Grassroots management □ Middle management □ Senior management □ Business owner

5. How many years has your company been established?

□ 0-2 years □ 3-5 years □ 6-10 years □ More than 10 years

6. How many employees does your company have?

□ Less than 20 □ 20-200 □ 201-500 □ More than 501

7. The industries in which your company's main business belongs to □ Computer, electronic, and communication equipment manufacturing; □ General and special equipment and transportation equipment manufacturing; □ Electrical machinery and equipment manufacturing; □ Automobile manufacturing; □ Bioengineering and pharmaceutical manufacturing; □ Manufacturing of articles for culture, education, arts, crafts, sports and entertainment activity; □ Furniture manufacturing; □ Manufacturing of petrochemicals, chemical fiber, rubber, and plastics products; □

Manufacturing of textiles, apparel, and clothing; □ Metal manufacturing; □ Food manufacturing; □ Other industries (please specify) ____ _____

8. Nature of property rights of your company: □ State-owned; □ Private; □ Foreign-funded; □ Joint venture; □ Others

II. Evaluations carried out by individuals and enterprises on the 3D printing service platforms they have used

Please tick the options according to your attitude. The numbers 1-5 represent how strongly you agree on the questions, with **"1" representing "strongly disagree" and "5" representing "strongly agree."**

How has the 3D printing platform helped your company over the past three years?

	Platform Empowerment Mechanism	Disagree→Agree				
1	The platform can help us convert the actual product requirements into the technical language (parameters) of 3D printing.	1	2	3	4	5
2	The platform can help us analyze technology/product optimization plans.	1	2	3	4	5
3	The platform can cultivate and provide technical talent for the 3D printing industry.	1	2	3	4	5
4	The platform has launched systematic 3D printing training courses.	1	2	3	4	5
5	The experience and customer application cases in the 3D printing industry pushed by the platform are helpful for us.	1	2	3	4	5
6	The platform can consolidate the supplier resources of the 3D printing industry (such as hardware manufacturers, software manufacturers, and material manufacturers).	1	2	3	4	5
7	The platform can meet our actual needs through ecological chain resources.	1	2	3	4	5
8	The platform can offer us access to 3D printing industrial clusters.	1	2	3	4	5

9	The platform allows us to know more about the business information related to 3D printing (such as the latest technology/product R&D information,	1	2	3	4	5

	market environment information, and user requirement information).					
10	The platform allows us to know more about the use of 3D printing technologies.	1	2	3	4	5
11	The platform enables us to know more about the development of 3D printing products.	1	2	3	4	5
12	The platform has done a lot for promoting 3D printing (such as information sessions, training, and science popularization).	1	2	3	4	5
13	The platform updates/releases the information and data related to 3D printing in a timely fashion.	1	2	3	4	5
14	The platform summarizes the application cases of advanced 3D printing technologies.	1	2	3	4	5
15	The platform allows us to know potential business opportunities for using 3D printing technologies.	1	2	3	4	5
16	The platform helps us explore potential scenarios where 3D printing technologies can be used.	1	2	3	4	5

17	The platform can provide us with the required technology/product support/services (such as 3D modeling, 3D scanning, and 3D modeling optimization)	1	2	3	4	5
18	The platform helps us choose appropriate production processes and materials for our products to meet our actual needs for final products.	1	2	3	4	5
19	The platform has the sufficient production capacity to receive relatively large orders.	1	2	3	4	5
20	The platform can solve the transportation and logistics problems of 3D printed products and meet the timely delivery requirement.	1	2	3	4	5
21	The technicians of the platform communicate with us for effective solutions immediately after quality or delivery problems arise.	1	2	3	4	5
22	The clerks (technicians) of the platform provide us with timely and effective assistance in answering questions to ensure the successful delivery of final products with quality and quantity guaranteed.	1	2	3	4	5
23	The clerks of the platform actively respond to the scattered orders of many categories and small quantities.	1	2	3	4	5

III. Evaluating the impact of the 3D printing service platform on the improvement of innovation performance of enterprises

Compared with the industry average, please indicate the overall situation of enterprise innovation performance over the past three years:

Enterprise Innovation Performance	Disagree→Agree				
1 Our operational efficiency has improved after using the platform.	1	2	3	4	5
2 Our R&D costs have been reduced.	1	2	3	4	5
3 The ability of our technical personnel has improved.	1	2	3	4	5
4 Our R&D efficiency has improved.	1	2	3	4	5
5 Our ability to provide customers with personalized, small-batch products has been improved.	1	2	3	4	5

Thank you for taking the time to complete this questionnaire! I wish you all the best in your work and life!