RESEARCH ARTICLES

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Data Empowerment and Innovation in Chinese Manufacturing Enterprises: Frontier Analysis and Prospect*

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Abstract The development of data science provides new opportunities for innovation in Chinese manufacturing enterprises. As the manufacturing sector urgently needs transformation and upgrading, studying how data empowerment drives innovation in manufacturing enterprises is of strategic significance. This work reviews domestic and foreign research from five aspects: product innovation, business model innovation, long-term competitiveness of enterprises, innovation ecosystem of enterprises, and industry upgrading. It summarizes the main forms and objects of data empowerment, analyzes the paths and mechanisms of data empowerment, and creates a systematic research framework to explore the "black box" of data empowerment that drives manufacturing innovation. Such a framework provides theoretical references for the transformation and upgrading of China's manufacturing sector. Finally, future prospects are proposed to address the extant research gaps and to conduct more in-depth research on innovation driven by data empowerment in the manufacturing sector.

Keywords data empowerment, manufacturing enterprises, innovation, industry upgrading

1 Introduction

Since the reform and opening up in 1978, China has achieved remarkable economic development, with manufacturing enterprises playing a crucial role. According to data from the National Bureau of Statistics of China, the industrial added value of China in 2018 is about 33.9% of total GDP, of which the manufacturing added value is about 29.4%. In terms of economic volume, manufacturing sector is the veritable national pillar. However, the extensive industrial development model makes Chinese manufacturing enterprises not only fail to generate their own "economic rent" in the global value chain, but fall into "low-end lock-in" (Hao & Zhang, 2016). Accordingly, China's economic development has shifted, from the basic state of demand exceeding supply and rapid economic growth to the basic state of an increasingly saturated market and slow economic growth (Guo,

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2016). The main problem facing China's manufacturing sector in the new normal is a severe imbalance between supply and demand (Xin, 2019), with an excessive supply of low value-added products and a severe shortage of high value-added supply. In the macroeconomic background mentioned above, the issue of transformation and upgrading of the manufacturing sector becomes urgent. Advances in data science undoubtedly now provide a critical opportunity for industrial innovation and upgrading.

Baumer (2015) believes that data science is an emerging interdisciplinary field. In specific application areas, data science can fully utilize knowledge in mathematics, statistics, and computer science to extract key and meaningful information from increasingly complex data environments. Cheng et al. (2020) further expound on the essence of data science from the unified perspectives of methodology and ontology, highlighting that data science is a fundamental theory and methodology concerning the realization of the data value chain. It primarily focuses on how to transform data into information, information into knowledge, and knowledge into decision-making, thereby understanding and controlling real world events. The rapid development of data science has made data empowerment a vital source of competitive advantage for manufacturing enterprises while expanding the boundaries of theoretical research and extracting new theoretical mechanisms (Chen et al., 2020). For example, in practice, developed countries have proposed various industrial innovation and upgrading plans around the core concepts of data science, such as Germany's *Industry 4.0*, the United States' *Advanced Manufacturing National Strategic Plan* (Huang & Chen, 2015), and Japan's *Science and Technology Industrial Alliance* (Lu, 2017). In 2015, the State Council of China passed the "Made in China 2025" initiative, with the first goal of manufacturing development being "major progress in digitization, networking, and intelligence."

From 2014 to 2020, big data was included in Premier Li Keqiang's Government Work Report for seven consecutive years, indicating that integrating data and manufacturing has become a key component of national strategy. In terms of theoretical research, scholars have extensively discussed the theoretical innovation brought about by data empowerment. George et al. (2016) believe that the development of data science is a crucial opportunity for the transformation of management science. The international top journal *Journal of Management Information Systems* launched a special issue in 2018 to discuss the strategic value of big data for enterprises (Chiang et al., 2018). Chen et al. (2020) construct a framework for enterprise operation management in the digital environment through theoretical research. Chen et al. (2020), based on a review of strategic management theory, discuss the challenges and opportunities faced by strategic management theory in the digital age. These research efforts have fully demonstrated the academic attention to the theory of data empowerment.

The application of data science in both theory and practice has been extensive,

providing new opportunities for innovation and upgrading of Chinese manufacturing enterprises. However, extant research is relatively scarce. For example, Sun et al. (2020) analyze the development process and concept of data empowerment through literature research, and some scholars have discussed the impact of general information technology investment on overall productivity of enterprises (Li, 2009; Melville, 2004; Qi, 2012; Tambe, 2012). However, less attention has been paid to unique enterprise innovation related behavior and phenomena. Extant research on data empowerment and innovation primarily focuses on business model innovation, value co-creation, and enterprise decision paradigm innovation. For example, Zeng (2019) uses case studies to construct a basic analysis unit of business model innovation in the context of big data. Zhou et al. (2018a) study the process by which platform enterprises promote value co-creation through data empowerment. However, most extant studies do not emphasize the industry background and primarily focus on a single level of innovation, lacking a comprehensive consideration of multiple levels. There is thus a lack of a systematic research framework on how data empowerment drives innovation in manufacturing enterprises. Challenges of understanding the promoting role of data empowerment on innovation in manufacturing enterprises from a theoretical perspective present an urgent issue for the academic community to address.

In light of this, the main objective of this paper is to understand innovation in manufacturing enterprises from the perspective of data empowerment. Unlike many studies that do not emphasize the industry background, this paper focuses on the manufacturing sector. By reviewing relevant literature from both domestic and international sources, the paper clarifies the evolutionary process of empowerment and proposes the forms and objects of data empowerment. It thus explores the paths and mechanisms of data-driven innovation in manufacturing enterprises from five aspects: product innovation, business model innovation, long-term competitiveness of enterprises, innovation ecosystem within enterprises, and industry upgrading. Finally, the paper constructs a multi-level research framework for data-driven innovation in manufacturing enterprises. On the one hand, a comprehensive research framework helps to analyze the empowerment of data technology from various aspects of innovation in manufacturing enterprises and from a theoretical perspective. It also helps researchers to identify theoretical gaps and to conduct a series of problem-oriented research. On the other hand, in the context of the urgent need for transformation and upgrading in the manufacturing sector, this research has particular practical value for enterprise managers and policy-makers.

2 The Essences, Forms, and Main Objects of Data Empowerment

2.1 | The Essences of Data Empowerment

The concept of empowerment originates from the idea of authorization and has since

been expanded. Traditionally, authorization empowerment has emphasized internal rights allocation within organizations. For example, Thomas and Velthouse (1990) define empowerment as intrinsic motivation reflected in four cognitive dimensions (meaning, complementarity, self-determination, and impact), which in turn reflect individuals' work role orientation. Currently, there is no consensus in the academic community regarding the concept and dimensions of empowerment. For example, Leong et al. (2015) suggest that empowerment can be understood in terms of three different dimensions: structural empowerment, psychological empowerment, and resource empowerment. Zhou et al. (2017) argue that extant literature mostly focuses on two research perspectives, namely employee empowerment and customer empowerment, where employee empowerment can be further divided into three dimensions: structural empowerment, leadership empowerment, and psychological empowerment. Lenka et al. (2017), based on qualitative data from four industrial manufacturing enterprises, conceptualize data empowerment from three aspects: intelligence capability, connect capability, and analytic capability.

From another perspective, scholars have proposed the concept of enablement (Chen et al., 2020). Bhatt et al. (2010) study the enabling effect of information technology infrastructure flexibility on organizational responsiveness and find that it can help enterprises to establish competitive advantages. Camisón and Villar (2014) utilize empirical research methods to verify that organizational innovation is an enabling factor for technological innovation capability and solid performance. Wamba et al. (2017) argue that big data analytics has become a new enabler of competitive advantage. Therefore, compared to empowerment, enablement has a broader scope of application. In this paper, the definition of empowerment is closer to that of enablement, and data empowerment refers to the ability to empower data, which is the ability to enhance a company's competitiveness through the application of data.

2.2 | Main Forms of Data Empowerment

2.2.1 *Knowledge Generation (Insights)*

This form of empowerment relies on information technologies such as artificial intelligence (AI), machine learning, and business intelligence. These new technologies, through algorithms, data, and AI, free people from low-level cognitive work and enable the production of products and services with high knowledge value (Mu & Ji, 2017). Ubiquitous sensors and smart devices can collect a massive amount of data, but raw data are not "intelligent." It is through the integration of values, theories, knowledge, and even intuition into algorithmic models by humans as innovative agents that intelligence is continuously improved through feedback, learning, and iteration. By combining human initiative and creativity, it is possible to generate the knowledge or insights required in the innovation process of manufacturing enterprises (Brantly, 2018).

2.2.2 *Perception of Change*

In the era of intelligent interconnectivity, enterprises face a rapidly changing business environment, especially with the widespread application of automated decision-making technologies. Enterprises must make quick decisions. The development of management information systems, big data, and AI technologies enhances the information dissemination and data processing capabilities of enterprises. Thereby, they improve their perception and their adaptability to external information and enhance organizational agility in dynamic market environments (Cepeda & Arias, 2019). In terms of innovation in the manufacturing sector, data empowerment can enhance the sensitivity, accuracy, and real-time processing capabilities of manufacturing enterprises, thereby improving their ability to perceive and respond to changes.

2.2.3 *Connectivity of Things and People*

Data technologies, such as the Internet of Things (IoT), intelligent manufacturing, and cloud computing, enable the digitization of the physical world, allowing information sharing and collaboration to occur between people, between people and their objects, and between objects themselves. For example, placing sensors in refrigerators in retail stores allows store managers to monitor sensor data in real time through the IoT. When the refrigerator experiences an anomaly, the alarm system alerts the store manager, who can then allocate repair tasks (Lee & Lee, 2015). Unlike the previous form of "perception of change," the "connectivity of things and people" emphasizes the convenience brought by data empowerment through connections. In the manufacturing sector, the widespread application of intelligent manufacturing can significantly reduce the cost of connectivity, making connections more convenient and improving the efficiency of industry resource integration, and thereby promoting innovation.

2.2.4 *Coordination of Activities*

The application of information systems can make organizational structures more flexible, enabling enterprises to respond quickly to external changes. For example, flexible innovation requires multifunctional teams, flattened hierarchical structures, and smooth communication channels. Successful management requires organizations to respond to dynamic external changes and ensure the achievement of organizational goals through effective coordination of resources and activities (Dubey et al., 2021). Data empowerment in manufacturing enterprises can, to a certain extent, better devise organizational activities and make coordination activities more targeted.

2.2.5 *Decision Support*

Data analysis is considered a game-changer in modern business rules, as it has high operational and strategic potential and can comprehensively improve the operational and business efficiency of enterprises, becoming the shaper of competitive advantage for enterprises (Wamba et al., 2017). In fact, in the era of big data, it is becoming increasingly common for enterprises to utilize more

business intelligence and decision support systems to assist in decision-making. The characteristics of big data, such as full samples, objectivity, and real-time data, can make decision-making more objective for enterprises. Furthermore, a series of new technologies, such as machine learning and big data mining, can predict customer behavior characteristics and dynamic paths of competitors through data analysis results, providing significant decision-making support.

2.3 | Empowerment of Main Entities

2.3.1 *Empowerment of Individuals and Teams*

Jia (2016), an economics professor of Renmin University of China, believes that the era of industrial intelligence based on information and data involves a process of replacing physical labor with mental labor and mental labor with AI. Data empowerment frees people from low-dimension repetitive work, allowing them to focus more on creative and challenging tasks, while enhancing their self-efficacy, thus unleashing their inner potential (Zhou et al., 2018c). Furthermore, data empowerment can facilitate communication, collaboration, and information sharing among individuals, enabling teams to allocate resources and make decisions more efficiently (Hu & Lu, 2018).

2.3.2 *Empowerment of Management Methods*

In the era of intelligent data empowerment, the operational status of enterprises is becoming more transparent. Sensors and smart terminals collect large amounts of operational data for enterprises, and a management team can make quick decisions based on real-time data to judge the operational status of the enterprise, so that virtualization becomes the norm of work (Li & Huang, 2017). Data empowerment can comprehensively optimize the production and management of enterprises, while managers can play the role of coaches, empowering subordinates with more choices, and improving the overall efficiency of enterprise management (Zhou et al., 2017). Furthermore, the internal and external environment that enterprises face in the era of intelligence is undergoing dramatic changes, forcing enterprises to rethink their business models and management methods. New technologies such as data empowerment can provide a solid technological foundation for the development of new management theories and changes in management methods in the new era.

2.3.3 *Empowerment of Technology*

Massive raw data is a rare resource that is tied to technology. Together, data produce intelligence, while big data is the development path of emerging technologies, which points out a new direction. This shows that data empowerment can rely on data technology to promote different technologies surgery further fusion.

2.3.4 *Empowerment of Organizational Structure*

In the context of data empowerment, the organizational structure of enterprises

also undergoes changes. Jarrahi (2018) believes that data mining and big data prediction can provide technical support for business intelligence and assist decision-making, while making the organizational structure flatter and more decentralized. Data empowerment can greatly improve the efficiency of information acquisition. Sharing information can somewhat solve the problem of organizational information asymmetry, and reduce organizational production costs and transaction costs. In the new technological environment, hierarchical organizational structures have difficulty in adapting to internal and external organizational environments, and in the era of data empowerment, organizational structures exhibit network characteristics (Feng, 2018). In summary, the main forms, objects, and corresponding representative data technologies of data empowerment are shown in Figure 1.

3 Data Empowerment Driving Mechanisms and Pathways for Innovation in Manufacturing Enterprises

Previous research on the essences, forms, and main objects of data empowerment is basic research, addressing the question of "what." Such research provides a foundation for studying the mechanisms that drive innovation in manufacturing enterprises through data empowerment. However, to open the "black box" of innovation in manufacturing enterprises driven by data

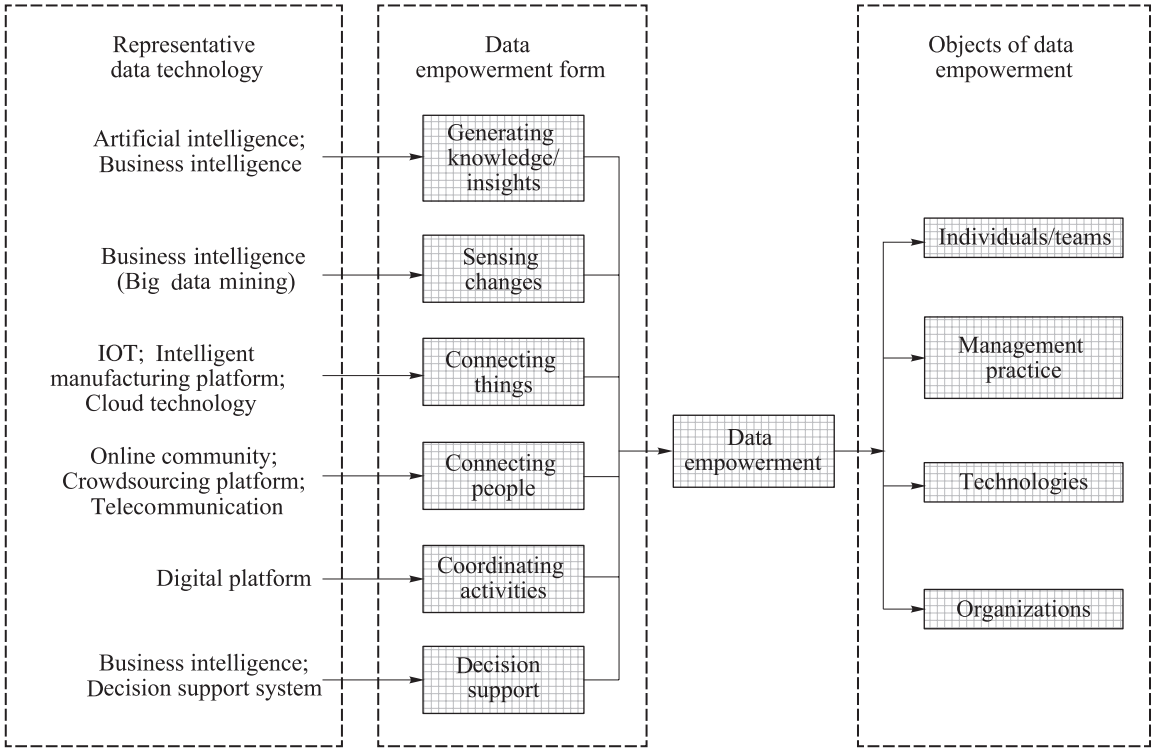

Figure 1 Main Forms of Data Empowerment, Their Objects, and Corresponding Representative Data Technologies

empowerment, it is necessary to conduct indepth research on mechanisms, thus considering the question of "why." Some scholars have conducted research and discussions on the relationship between data empowerment and enterprise innovation from perspectives such as data empowerment (Zhao & Jing, 2019; Zhou et al. 2018a), ecosystem (Hu & Lu, 2018), co-creation of value (Hao & Yin, 2018; Kong, 2019; Lenka et al, 2017; Zhao & Jing, 2019; Zhou et al. 2018a), strategic entrepreneurship (Zhou et al., 2017), platform empowerment (Zhou et al., 2018b), agile manufacturing (Sun & Su, 2018), and large-scale customization technology (Zhou et al., 2018c). However, most of the extant research does not emphasize the industry background and has not developed a complete research framework. In light of this, this paper focuses on the manufacturing sector and establishes the connection between data science and organization science. It analyzes how data empowerment drives innovation in manufacturing enterprises from five dimensions: product innovation, business model innovation, long-term competitiveness of enterprises, innovation ecosystem of enterprises, and industry upgrading in the manufacturing sector. The paper attempts to open the "black box" of explanations of mechanisms and pathways.

3.1 | Data Empowerment and Product Innovation in Manufacturing Enterprises

Cooper (1990) argues that product innovation, whether it involves developing new products or improving existing ones, is crucial for the survival and development of modern enterprises. In the context of data empowerment, enterprises can fully utilize data technology to rapidly iterate and innovate their products, and this utilization becomes a source of their competitive advantage. For example, Zhan et al. (2017) propose that accelerating the innovation process, strengthening customer relationships, and building an innovation ecosystem can help enterprises develop products at a faster pace and lower cost. Sun and Su (2018) use a case study approach to construct a process model for data empowerment to help manufacturing enterprises to achieve agile manufacturing. By reviewing extant literature, the present paper elucidates the mechanisms through which data empowerment drives product innovation in manufacturing enterprises from three aspects: technological innovation, open innovation, and agility. The specific research framework is shown in Figure 2.

3.1.1 *Pathway One: Data Empowerment–Technological Innovation–Product Innovation in Manufacturing Enterprises*

Utterback and Abernathy (1975) define product innovation as the introduction of new technologies or technological combinations in business to meet customer or market needs. Their work highlights the importance of technological innovation for product innovation. The increasingly mature data analysis and data mining technologies can identify complex relationships that are not easily discovered from massive raw data. This

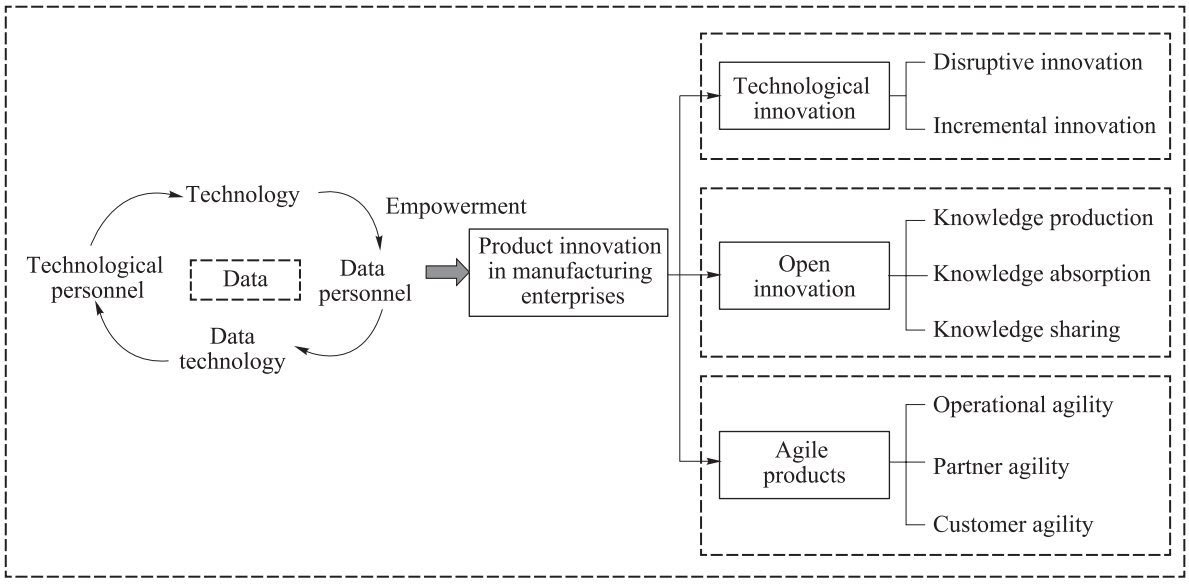

Figure 2 Research Framework of Data Empowerment and Product Innovation of Manufacturing Enterprises

helps enterprises to reconfigure production elements, to optimize resource allocation, and to further identify new customer markets. This data-driven innovation allows manufacturing enterprises to achieve disruptive innovation in technology. Furthermore, in the context of data empowerment, the distance between enterprises and consumers is shortened, making interactions between the two more convenient and enhancing customer participation. For example, the MI company encourages customer participation in product development. Meanwhile, enterprises continuously mine and analyze data, from customer comments, browsing records, and search records, to gradually optimize products and technologies, realizing incremental innovation (Zheng & Zhou, 2019). In this context, technological innovation gradually becomes the cornerstone of product innovation in manufacturing enterprises.

3.1.2 *Pathway Two: Data Empowerment–Open Innovation–Product Innovation in Manufacturing Enterprises*

In the era of data empowerment, more and more enterprises actively expand their organizational boundaries and join open innovation networks. Chesbrough (2006) defines open innovation as purposefully using the inflow and outflow of knowledge to accelerate internal innovation and expand external innovation markets. It is clear that knowledge is the core element of open innovation. In the era of intelligence, data grow exponentially. In the context of data empowerment, manufacturing enterprises can generate knowledge and insights through data mining and data analysis technologies, reducing the cost of knowledge production. After new knowledge is generated, AI and machine learning technologies can quickly absorb and transform it into the enterprise's own productivity. Moreover, innovation networks accelerate the flow of knowledge, further promoting knowledge sharing. In summary, data empowerment can reduce the cost of knowledge production, facilitate knowledge absorption and sharing, and make open innovation more common in enterprises, thereby further improving the efficiency of product innovation in manufacturing enterprises.

3.1.3 *Pathway Three: Data Empowerment–Organizational Agility–Product Innovation in Manufacturing Enterprises*

Based on the dynamic capability perspective, organizational agility is mainly composed of operational agility, partner agility, and customer agility (Sambamurthy, 2003). In terms of operational agility, manufacturing enterprises can observe their operational status in real time by transmitting data through intelligent terminals. They can make management decisions quickly, based on intelligent decision support systems and further optimize operational processes by mining operational data. Moreover, in terms of partner agility, manufacturing enterprises can enhance cooperation flexibility by dynamically evaluating and selecting partners, while reducing cooperation risks. Finally, in terms of customer agility, manufacturing enterprises can improve their ability to perceive customer needs by analyzing customer requirements and interacting with customers closely. It is evident that the data empowerment environment can enhance organizational agility, enable manufacturing enterprises to operate efficiently, communicate conveniently with partners, and have a good grasp of customer needs. Meanwhile, high organizational agility can reduce the cost and risks of product innovation, improving alignment of product innovation with personalized customer demands. In summary, from the perspective of dynamic capabilities, data empowerment can promote product innovation in manufacturing enterprises by enhancing organizational agility.

3.2 | Data Empowerment and Business Model Innovation in Manufacturing Enterprises

Ng (2014) argues that data is a new economic resource that can motivate enterprises to innovate their business models and transform the relationship between producers and consumers. Li and Xia (2013) propose a three-dimensional perspective of big data-driven business model innovation. Hao and Yin (2018) introduce the concept of value co-creation to explain the mechanism of empowerment and business model innovation. Based on extant literature, this paper focuses on the following three perspectives: intelligent manufacturing, marketing channels, and Chinese-style "bricolage innovation." The specific research framework is shown in Figure 3.

3.2.1 *Pathway One: Data Empowerment–Enterprise Intelligent Manufacturing–Business Model Innovation in Manufacturing Enterprises*

The development of the internet and intelligent technology has enhanced the manufacturing sector's capabilities in collecting, transmitting, and processing big data. There is now deep integration of manufacturing technology with information and communication technology, as well as intelligent technology, and especially integration with product-related expertise. This is leading to an unprecedented transformation in manufacturing models, methods, and ecosystems. Intelligent manufacturing is becoming increasingly critical for manufacturing enterprises in

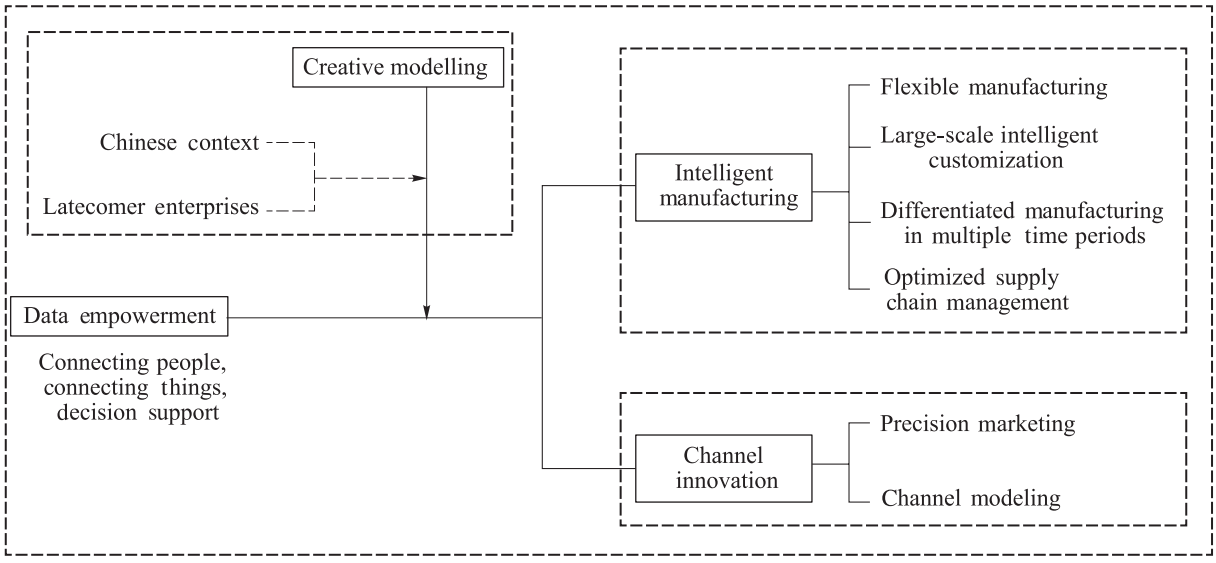

Figure 3 Research Framework for Data Empowerment and Business Model Innovation in Manufacturing Enterprises

gaining competitive advantages.

Firstly, in the context of data empowerment, various intelligent terminals enable production equipment to become more intelligent (equipment intellectualized). The application of AI and machine learning makes the entire production process intelligent and controllable (production intellectualized). The development of data technology lays the technological foundation for manufacturing enterprises to achieve flexible manufacturing and large-scale intelligent customization, and even allows advanced production technologies such as differentiated manufacturing in different time periods (Zhou et al., 2018c).

Secondly, supply chain management based on data and real-time feedback becomes more efficient (supply chain management intellectualized). On this basis, it is possible to reduce the cost of energy management for enterprises and improve the efficiency of resource allocation in the manufacturing sector (energy management intellectualized) (Cheng et al., 2016). In the context of data empowerment, intelligent manufacturing has become an important pathway to business model innovation in manufacturing enterprises.

3.2.2 *Pathway Two: Data Empowerment–Marketing Channel Innovation–Business Model Innovation in Manufacturing Enterprises*

Currently, the various marketing channels used by the manufacturing sector have complex relationships. Should enterprises choose a single channel to advertise, or should they simultaneously advertise on television, online channels, and mobile channels? Which advertising channel has a greater impact on consumers? Do sales channels cannibalize each other or complement each other (Chiu et al., 2011)? These are the challenging questions that enterprises urgently need to address. Data empowerment can provide new insights for manufacturing enterprises to optimize their marketing channels. Manufacturing enterprises can analyze the relationships between advertising channels using data mining techniques and measure their impacts on consumers. Precision marketing based on this analysis can minimize costs and improve marketing efficiency.

Similarly, enterprises can establish models to assess single and multiple sales channels to find the channel combination that maximizes profits, or even create marketing channels based on personalized needs. In this context, business model innovation through marketing channel innovation is gradually becoming an important driving force for business model innovation in manufacturing enterprises.

3.2.3 *Pathway Three: Data Empowerment–"Bricolage"–Business Model Innovation in Manufacturing Enterprises*

The concept of "bricolage" was introduced by Nelson in 2005 in the field of innovation and entrepreneurship. He notes that when entrepreneurs have limited resources to meet their needs, they can make full use of existing resources to address immediate problems (Li & Zhou, 2017). Manufacturing enterprises, especially small-scale latecomers in the industry, can quickly respond to external environments when resources are scarce. This response is based on their ability to perceive changes, as these enterprises with simple organizational structures can quickly assess market changes. Additionally, such enterprises are good at generating new knowledge and promoting team learning and the development of learning organizations using limited resources. Therefore, in the context of data empowerment, the "bricolage" model promotes business model innovation in manufacturing enterprises, especially among latecomers, through the perception of changes, knowledge generation, and other forms of innovation.

3.3 | Data Empowerment and Long-Term Competitiveness of Manufacturing Enterprises

The enterprise-resource-based view suggests that an enterprise is a collection of resources and capabilities. Data and data technologies are important heterogeneous resources within organizations, and these resources play crucial roles in enabling enterprises to gain competitive advantage and achieve above-average profits. For enterprises, obtaining competitive advantage and then maintaining competitive advantage are equally important. Dynamic capabilities, absorptive capacity, and ethical considerations in the context of data empowerment are of great significance in maintaining long-term competitiveness. The specific research framework is illustrated in Figure 4.

3.3.1 *Pathway One: Data Empowerment–Dynamic Capabilities–Long-Term Competitiveness of Manufacturing Enterprises*

The dynamic capabilities theory analyzes the sources of wealth creation and wealth acquisition capabilities in rapidly changing environments. This theory assumes that highly dynamic enterprises have a competitive advantage compared to enterprises with low dynamic capabilities. It explains how enterprises create and maintain competitive advantages relative to other enterprises (Teece et al., 1997). Pavlou and El Sawy (2011) have constructed a model for analyzing dynamic capabilities, which includes four components: sensing capabilities, learning capabilities, integrating capabilities, and coordinating capabilities.

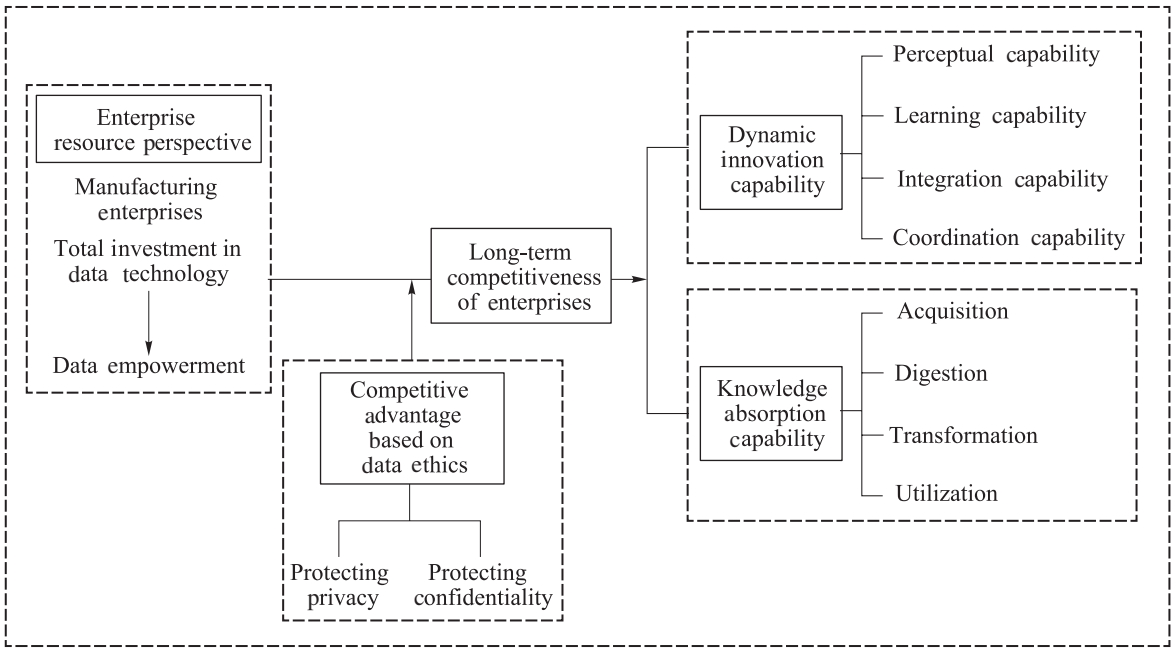

Figure 4 Research Framework for Data Empowerment and Long-Term Competitiveness of Manufacturing Enterprises

In the context of data empowerment, manufacturing enterprises can enhance their environmental sensing capabilities by using intelligent technologies, particularly big data technologies. Furthermore, enhanced learning capabilities facilitate the generation of new knowledge and insights, and digitized operational data enables managers to make quick decisions. In addition, more flexible organizational structures help enterprises to efficiently allocate resources, thereby improving their coordinating capabilities. Therefore, manufacturing enterprises can obtain and maintain long-term competitive advantages by implementing the aforementioned strategies.

3.3.2 *Pathway Two: Data Empowerment-Absorptive Capacity-Long-Term Competitiveness of Manufacturing Enterprises*

The absorptive capacity theory examines the process by which organizations identify, acquire, and apply new knowledge to achieve organizational goals (Cohen & Levinthal, 1990). Zahra and George (2002) identify four dimensions of absorptive capacity: acquisition, assimilation, transformation, and exploitation. All of these are focused on new knowledge. In the context of data empowerment, manufacturing enterprises can acquire more new knowledge, and mine and identify existing knowledge through data technologies. Machine learning and AI algorithms can further facilitate the assimilation and absorption of new knowledge. Additionally, in a data-empowered environment, manufacturing enterprises become more flexible and can quickly transform and exploit new knowledge. The aforementioned analytical framework explains how data empowerment promotes the absorptive capacity of manufacturing enterprises, thereby maintaining their long-term competitiveness.

3.3.3 *Pathway Three: Data Ethics-Competitive Advantage-Long-Term Competitiveness of Manufacturing Enterprises*

Ethical theory provides perspectives and recommendations on how individuals should conduct themselves (Brady &

Hart, 2007). Sound ethics have a common feature: enabling individuals to present persuasive and logical arguments based on ethical theory principles. In the era of data empowerment, as data are increasingly collected independently of customer activities, customers face risks of being subject to data misuse and privacy breaches. Responsible application of data has become a strong demand from consumers. Mandinach et al. (2015) point out that data ethics include how data are used and how privacy and data confidentiality are protected. In the context of data empowerment, manufacturing enterprises can develop long-term data utilization strategies, commit to protecting customer privacy, and respect customer choices, making data processing transparency a long-term competitive advantage.

3.4 | Data Empowerment and the Innovation Ecosystem of Manufacturing Enterprises

The concept of an innovation ecosystem is emerging, and many enterprises are attempting to establish or join a strong innovation ecosystem to enhance their innovation capabilities and market responsiveness. Well-known enterprises such as Apple, Google, Microsoft, and Siemens have built large-scale innovation ecosystems based on their strong technological capabilities and resource advantages (Su et al, 2018). Huang and Chen (2016) have studied collaborative innovation models in innovation ecosystems, and Zhang et al. (2018) have studied the formation paths of competitive advantages for platform enterprises in innovation ecosystems. Based on this, this paper analyzes the mechanism by which data empowerment drives the cultivation of innovation ecosystems in manufacturing enterprises.

3.4.1 *Pathway One: Data Empowerment-Enterprise Collaborative Innovation-Innovation Ecosystem of Manufacturing Enterprises*

In a competitive environment with high complexity and uncertainty, organizations exchange information and resources with the external world, resulting in the overall or synergistic effect of industry-university-research institute integration. In the context of data empowerment, the factors influencing enterprise collaborative innovation can be divided into two parts: internal and external (Wang & Wei, 2019). Internally, data empowerment facilitates the generation of knowledge and insights in manufacturing enterprises, laying the foundation for collaborative innovation. The application of data technology can reduce communication costs between organizations, increase enterprise profits, and provide a material foundation for collaborative innovation. Externally, data empowerment can reduce information asymmetry among enterprises, thereby reducing moral risks and promoting collaborative innovation. Information sharing helps to enhance trust among supply chain enterprises, laying a solid cooperative foundation for collaborative innovation. Data empowerment promotes collaborative innovation in manufacturing enterprises by influencing internal and external factors, further promoting the

cultivation and development of innovation networks and innovation ecosystems in enterprises.

3.4.2 *Pathway Two: Data Empowerment–Enterprise Platform Innovation–Innovation Ecosystem of Manufacturing Enterprises*

Platform innovation is a product of the times. It is a process of achieving win-win cooperation among bilateral or multilateral groups through the creation of new platforms or iterative improvement of existing platform business models (Adner, 2017). The *Industrial Internet Platform White Paper (2019)* released by the Industrial Internet Industry Alliance shows that the overall development of industrial internet platforms is in the early stage and has shown a booming trend. There are already hundreds of well-known industrial internet platforms across the country, such as Haier, Baosight, XCMG, and Foxconn, which have industry influence. In the context of data empowerment, manufacturing platforms expand the scope of data collection, enhance the effectiveness of data applications, and broaden the application areas of data. Industrial data have become the source of industrial knowledge, and the resulting industrial knowledge can modularize and write software of traditional empirical judgments. Moreover, the development of industrial platform apps and AI further lays the technological foundation for knowledge innovation. Data-driven manufacturing platform innovation is gradually becoming an essential component of the manufacturing innovation ecosystem.

3.5 | Data Empowerment and Manufacturing Sector Upgrading

The Chinese economy has evolved into a new normal, and promoting industry upgrading and economic restructuring has become a key task for future economic development. Upgrading the manufacturing sector has always been a focus of industrial economics research, with extant studies mainly focusing on the essences, the driving factors, and the upgrading paths and strategies. It is generally believed that upgrading the manufacturing sector can be approached from the perspectives of industrial structure and value chain (Fu & Liu, 2017). In the context of data empowerment, this paper analyzes the impact path of data empowerment on the upgrading of the manufacturing sector from two aspects: service-oriented manufacturing, and the reconstruction of the manufacturing value chain.

3.5.1 *Pathway One: Data Empowerment–Service-Oriented Manufacturing–Manufacturing Sector Upgrading*

Service-oriented manufacturing has occurred in almost all industries worldwide. Vandermerwe and Rada (1988) have proposed that service-oriented manufacturing has gone through three stages: product or service, product+service, product+service+support activities+knowledge+self-service. Currently, service-oriented manufacturing in the manufacturing sector is at the third stage. Xu et al. (2016) argue that manufacturing enterprises are transitioning from product-centric manufacturing to service-centric

manufacturing. In the context of data empowerment, manufacturing enterprises can secure a large amount of consumer data at a very low cost and use data analysis and mining technologies to accurately identify consumer preferences. Consumers can customize personalized products and services based on their own needs and preferences, while enterprises can engage in large-scale personalized production based on consumer preferences, truly achieving flexible manufacturing. Moreover, manufacturing enterprises can proactively design the evolutionary path of consumer preferences by predicting them, and then they can integrate enterprise resources, reduce operating costs, and produce products and services that meet consumer expectations. Practical experience has shown that service-oriented manufacturing is a feasible path for upgrading of manufacturing enterprises in China (Xu et al., 2016).

3.5.2 *Pathway Two: Data Empowerment–Manufacturing Value Chain Reconstruction–Manufacturing Sector Upgrading*

In the era of AI, the global value chain is undergoing a series of deconstruction and reconstruction processes, providing excellent opportunities for China's manufacturing sector to succeed in overtaking and rising to the high-end segments of the value chain. In the context of data empowerment, technology primarily drives the reconstruction of the value chain by influencing the high value-added segments of the "smile curve" through product R&D and marketing channels (Yu & Shui, 2017). Manufacturing enterprises can generate knowledge and insights based on massive customer data, promptly measuring customer satisfaction, and adjusting product design accordingly. Moreover, manufacturing enterprises can respond quickly to external changes and achieve organizational and product agility. Furthermore, data empowerment can change the traditional marketing channels of manufacturing enterprises, integrate online and offline channels, and build optimal channel combinations through data analysis. Data empowerment, by influencing the high value-added segments of the manufacturing value chain, achieves value chain reconstruction and value chain upgrading, furthering upgrading the manufacturing sector.

4 Integration of Data Empowerment and Manufacturing Enterprise Innovation Research Framework

Based on the above analyses of the main forms and objects of data empowerment, this paper opens the "black box" of mechanisms through which data empowerment affects innovation in manufacturing enterprises, based on relevant organization theory, and establishes the connection between organization science and data science. On this basis, this paper constructs a research framework for the integration of data empowerment and innovation in manufacturing enterprises, as shown in Figure 5.

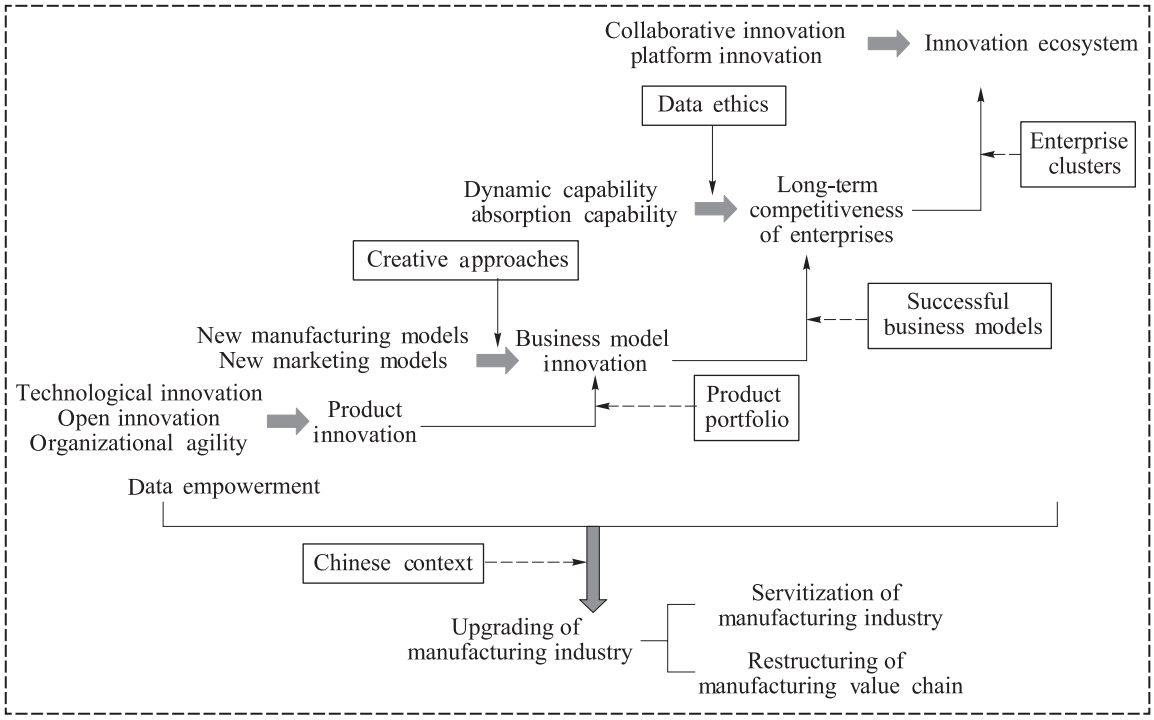

Figure 5 Research Framework for Data Empowerment and Innovation in Manufacturing Enterprises

This study constructs a multi-level and theoretically supported data-empowered innovation model for manufacturing enterprises, integrating data empowerment with innovation in manufacturing enterprises. Firstly, at the micro level, it analyzes how data and data science empower individuals and teams in manufacturing enterprises, i.e., how they influence individuals' and teams' initiative and innovation capabilities. Secondly, at the meso level, it investigates how data technology empowers enterprise organization and management, including the impact of data empowerment on the innovation capability of business models, long-term competitive capabilities of enterprises, and the construction of enterprise innovation ecosystems. Finally, at the macro level, it analyzes how data and data science empower the productivity improvement of the manufacturing sector.

From the micro level to the meso level and then to the macro level, data-empowered innovation in manufacturing enterprises is a multi-level and interconnected phenomenon. Product innovation is the foundation of business model innovation. Such innovation creates long-term competitive capabilities for enterprises, and an innovation ecosystem is formed integrating individual enterprise innovation with cluster innovation, ultimately leading to industry upgrading as the ultimate outcome of data empowerment. This research framework starts from a theoretical perspective and is grounded in practice, aiming to provide guidance for academic researchers and business managers.

5 Conclusions and Outlooks

5.1 | Research Conclusions

In the current context of the urgent need for transformation and upgrading of the manufacturing sector, studying how data empower innovation in manufacturing enterprises is of strategic importance. This paper explores the frontier dynamics of data empowerment and innovation in manufacturing enterprises through a literature review, and draws the following conclusions.

First, the essence of data empowerment is the ability of the application of data to enhance competitiveness. Second, there are five main forms of data empowerment which are generating knowledge (insights), perceiving changes, connecting things and people, coordinating activities, and decision support. Third, the targets of data empowerment mainly include individuals and teams, management methods, technology, and organizational structure. Fourth, following the logic from the micro level to the meso level and then to the macro level, data primarily drive innovation in manufacturing enterprises through five mechanisms: empowering product innovation, business model innovation, long-term competitive capabilities of enterprises, enterprise innovation ecosystems, and industry upgrading. Each mechanism has its corresponding empowerment path. Fifth, from a holistic and systematic perspectives, this paper integrates the forms and objects of data empowerment, and the mechanisms and corresponding theoretical paths of data-empowered innovation in manufacturing enterprises. It then provides a new knowledge map for researchers and practitioners in enterprise management.

5.2 | Outlooks

The flourishing research on data empowerment and innovation in manufacturing enterprises has attracted increasing attention from scholars, leading to a series of research achievements. Based on the previous discussion and analysis, this paper suggests that future research can focus on the following three aspects.

5.2.1 *Effective Integration of Research on Data Empowerment and Innovation in Manufacturing Enterprises with Organization Theory*

In the process of its development, organizational theory has generated various further theories that explain different aspects of enterprise activities. The development of data science provides an opportunity for constructing new theoretical perspectives in the new era. Some scholars argue that there is a significant change happening in data, methods, and categories of knowledge, and researchers urgently need to supplement, understand, and utilize new theoretical viewpoints. Furthermore, new data and methods provide researchers with new avenues for theoretical construction (Burton-Jones et al., 2018).

This paper attempts to connect research on data empowerment with organization theory and integrate data

empowerment with relevant theories within the research framework of data empowerment and innovation in manufacturing enterprises. However, the role of data technology in the aforementioned important research theories has not been clearly elucidated. Therefore, this paper suggests that future research should focus on connecting data empowerment with various theories within the framework of organization theory.

5.2.2 *Research Methods and Data for Data Empowerment and Innovation in Manufacturing Enterprises*

This paper establishes a multi-level research framework for data empowerment and innovation in manufacturing enterprises, covering individuals, organizations, and multiple enterprises or industries. Different research methods are applicable to different research subjects, but extant research methods mainly focus on case studies (Luo et al., 2017; Sun & Su, 2018; Zhou et al., 2017; Zhou et al., 2018a; Zhou et al., 2018b). In the future, diversified research methods can be employed to study data empowerment and innovation in manufacturing enterprises from different levels.

There are significant deficiencies in the existing relevant data, particularly in domestic data. For example, in the academic community there is a lack of large-scale secondary data on data empowerment. Extant research data often rely on questionnaire surveys, which, despite their advantages, may have subjective biases and may not address endogeneity issues in data analysis. Currently, the estimation of data empowerment in Chinese enterprises is based on specific items of fixed assets and intangible asset investments in the annual reports of listed companies (Li & Gao, 2013), and this raises considerable accuracy concerns. To address this problem of data, future research could follow the approach of analyzing job website information using machine learning techniques (Tambe, 2014) to construct a large-scale panel dataset on data empowerment in Chinese manufacturing enterprises. This can serve as the basis for a series of empirical studies and provide more research opportunities for scholars interested in data empowerment through data openness initiatives.

5.2.3 *The Impact of Data Empowerment on Innovation in Manufacturing Enterprises in the Specific Context of China*

A review of the literature reveals that most empirical studies on data empowerment and innovation in manufacturing enterprises are based on Western samples (Tambe & Hitt 2012; Tambe, 2014). However, Chinese manufacturing enterprises have their own unique characteristics, which are mainly manifested in the following ways. Firstly, China is a populous country with a large number of mobile internet users, generating massive user behavioral data. Secondly, China is a manufacturing powerhouse with a large market size for manufacturing enterprises, resulting in abundant transaction data and a wide range of application scenarios for data empowerment. Thirdly, Chinese manufacturing enterprises

face dynamically changing consumer demands. The rapid development of mobile internet and information technology has significantly upgraded consumer spending levels. Manufacturing enterprises need to drive innovation and development through data empowerment in areas such as product, technology, and business models to meet the dynamic needs of consumers.

Therefore, future research needs to consider the changes that the specific Chinese environment brings to data-empowered innovation in manufacturing enterprises. Building on extant research, further studies should analyze specific issues based on the unique characteristics of Chinese manufacturing enterprises. Additionally, the research findings can provide valuable insights for government policy-making, effectively promoting data-empowered innovation in manufacturing enterprises.

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