Data Science in Finance and Economics

DSFE, 3 (1): 30–54.
DOI: 10.3934/DSFE.2023003
Received: 25 July 2022
Revised: 28 February 2023
Accepted: 05 March 2023
Published: 10 March 2023

http://www.aimspress.com/journal/dsfe

Research article

Research on measurement and disequilibrium of manufacturing digital transformation: Based on the text mining data of A-share listed companies

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Abstract: Quantitative analysis of digital transformation is an important part of relevant research in the digital field. Based on the annual report data of China's manufacturing listed companies from 2011 to 2019, this study applies cloud computing to the mining and analysis of text data, and uses the Term Frequency-Inverse Document Frequency method under machine learning to measure the digital transformation index value of manufacturing enterprises. The results show that: (1) On the whole, the current pace of digital transformation of manufacturing enterprises continues to accelerate, and the digital transformation of manufacturing has gradually spread from the eastern coastal areas to the central and western inland areas. (2) In horizontal comparison, among the five types of "ABCDE" digital modules constructed, artificial intelligence develops the fastest, cloud computing index value is second, and block chain value is the smallest. In vertical comparison, the leading provinces such as Beijing, Guangdong, and Shanghai have certain stability and a solid leading position, and there are occasional highlights in the central and western provinces. (3) In terms of polarization distribution, the digitalization of the manufacturing industry has obvious multi-peak patterns, showing the phenomenon of multi-polarization of digital services. The eastern region has both aggregate advantages and equilibrium disadvantages. (4) In terms of industry differences, the level of digital transformation in the high-end manufacturing industry is significantly higher than that in the mid-end and low-end industries. On the ownership attributes of enterprise digital transformation, private enterprises are the highest, followed by foreign-funded enterprises, and state-owned enterprises are the lowest. This research provides theoretical enlightenment and factual reference for manufacturing enterprises to carry out digital activities.

Key words: manufacturing enterprise; digitization; kernel density estimation; disequilibrium

JEL Codes: L60, O32, R12, R13

1. Introduction

The manufacturing industry is making full use of digital technology to promote industrial technological innovation and model change, so as to stimulate new momentum. Recently, many Chinese manufacturing enterprises have widely used digital technologies such as artificial intelligence, big data, cloud computing and block chain, as well as digital management systems such as ERP and MES, mainly to solve the problems of production and operation in many aspects such as management, decision-making, production and sales. These applications are constantly promoting the transformation of manufacturing industry to network, intelligent and digital. For example, cloud computing has played a significant role in epidemic monitoring, drug research and development, information dissemination and other aspects in the fight against the epidemic. The use of such digital technologies can not only reduce costs, improve efficiency, promote innovation and optimize management in the short term, but also promote the stable growth of business performance in the long term. The development of the digital economy mainly includes digital industrialization (expansion of digital industry) and industrial digitalization (digital transformation of traditional industries). According to data released by the China Academy of Information and Communications Technology in 2020, the scale of China’s industrial digitalization added value in 2019 was about 28.8 trillion yuan, accounting for 29% of GDP from 7% in 2005 to 29% in 2019. Industrial digitalization has been accelerating growth in China recently.

From an international perspective, in the past 10 years, major countries in the world have been vigorously developing intelligent manufacturing in order to build a competitive advantage in domestic manufacturing (Zhou er al., 2018). It aims to realize the deep integration of digitalization and manufacturing through the application of new-generation network information technologies such as cloud computing, big data, mobile Internet, emerging software and intelligent hardware. Continuously carry out intelligent manufacturing projects. For example, the United States released the “Advanced Manufacturing Strategic Plan” (Adamick, 2012), Germany announced the “Industry 4.0 Strategic Plan” (Scheel, 2013), and Japan proposed the “Social 5.0 Strategy” (Holroyd, 2020). In 2021, China’s “14th Five-Year Plan” and the Outline of Vision for 2035 proposed to build a manufacturing powerhouse and a Digital China. It is required to take advantages of China’s massive data and rich application scenarios, so as to promote the high-quality transformation and upgrading in the entire value chain of the manufacturing industry. Driven by this kind of practice and policy, digital transformation has become the only way for the high-quality development of economic entities, and it is also a hot issue of common concern among the political, academic, and academic circles.

According to the “2018 China Enterprise Digital Development Report” released by the International Data Corporation (IDC), more than 85% of China’s manufacturing enterprises have begun to implement digital transformation to varying degrees. However, the digitalization of more than 50% of these manufacturing enterprises is still in the stage of single-point experimentation and local promotion. These manufacturing enterprises generally face problems such as low level of industrial digitalization and weak basic innovation capabilities (Wu, 2019; Du, 2020). Moreover, in terms of digital infrastructure and key core technologies, China lags far behind the international advanced level in the fields of high-end chips, intelligent sensors, intelligent instruments, basic software, development tools, radio frequency identification (RFID) equipment, integrated circuits, automatic data processing equipment and so on. Therefore, what is the current level of digital transformation of Chinese manufacturing enterprises? The current research results can not accurately answer this question (Gray, 2017; Dimitrov, 2016). It is necessary to evaluate the digital transformation level of manufacturing industry using cloud computing based text mining data, and to further analyze the internal law of transformation, which is also the premise and foundation for the high-quality development of the domestic manufacturing industry.

This research is based on the theory of enterprise management innovation, drawing on the theoretical framework of digital transformation constructed by Qi and Xiao (2020), systematically considering the technical connotation of digital transformation of manufacturing industry, selecting five digital core modules: artificial intelligence, blockchain, cloud computing, big data, and business model. Finally, we use cloud computing A-share listed company text mining to measure the digital transformation of manufacturing industry, and analyze the imbalance of the measurement results. The marginal contributions of this study are: (1) Constructing a digital transformation measurement framework for manufacturing enterprises and making scientific calculations. (2) Using kernel density estimation to analyze the disequilibrium and dynamic evolution of the manufacturing enterprises digital transformation in China and its three major regions. (3) The regional disequilibrium and industry differences of digital transformation are systematically analyzed.

2. Literature review

2.1 Connotation of digital transformation

Regarding the connotation of digital transformation, there is currently no consensus in the academic community. Chanias (2019) and Legner et al. (2017) believe that the transformation of enterprises using information technology can be considered as digital transformation. Besides, Fitzgerald et al. (2014) interpret digital transformation as the use of digital technologies (eg, mobile application, embedded devices, etc.) to carry out major business restructuring such as improving user experience, simplifying operating models, and innovating business models. Additionally, Mergel et al. (2018) summarized the definition of digital transformation as a need to use advanced digital technologies to provide products and services online and offline to maintain competitiveness in the Internet era. From this point on, Vial (2018) regards digital transformation as a transformation process, in which various organizations change their value creation path due to the impact of digital technologies, while managing the process of structural change that has both positive and negative impacts on the organization. Schallmo et al. (2018) and Verhoef et al. (2021) argue that digital transformation is the process, collation and analysis of collected data through digital technology to transform it into specific forms of information. This information can be used for enterprise evaluation and decision-making, and develop new digital business models, thus improving enterprise performance and influence. Hence, digital transformation can be understood as "enterprise + technology + data", with new features such as model innovation, value creation, and new economic forms.

At present, the academic research on the digital transformation of manufacturing enterprises is still insufficient, and there is still no consensus on the core content such as its connotation and composition (Calvino et al., 2018; McKinsey Global Institute, 2014). The current literature examining the connotation of enterprise digitalization can be mainly divided into two types: the digitalization of production factors and the digitalization of production management. The digitalization of production factors mainly refers to the digitalization of enterprise production equipment and infrastructure, as well as the mastery of digital skills and the use of information technology equipment by enterprise employees. The research of Bertschek et al. (2015) found that the access to Internet broadband can significantly improve the technological innovation level of enterprises. In the meantime, He et al. (2019) found that the higher the proportion of employees who frequently use computers, the higher the application level of information and communication technology, and the higher the production efficiency of the enterprise. Moreover, the digitalization of production management is a process of gradual transformation from enterprise personnel management, manufacturing and product innovation to digitization. Qi and Cai (2019) found that digital technology plays an important role in boosting innovation in business models, production decisions, corporate culture, and governance mechanisms. Additionally, Li et al. (2020) believe that digital technology can help enterprises break through the theoretical constraints of "economies of scale" and "information asymmetry" in traditional economic theories. Enterprises can use advanced data acquisition and analysis tools to collect, process, process and discover scattered information. Implicit and personalized needs of consumers. In fact, there are various forms of enterprise digitalization, the most basic and common is the Internetization of enterprises (2019).

This paper defines digital transformation as an industrial transformation process driven by a new generation of information technology with data as the core, aiming at improving the quality and efficiency of industries and enterprises, including all the contents of "digitalization, internetization, and Intellectualization". There are overlapping and ambiguous parts between digital transformation and popular words such as "Internetization", "Informatization" and "Digital Economy", and there is also a progressive logical relationship that complements each other (Tan, 2022; Siqueira, 2022). The explanation is as follows: (1) Compared with the concept of "Internetization", digital transformation contains more trending technologies and is not limited to the innovation achievements of the Internet. (2) The similarity between "informatization" and "digitization" is that both propose information technology to drive industrial changes, but the former emphasizes traditional IT technologies, such as microelectronics and integrated circuits. Digital transformation corresponds to a new generation of information and communication technologies, especially the integration of emerging technologies such as the Internet of Things, 5G, industrial intelligence, and cloud computing. (3) Digital transformation is the core essence of the digital economy. Digital transformation emphasizes the process of systematic innovation, while the digital economy is a change in the overall form, and there is a progressive relationship between the two meanings. (4) The digital economy mainly includes two modules: digital industrialization and industrial digitalization. Among them, industrial digitalization mainly refers to digital transformation.

2.2. Calculation research on manufacturing enterprises digital transformation

As for the relevant research on the digital transformation of manufacturing industry, most of the current research is based on theoretical qualitative analysis, such as Matthew et al. (2021), Chen et al. (2020), D'Almeida (2022), etc. In contrast, quantitative research based on enterprise digital transformation is rare. For example, corporate homepage, email, Weibo, etc. are used as alternative indicators for corporate Internetization (Shen and Yuan, 2020). The number of industrial robot inputs between countries or regions and industries is used as an alternative indicator for enterprise production automation (Acemoglu and Restrepo, 2020). Whether the company's business scope discloses Internet involvement in the company's annual report is used as an alternative indicator to measure the Internet thinking of enterprises (Chen et al., 2019). Enterprise resource planning system (ERP) is used as an alternative indicator for enterprise digital management (Liu et al., 2021), etc. However, these alternative indicators selected by scholars can not directly reflect the diverse forms of digitalization of enterprises, but can only indirectly or unilaterally reflect the degree of digitalization of enterprises. Many scholars have made continuous attempts to overcome the defects of these indicators. For example, He and Liu (2019) describe digital transformation by designing a "0–1" dummy variable of "whether there is digital transformation in the year". However, this technical approach has not been able to effectively demonstrate the "intensity" of the digital transformation of enterprises, which is likely to result in a miscalculation.

This paper believes that the digital transformation of enterprises is a major strategy for high-quality development of enterprises in the new era, and this type of characteristic information is more likely to be reflected in the annual reports of enterprises with a summary and guidance nature. The vocabulary description and strategic content disclosed in the corporate annual report can largely reflect the business philosophy advocated by the company and the development path under the guidance of this philosophy. At the same time, the development of data processing technology and the improvement of computer computing power have provided more methods to convert qualitative materials into quantitative data, such as text mining technology. In a similar study, Han et al. (2017) calculated the cumulative number of corresponding industrial policy documents of each city by matching and screening keywords to quantitatively evaluate industrial policies. This provides enlightening thinking for cloud computing of keywords in this paper, that is, it can be measured by the word frequency of the corresponding keywords in the annual report published by listed enterprises, which can be used as a proxy indicator of the degree of enterprise digital transformation. The cloud computing method to be adopted can not only overcome the fuzziness and singleness of alternative indicators, but also accurately depict the intensity of digital transformation.

3. Research design

3.1. Research steps

First of all, from the perspective of the technical implementation of variable design, this paper collects and sorts out the annual reports of all A-share listed companies in Shanghai Stock Exchange and Shenzhen Stock Exchange through the python 3.10 crawler function on cninfo website. With the help of the PdfPlumber library, all text content is extracted, and the annual report dictionary is obtained through the Chinese word segmentation technology of the Jieba library, which is used as a data pool for subsequent feature word screening and word frequency statistics. Secondly, by combining policy text and typical enterprise text analysis, the high-frequency feature words of the digitization of manufacturing enterprises are finally locked to form a high-frequency keyword dictionary. Thirdly, according to the "digital technology-business model", the structural classification is carried out to classify the digital feature words of manufacturing enterprises. Furthermore, digital technology and its application are selected to jointly construct a comprehensive evaluation index for the digital transformation of manufacturing enterprises. Finally, based on the cloud computing method, the term frequency inverse document frequency method under machine learning is used to calculate the digital transformation index of listed manufacturing companies.

3.2. Data channel

Since the first 3G communication license was issued by the Ministry of Industry and Information Technology in 2009, the mobile Internet has risen rapidly, and the underlying concepts related to digitization have emerged. At this time, enterprises' cognition of digitalization is still limited to isolated parts such as "Internet+", ERP, CRM, Office Automation (OA), U9cloud, etc., which have not been linked as a digital whole. After 2011, with the popularization of related digital technologies, enterprises generally adopted ERP, CRM, OA, U9cloud, etc., laying a certain material foundation for digitalization. Therefore, the study period was limited to 2011–2019. Among the listed companies in the manufacturing industry, those listed after 2011 and those that have been delisted before 2020 will be deleted. Finally, a total of 11,331 data of 1,259 listed manufacturing companies in 9 years were obtained as research samples. The financial data of the selected company mainly comes from China Stock Market & Accounting Research Database, Wind Ip Network Database and other databases as well as the annual report issued by the listed company.

3.3. Index construction and dictionary selection

Table 1. Construction of digital transformation index of manufacturing enterprises and keyword selection.

Index	Dimension	Classfication Words	High frequency keyword dictionary
Digital Transformation Index Value of Manufacturing Enterprises （Z1）	Digital Technology （D1）	Artificial Intelligence	Artificial intelligence (AI), business intelligence (BI),computer vision(CV), investment decision assistance systems, intelligent robots, expert system, machine learning, semantic search, biometrics, face recognition, Identity verification, unmanned driving, autonomous driving, electronic design automation (EDA), natural language processing (NLP), customer relationship management (CRM), manufacturing resource management system (EPR), enterprise resource management (ERP), production information management System (MES), Digital Control (NC), Office Automation (OA), Product Lifecycle Management (PLM), Robotic Process Automation (RPA), Enterprise Resource Management Software System (SAP), Financial System, Financial Management System, Kingdee (EAS), UFIDA (U9), intelligent, intelligent office, intelligent technology, intelligent identification, intelligent manufacturing, intelligent terminal, robot, automatic control, intelligent equipment, intelligent workshop, intelligent factory, intelligent decision-making, flexibility, integration, numerical control industrialization, fine management, industrial intelligence, intelligent system, intelligent operation and maintenance, intelligent warehousing.
		Block Chain	Blockchain, digital currency, distributed computing, differential privacy technology, distributed communication, smart financial contracts, distributed control system (DCS), Infrastructure as a service (IaaS), Platform as a service (PaaS), peer-to-peer (P2P), Virtual currency.
		Cloud Computing	Cloud computing, fog computing, haze computing, edge computing, memory computing, multi-party secure computing, brain-like computing, green computing, cognitive computing, converged architecture, SOA Architecture, billion-level concurrency system, EB-level storage, Internet of Things, cloud storage, cloud networking, cloud platform, cloud migration, cloud technology, edge infrastructure, server virtualization.
		Big Data	Big Data (BD), data mining, data storage, data visualization, heterogeneous data, credit reporting, augmented reality, mixed reality, virtual reality, multi-level data compression, geographic information system (GIS), cyber-physical system, database (Oracle), data empowerment, data visualization, data acquisition, data cleaning, data exchange, data mining, relational database, data-driven, data industry, industrial data, digital transformation.
	Digital Technology Applications （D2）	Enterprise business model	Medical digitalization, mobile wallet, barcode payment, NFC payment, smart equipment, smart workshop, smart terminal products, smart energy, Internet connection, smart energy conservation and environmental protection, smart logistics, smart medical care, smart customer service, smart home, smart investment consulting, smart cultural travel, smart power, digital control, digital retail, Unmanned Retail, Internet Finance, Digital Finance, Fintech, Quantitative Finance, Open Banking, Electronic Medical Records (EMR), New Retail, B2B, B2C, C2B, C2C, C2M, Online For offline (O2O), online retail, e-commerce, official account, WeChat applet, application (APP), live broadcast, Weibo, mobile e-commerce (M2M), pre-sale, online office, online education, telemedicine, Unmanned delivery.

Notes: Common English abbreviations corresponding to Chinese keywords in parentheses are also included in the text search to avoid omission of statistics.

In the determination of the characteristic words of enterprise digital transformation, the paper combines the academic field and the industrial field for classification and exploration. We choose enterprise management innovation as the theoretical basis, and draw on the theoretical framework of digital transformation by Qi and Xiao (2020). Select the key technologies and core methods of digital transformation such as Artificial Intelligence, Block chain, Cloud Computing, Big Data, and

Enterprise Business Model. That is, based on the “ABCDE” core module, build a digital transformation evaluation index system for manufacturing enterprises. In this index system, a dictionary of specific keywords related to digital transformation is summarized. At the same time, based on important policy documents and government research reports for reference, this study selected the “Guiding Opinions on Accelerating the Cultivation and Development of High-quality Manufacturing Enterprises”, “Special Action Plan for Digital Empowerment of Small and Medium-sized Enterprises”, “Implementation Plan for Promoting Data Intelligence Technology Actions to Cultivate New Economic Development”, “2020 Digital Transformation Trend Report”, “Building Materials Industry Intelligent Manufacturing Digital Transformation Action Plan (2021–2023)”, “Government Work Report” in recent years and “14th Five-Year Plan for Digital Economy Development” as a blueprint. This further expands the feature vocabulary of digital transformation. On the reference of the annual reports of typical enterprises in digital transformation, through manual sorting, the basic ways of digital related information expression of typical enterprises such as Gree, Shenzhou high speed railway and Wuliangye were determined, and the lexicon of digital transformation characteristics was checked and filled. Then, according to the “digital technology business model”, the structure is classified, and the digital-related feature thesaurus other than digital technology and business model is collected and arranged as an instrumental variable for digital transformation. Finally, the feature vocabulary in Table 1 is formed. On this basis, the expressions of negative words such as “no”, “none” and “without” before the keyword cloud are removed, and the keywords of “digital transformation” that are not of the company (Including the company’s shareholders, customers, suppliers, company executive profiles, etc.) are also removed.

3.4. Diagnostic analysis of text mining

The high-frequency word cloud diagram of manufacturing enterprises’ digital transformation shows that “Internet” is the most important factor for enterprises in the process of digitalization (see Figure 1), and the frequency of this word is obviously higher than that of other keywords. Existing literature usually focuses on “Internet +”. In this case, although the most important factors are captured, the keyword cloud that reflect other digital technologies and business models, such as OA, CRM, O2O, and ERP, are ignored. In the process of sampling and data cleaning of corporate annual reports, and checking the position and internal meaning of keywords, this study found that keywords such as “Internet +”, “smart manufacturing”, and “smart city” mostly appear in the future outlook and macro environment of enterprises. In the description, not the description of the application of digital technology within the enterprise. This type of enterprise has not carried out digital production technology transformation, and the digital technologies introduced and applied are concentrated in OA, ERP, etc., and lack core technologies such as intelligent robots, engineering control, and industrial cloud. Based on a comprehensive judgment, unlike manufacturing companies that actively promote digital transformation in sales, management, and logistics, these companies have not actively promoted production digitization. If we only use “Internet +” as the core in the research, it is easy to ignore the impact of other digital technologies. Therefore, this study combines manual screening and cloud computing to construct indicators that can better utilize the information contained in the text.

Figure 1. Word cloud of high-frequency words in the digital transformation of manufacturing enterprises.

4. Calculation method and specific steps

4.1. Calculation of the total index of manufacturing enterprises digital transformation

Digital transformation feature word frequency data has a typical "right-biased" feature. This study refers to the idea of Loughran and McDonald (2014), and based on the technical method of cloud computing, uses the Term Frequency-Inverse Document Frequency (*TF-IDF*) method under machine learning to calculate the digital transformation index of listed manufacturing companies. Calculated as follows:

$$TF = Y_{it} / \sum_{w} Y_{it}(w) \tag{1}$$

$$IDF = N_t / (n_t(w) + 1) \tag{2}$$

$$TF - IDF = TF * IDF \tag{3}$$

$$lnTF - IDF_{it} = \sum_{w} \{ln[TF_{it}(w) + 1] \times ln[N_t / (n_t(w) + 1)]\} \tag{4}$$

In the formula, *TF* is the statistical word frequency of the digital keyword *w* that appears in the annual report of the listed manufacturing company *i* in the *t* year. The *IDF* is the inverse text frequency containing the keyword *w*. N_t represents the total number of annual reports of listed companies obtained in year *t*, and $n_t(w)$ represents the number of annual reports containing keyword

w in year t. In order to avoid too great disparity in data, the calculated basic data is processed logarithmically, and finally the digital transformation index value of the enterprise is calculated. D1 represents the development level of digital technology. According to the keyword selection rules, the larger the index, the higher the degree of digital technology development. If the index is 0, it means that the enterprise has not been digitized. D2 stands for business model innovation. According to the keyword selection rules, the larger the index, the more business model innovation of the enterprise. If the index is 0, it means that the enterprise has not carried out business model innovation.

4.2. Kernel density function analysis of regional disequilibrium dynamic evolution process

The kernel density estimation method is a non-parametric estimation method. Its principle is to fit the sample data through a smooth peak function, and use a continuous density curve to describe the distribution of random variables (Zambom and Ronaldo, 2013). The kernel density estimation method has the advantages of strong robustness and weak model dependence in the application process, which is why this method is widely used in the study of variable space disequilibrium. The most commonly used form of density function in research is:

$$f(x)=\frac{1}{Mk}\sum_{i=1}^{M}H\left(\frac{X_i-\bar{x}}{k}\right) \tag{5}$$

In the formula, M represents the number of research objects, and in this paper is the number of provinces observed. X_i represents the independent and identically distributed observations, and this paper refers to the manufacturing digitization index of the 31 observed provinces. $\bar{x}$ is the average value of the manufacturing digitization index of the 31 observed provinces; H is the kernel Density, and k is the bandwidth. This study uses the Gaussian kernel function to analyze the regional differences and dynamic evolution of the digitalization degree of Chinese manufacturing enterprises. According to China's economic development level and geographical location, the 31 provinces observed in this paper are divided into three regions: eastern region, central region and western region[a]. Taking the annual cross-sectional data from 2011 to 2019 as the inspection object, according to its kernel density distribution curve, it analyzes the unevenness and dynamic evolution trend of the digital development of the manufacturing industry in China.

5. Analysis of digitalization level of Chinese manufacturing enterprises

5.1. Digital index of Chinese manufacturing enterprises and its internal structure

According to the measurement of digital transformation of manufacturing industry using cloud computing-based text mining data of A-share listed companies, the digital index value of manufacturing enterprises is obtained. The results are shown in Table 2, and the corresponding

[a] The eastern region includes: Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan 11 provinces; the central region includes: Shanxi, Henan, Hubei, Hunan, Jilin, Heilongjiang, Anhui and Jiangxi 8 Provinces; Western regions include: Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Tibet, Guangxi and Inner Mongolia 12 provinces.

broken lines are drawn as shown in Figure 2. The solid line is the time development trend graph of the total digitalization index of manufacturing enterprises. The total digital index rose from 1.283 in 2011 to 2.666 in 2019, with a large increase and a trend of increasing year by year. It shows that the pace of digital transformation of manufacturing enterprises has accelerated significantly in the past 10 years, especially after 2015. This is mainly due to the scientific guidance of recent policies and the maturing of digital technologies.

Table 2. Manufacturing digital index and digital structure.

Years	Total Index	Artificial Intelligence	Block Chain	Cloud Computing	Big Data	Enterprise business model
2011	1.283	1.029	0.248	1.228	0.453	0.900
2012	1.325	1.003	0.659	1.268	0.381	0.957
2013	1.524	1.117	0.193	1.142	0.541	1.077
2014	1.703	1.144	0.238	1.156	0.659	1.289
2015	2.052	1.376	0.185	1.190	0.896	1.468
2016	2.221	1.544	0.355	1.267	0.968	1.521
2017	2.401	1.785	0.567	1.270	1.005	1.531
2018	2.544	1.926	0.638	1.316	1.038	1.555
2019	2.666	2.008	0.539	1.305	1.073	1.650

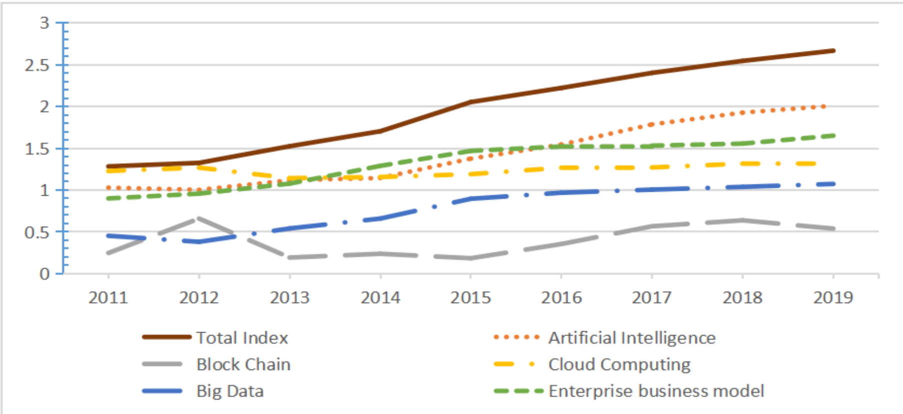
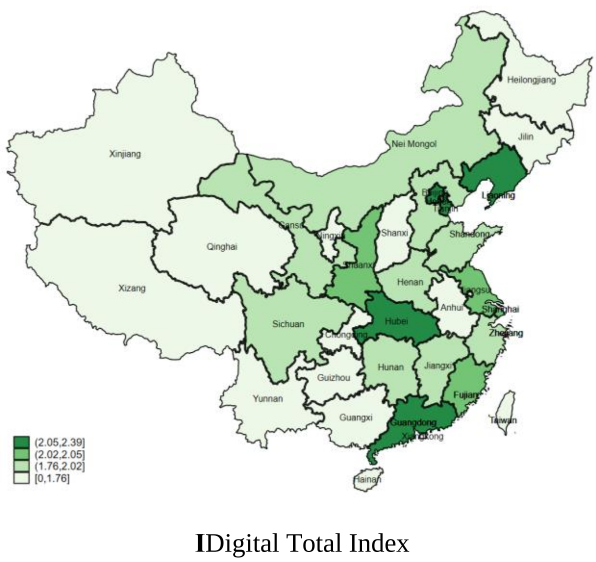


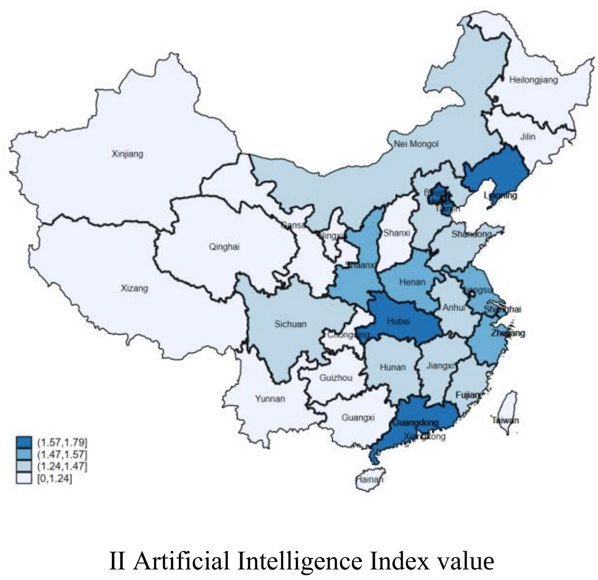
Figure 2. Time trend of manufacturing digital index from 2011 to 2019.

Among enterprises that have already carried out digital transformation, enterprises have achieved remarkable results in the application of artificial intelligence technology, with the index value increasing nearly twice, followed by big data technology and business model transformation. However, the construction and application of cloud computing technology stagnated, and the index rose from 1.228 in 2011 to 1.305 in 2019, a small increase of only 6.27%. After the block chain technology application index reached its peak in 2012, there was a relatively large fluctuation. It shows that the block chain technology is still in the early stage of development, and the practical application of enterprises is still at the level of testing the water. It can be seen from the index that China’s manufacturing enterprises have gradually entered the road of digital transformation. It is constantly forming a transformation trend that is supported by intelligent and digital technologies to empower enterprise operations and reshape the core of the business model. However, there are still the dilemmas that the systemic growth lags, the overall transformation level and the overall ecological quality are not high.

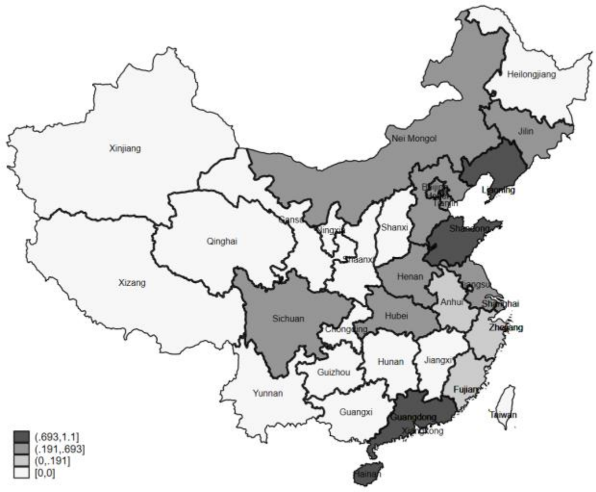
Further, Stata16.0 is used to draw the digital distribution map of manufacturing enterprises. The value is the average value of each index from 2011 to 2019, as shown in Figure 3. It can be seen that the digitalization of the manufacturing industry is different from the “club effect” in the eastern, central and western regions that often appeared in the past economic opening. Each region is competing for the “new track” empowered by digital from different directions. For example, in the business model index, central inland provinces such as Jiangxi and Hubei, as well as Chongqing, Inner Mongolia, Tibet, Yunnan, Guangxi and other places in the western region attach great importance to the development of digital business models, and the commercialization index ranks at the forefront. The analysis believes that the number of listed companies in the central and western regions is small, and they are more inclined to digital business models, so the index value is higher. The first tier of the digital transformation index is Beijing, Guangdong, Hubei, Tianjin, and Liaoning, and the second tier includes Shanghai, Fujian, Shaanxi, and Jiangsu. The third tier is Zhejiang, Henan, Inner Mongolia, Jiangxi, Sichuan, Shandong, Hunan, Hebei, Gansu, and Hainan. The fourth tier is the central and western provinces of Anhui, Guizhou, Ningxia, Jilin, Chongqing, Yunnan, Shanxi, Xinjiang, Heilongjiang, Guangxi, Qinghai, and Tibet. Therefore, in general, the digital transformation of manufacturing enterprises has the characteristics of spreading from the eastern region to the central and western regions, while the digital potential of the manufacturing enterprises in the central and western regions is being released, and the difference with the developed coastal areas is constantly narrowing. From the perspective of regional distribution, in the new track of digital transformation, although the central and western regions have shortcomings, there are also bright spots, which provides the basic conditions for the coordinated development of digital in the east and the west.



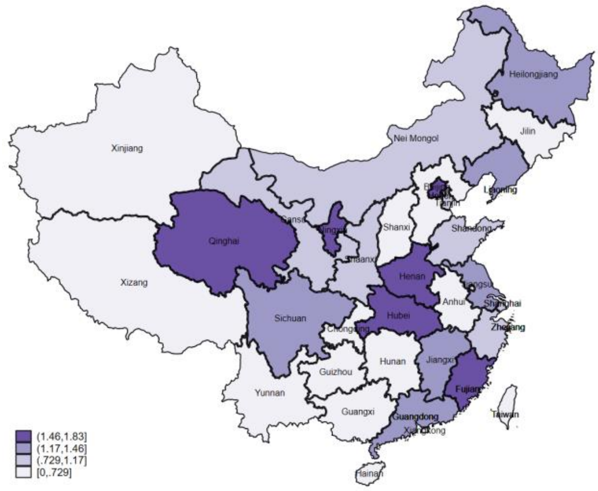
IDigital Total Index



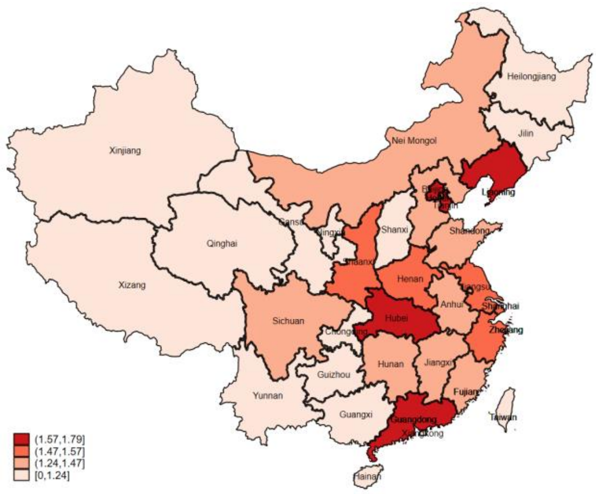
II Artificial Intelligence Index value



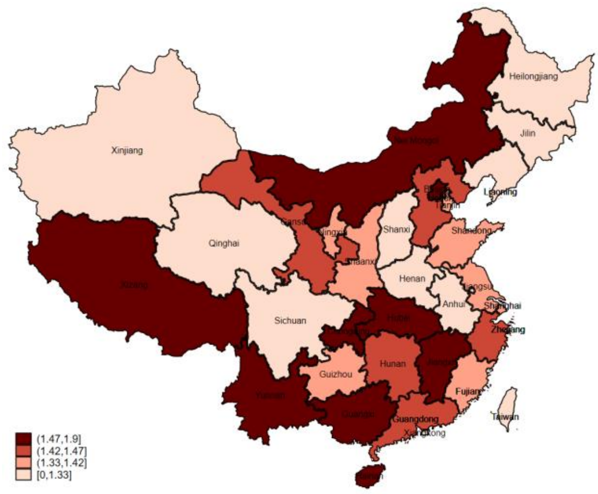
III Block Chain Index value



IV Cloud Computing Index value



V Big Data Index value



VI Enterprise business model Index value

Figure 3. Regional characteristics of the annual average value of manufacturing digitalization index.

5.2. Inter-provincial horizontal comparison of manufacturing digitalization index

Table 3 reports the overall digitalization index and digital structure of manufacturing Enterprises in 2019. The calculation result shows: First of all, from the perspective of the internal composition of digitalization, among the five types of "ABCDE" digital modules, the national artificial intelligence index value is the largest at 2.408, and the index value of all provinces except Tibet is greater than 1. Secondly, the average cloud technology index is 1.305, of which 18 provinces have an index greater than 1, 16 provinces have an index less than 1, and there are two provinces with Hainan and Tibet with an index of 0. Thirdly, the big data technology index value is 1.073, of which only 9 provinces have an index greater than 1; in addition, the minimum block chain technology index is 0.539, which is only calculated in the annual reports of manufacturing enterprises in 16 provinces. Fourthly, the national digital business model index value is 1.650, which is second only to artificial intelligence in the digital structure composition, and the index value of 31 provinces is greater than 1. Finally, from the perspective of the overall digitalization index of manufacturing enterprises, the overall digitalization index at the national level is 2.666, of which 9 provinces of Beijing, Guangdong, Shanghai, Tianjin, Sichuan, Hubei, Chongqing, Inner Mongolia, and Yunnan exceed the national average, indicating that Chinese manufacturing enterprises There is still room for further improvement in the degree of digitalization, which also reflects the inter-provincial differences in the digitalization of the manufacturing industry.

Table 3. Construction of digital transformation index of manufacturing enterprises and keyword selection.

Province	Total Index	Artificial Intelligence	Block Chain	Cloud Computing	Big Data	Enterprise business model
Beijing	3.157	2.408	0.706	1.698	1.698	1.832
Guangdong	3.088	2.400	0.905	1.641	1.352	1.810
Shanghai	2.671	2.016	0.499	1.286	0.95	1.521
Jiangsu	2.564	1.988	0.358	1.152	1.188	1.406
Zhejiang	2.645	2.019	0.219	1.173	0.913	1.621
Shandong	2.626	1.899	0.758	1.272	1.052	1.799
Tianjin	2.747	2.188	0.693	1.124	0.913	1.412
Fujian	2.534	1.683	0.173	1.62	1.331	1.664
Sichuan	2.682	2.021	0.355	1.279	1.19	1.702
Anhui	2.579	1.929	0.347	0.68	1.113	1.729
Henan	2.632	2.002	0.597	1.145	0.791	1.572
Hubei	2.760	2.315	0.652	1.842	1.09	1.669
Shaanxi	2.639	1.968	-	0.829	0.974	1.239
Hunan	2.321	1.751	-	0.347	0.866	1.535
Liaoning	2.47	1.841	3.332	1.266	0.864	1.464
Hebei	2.487	1.819	0.347	0.803	0.526	1.727
Chongqing	2.795	1.792	-	0.231	0.366	2.416
Inner Mongolia	2.757	2.14	-	1.025	0.98	1.75
Jiangxi	2.584	2.013	-	1.467	0.535	1.613
Heilongjiang	1.863	1.38	-	1.477	0.805	1.671
Jilin	2.044	1.551	0.347	1.112	0.965	1.336
Guangxi	2.366	1.898	-	0.738	0.932	1.413
Yunnan	2.774	1.622	-	0.833	0.374	2.051
Guizhou	2.194	1.265	-	0.723	0.484	1.482
Gansu	2.056	1.633	-	1.221	0.413	1.234
Shanxi	2.145	1.389	-	0.462	0.939	1.359
Xinjiang	2.248	1.783	-	0.761	0.692	1.484
Hainan	2.238	1.16	1.099	-	0.597	1.669
Qinghai	2.145	1.607	-	0.842	1.235	1.275
Ningxia	2.548	1.298	-	2.485	0.347	2.007
Tibet	2.482	0.774	-	-	0.347	2.282
National	2.666	2.008	0.539	1.305	1.073	1.650

Notes: “-” indicates that there is no statistical value in this sample.

5.3. Inter-provincial vertical comparison of manufacturing digitalization index

Table 4. Top ten provinces of China's manufacturing digitalization level.

Rank	Total Index		Artificial Intelligence		Block Chain		Cloud Computing		Big Data		Enterprise business model	
	2011	2019	2011	2019	2011	2019	2011	2019	2011	2019	2011	2019
1	Liaoning	Beijing	Qinghai	Beijing	Shandong	Liaoning	Hunan	Ningxia	Inner Mongolia	Beijing	Yunnan	Chongqing
2	Jiangxi	Guangdong	Liaoning	Guangdong	Guangdong	Hainan	Henan	Hubei	Beijing	Guangdong	Hunan	Tibet
3	Shaanxi	Chongqing	Shaanxi	Hubei	-	Guangdong	Liaoning	Beijing	Guangdong	Fujian	Guangxi	Yunnan
4	Hubei	Yunnan	Jiangxi	Tianjin	-	Shandong	Shaanxi	Guangdong	Hebei	Qinghai	Shanxi	Ningxia
5	Beijing	Hubei	Hubei	Inner Mongolia	-	Beijing	Beijing	Fujian	Shanxi	Sichuan	Hebei	Beijing
6	Inner Mongolia	Inner Mongolia	Shanghai	Sichuan	-	Tianjin	Fujian	Heilongjiang	Heilongjiang	Jiangsu	Jiangxi	Guangdong
7	Guangdong	Tianjin	Fujian	Zhejiang	-	Hubei	Jiangsu	Jiangxi	Tibet	Anhui	Hubei	Shandong
8	Shanxi	Sichuan	Guangdong	Shanghai	-	Henan	Hubei	Shanghai	Jiangxi	Hubei	Beijing	Inner Mongolia
9	Henan	Shanghai	Beijing	Jiangxi	-	Shanghai	Guangdong	Sichuan	Liaoning	Shandong	Zhejiang	Anhui
10	Shanghai	Zhejiang	Henan	Henan	-	Jiangsu	Sichuan	Shandong	Henan	Inner Mongolia	Inner Mongolia	Hebei

Notes: "-" indicates that there is no statistical value in this sample.

Table 4 reports the top ten provinces of the main indicators of the digitalization degree of Chinese manufacturing enterprises in 2011 and 2019. From 2011 to 2019, the inter-provincial ranking of China's manufacturing digitalization varies greatly. Among the top ten provinces, Beijing, Shanghai, Guangdong, Hubei and Inner Mongolia ranked steadily, Liaoning, Jiangxi, Shaanxi, Shaanxi and Henan fell off the list, and Chongqing, Yunnan, Tianjin, Sichuan and Zhejiang were on the list. New additions and withdrawals in the list showed that China's manufacturing digitalization was in a period of transformation and growth. The application of digital technology and business models can play a late-mover advantage in provinces with relatively weak manufacturing industries, indicating that digital transformation can help break the path dependence of traditional manufacturing upgrades. With the promotion of a new round of digital technology and the exertion of industrial agglomeration effect, digital manufacturing industry agglomeration and regional structure solidification may occur in the future. Specifically, in terms of artificial intelligence technology index, in 2019, compared with 2011, Beijing, Guangdong, Hubei, Shanghai, Jiangxi, and Henan were firmly in the top ten, and Qinghai, Liaoning, Shaanxi, and Fujian dropped out of the top ten. Instead, the four provinces of Tianjin, Inner Mongolia, Sichuan, and Zhejiang with relatively good manufacturing foundations are the provinces, indicating that provinces with relatively good manufacturing foundations are more likely to achieve technological upgrades and even technological leaps in manufacturing artificial intelligence. In terms of big data technology index, Beijing and Guangdong are firmly in the top three. Inner Mongolia's manufacturing industry is the first to use big data technology, but its development speed is weak in the later stage, and its ranking has dropped from first to tenth. The index gap of other provinces is small. There is a tendency to go hand in hand.

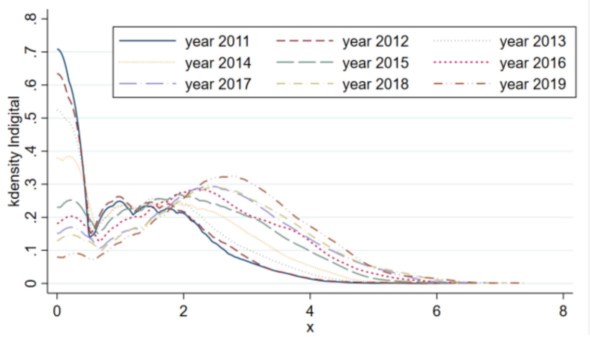
In terms of cloud computing index, Hubei, Beijing, Guangdong, Fujian and Sichuan have remained in the top ten. It is worth noting that Ningxia has emerged as a new cloud computing city in the innovative model of "front shop, back factory" cooperating with Beijing, and Ningxia's manufacturing industry has become digitalized. The index ranking also turned from the end to the first, indicating that cloud computing is an important means for the joint development of manufacturing in the east and west regions. In terms of block chain index, Guangdong and Shandong are the earliest pilots in the manufacturing industry, ranking in the top four all the time, and block chain technology is more widely used in provinces with better manufacturing foundations. In terms of digital business model, Yunnan and Inner Mongolia in the western region have always been in the top ten, Chongqing, Ningxia and Tibet have also performed prominently, and the eastern and central regions have shown a ladder trend in the timing of the application of digital business model from the east to the West. In terms of digital business models, Yunnan and Inner Mongolia in the western region have consistently ranked among the top ten, while Chongqing, Ningxia, and Tibet also performed prominently. In the chronological order, there is a step-by-step trend of the east, then the middle and the west.

6. Regional disequilibrium and industrial differences of digitalization of Chinese manufacturing enterprises

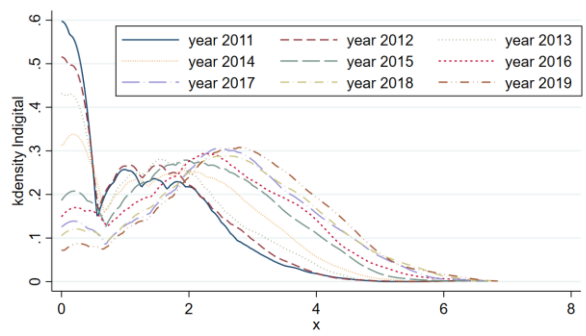
6.1. Kernel density estimation

Through the observation and analysis of the above calculation results, it is judged that the digitalization process of manufacturing enterprises in various provinces in China is relatively rapid from 2011 to 2019. At the same time, through the horizontal and vertical comparison, it is initially recognized that there are certain imbalances and regional differences in the development of the digital economy between provinces. In order to further characterize the development characteristics and trends of China's inter-provincial digital economy, the regional differences and sources of the digital economy are analyzed. Kernel density estimation is used to analyze the disequilibrium and dynamic evolution of the degree of digitization of manufacturing in China and the three major regions.

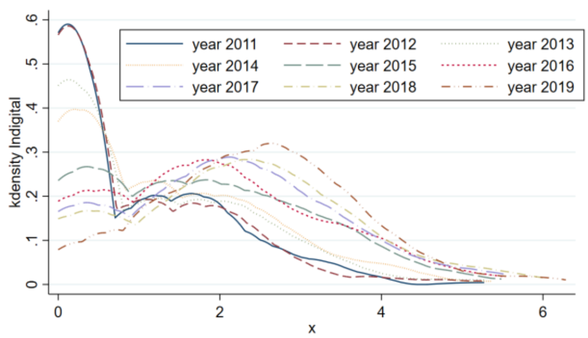
The four sub-graphs in Figure 4 respectively describe the dynamic evolution trend of manufacturing digitization in the whole country and the eastern, central and western regions within the sample observation time range. The commonality of the four sub-graphs is that: First of all, from the perspective of distribution location, the center of the national and three major regional distribution curves and the right-shifting trend of the change interval are very obvious, indicating that the digitization level in the sample time range is generally on the rise. This is consistent with the descriptive statistics and typification facts of the previous indices. Secondly, judging from the time distribution pattern, the height of the curve dropped significantly from 2011 to 2019, and the width became wider, indicating that the overall gap in the digital transformation of the manufacturing industry has intensified over time. Thirdly, from the perspective of polarization distribution, each nuclear density estimation curve shows different degrees of "double-peak", "triple-peak" and even evolves into a "multi-peak" distribution trend, indicating that manufacturing digitalization has an obvious multi-peak shape, showing the phenomenon of multi-polarization in digital services. There are significant regional differences under the general trend of digitalization. Finally, from the point of view of distribution ductility, the distribution curves of the whole country and the three major regions are skewed to the right, and there is a significant right trailing, and their ductility shows a widening trend to varying degrees. This means that the gap between the provinces with a high level of digital development of manufacturing and the average across the country continues to widen.



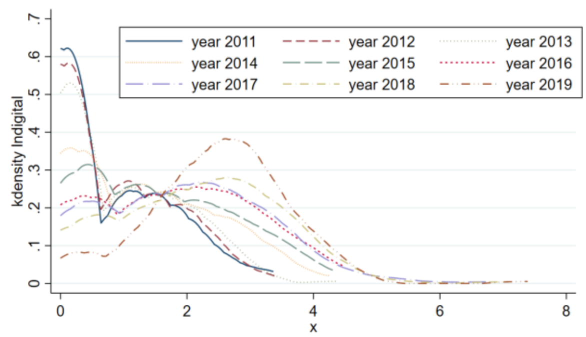
(a) National sample



(b) Eastern region sample



(c) Central region sample



(d) Western region sample

Figure 4. Kernel density estimation of manufacturing digitalization level.

The differences between the four sub-graphs are as follows: First, the digitization of manufacturing in the eastern provinces is similar to the nuclear density estimation curve at the national overall level, indicating that the digitization of manufacturing in the eastern region has a greater impact on the overall national level. The “multi-peak” and “double-peak” forms of the Kernel density curve in the eastern region are more significant, indicating that the polarization of manufacturing digitalization in the eastern region is more serious than that in the whole country. Second, from 2011 to 2019, the digital multi-polarization of the manufacturing industry has gradually improved in the central and western regions over time. It has gradually transitioned from multi-peak to double peak and single peak, and the differentiation phenomenon is constantly weakening. This shows that the digitalization of these provinces has begun to take advantage of the latecomers, and the gap within the region is constantly narrowing. On the whole, the multipolar differentiation phenomenon in the eastern region is more serious than that in the central and western regions, indicating that in the process of manufacturing digitization, although the eastern region has a total advantage, it has a balanced disadvantage.

6.2. Analysis by industry

Table 5. Average value of digital transformation index (National economy manufacturing industry classification and code).

Industry code	Manufacturing industry segment	Digital index	A Technology	B Technology	C Technology	D Technology	E mode
C40	Instrumentation Manufacturing	3.071	2.061	0.741	2.449	1.757	1.671
C39	Computer, communications and other electronic equipment manufacturing	2.711	1.988	0.559	1.621	1.417	1.585
C24	Cultural and educational, industrial beauty, sports and entertainment products manufacturing	2.684	1.807	0.667	3.138	1.336	1.451
C35	Special equipment manufacturing	2.390	1.953	0.784	0.937	0.949	1.430
C38	Electrical machinery and equipment manufacturing	2.371	1.834	0.335	1.298	1.009	1.466
C34	General equipment manufacturing	2.356	1.989	1.828	1.253	0.984	1.374
C21	furniture manufacturing	2.269	1.903	0.000	0.000	0.912	1.188
C23	Printing and recording media reproduction industry	2.187	1.478	1.395	1.800	0.703	1.419
C33	metal products industry	2.055	1.595	0.077	0.690	0.530	1.415
C36	Automotive Manufacturing	1.999	1.595	0.173	0.890	0.582	1.369
C18	Textile and apparel industry	1.997	1.355	0.520	0.566	0.746	1.324
C37	Railway, ship, aerospace and other transportation equipment manufacturing	1.876	1.385	0.000	0.639	0.569	1.529
C42	Comprehensive utilization of waste resources	1.819	0.872	0.000	1.683	0.000	1.785
C13	Agricultural and sideline food processing industry	1.743	0.957	0.154	0.509	0.907	1.350
C17	textile industry	1.722	1.151	0.231	0.959	0.611	1.393
C31	Ferrous metal smelting and rolling industry	1.682	1.191	0.087	0.596	0.568	1.324
C22	Paper and paper products industry	1.678	0.931	1.099	1.394	0.539	1.353
C29	Rubber and plastic products industry	1.668	1.246	0.000	0.899	0.516	1.283
C30	Non metallic mineral products industry	1.655	1.178	0.288	0.661	0.430	1.245
C26	Chemical raw materials and chemical products manufacturing	1.623	0.958	0.177	0.863	0.590	1.394
C14	food manufacturing	1.588	1.132	0.000	0.490	0.771	1.259
C20	Wood processing and wood, bamboo, rattan, palm and grass products industry	1.587	1.000	0.000	0.000	0.520	1.272
C28	Chemical fiber manufacturing	1.569	1.245	0.000	0.725	0.570	1.465
C41	Other manufacturing	1.530	0.619	0.000	0.994	0.798	1.260
C32	Non-ferrous metal smelting and rolling processing industry	1.507	0.906	0.000	0.495	0.475	1.365
C15	Wine, Beverage and Refined Tea Manufacturing	1.494	1.008	0.275	0.294	0.509	1.267
C27	Pharmaceutical Manufacturing	1.490	0.876	0.112	0.557	0.587	1.318
C25	Petroleum processing, coking and nuclear fuel processing industries	1.457	0.747	0.000	0.231	0.108	1.388
C19	Leather, fur, feathers and their products and footwear	1.238	0.347	0.000	0.000	0.244	1.354

Further subdivide the industry, analyze which specific manufacturing industries have achieved significant digital transformation, and calculate the average transformation of digitalization and its five ABCDE modules in different manufacturing industries. Ranked in descending order of the degree of digital transformation, the results in Table 5 show that the instrument manufacturing, computer, communications and other electronic equipment manufacturing, cultural and educational, industrial and aesthetics, sports and entertainment products manufacturing industries have the highest digital transformation index. The digital transformation of these industries is the most typical, and it is the backbone of the industry that promotes digital transformation. Pharmaceutical manufacturing, petroleum processing, coking and nuclear fuel processing industries, leather, fur, feathers and their products, and footwear industry are low in the digital transformation rankings, and the transformation is slower.

Table 6. Average value of digital transformation index (Different types of technologies).

Category	Industry code	Digital index 2011	Digital index 2019	A Technology2011	A Technology2019	B Technology2011	B Technology2019	C Technology2011	C Technology2019	D Technology2011	D Technology2019	E mode 2011	E mode 2019
Low-end	C13	1.491	2.214	1.055	1.056	0.000	0.231	0.000	0.548	0.000	1.053	1.338	1.851
	C14	0.874	2.260	0.916	1.779	0.000	0.000	0.000	0.519	0.000	1.190	0.448	1.077
	C15	0.685	2.013	0.776	1.391	0.000	0.549	0.000	0.353	0.000	0.817	0.535	1.438
	C17	1.283	2.261	0.829	1.616	0.000	0.347	0.000	0.886	0.000	0.456	1.188	1.725
	C18	1.719	2.725	1.474	1.323	0.000	0.416	0.000	0.738	0.000	1.051	1.009	1.837
	C19	0.549	1.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.347	1.304
	C20	1.207	1.979	0.855	1.536	0.000	0.000	0.000	0.000	0.000	0.549	1.175	0.896
	C21	1.242	3.708	1.242	1.857	0.000	0.000	0.000	0.000	0.000	1.320	0.000	2.922
	C22	0.457	2.091	0.353	1.262	0.000	1.099	1.946	1.328	0.000	0.624	0.549	1.482
	C23	1.585	3.158	1.397	1.990	0.000	1.365	1.320	2.733	0.347	1.062	0.536	1.711
	C24	0.462	3.874	0.366	2.480	0.000	0.768	0.000	2.275	0.000	1.782	0.000	2.252
	C41	0.855	1.991	0.805	0.723	0.000	0.000	0.000	1.242	0.000	1.748	0.520	0.649
	C42	0.000	2.124	0.000	1.242	0.000	0.000	0.000	1.946	0.000	0.000	0.000	1.099
Mean		0.955	2.454	0.775	1.404	0.000	0.367	0.251	0.967	0.027	0.896	0.588	1.557
Mid-end	C25	0.900	2.342	0.520	1.020	0.000	0.000	0.000	0.000	0.000	0.000	0.536	2.357
	C29	1.063	2.279	0.710	1.733	0.000	0.000	1.386	0.784	0.693	0.687	1.017	1.654
	C30	1.141	2.397	0.896	1.572	0.000	0.000	0.693	0.385	0.277	0.274	0.848	1.506
	C31	1.202	2.509	0.792	1.752	0.000	0.231	0.693	0.551	0.366	0.787	0.578	2.039
	C32	0.954	2.224	0.734	1.490	0.000	0.000	0.000	0.352	0.000	0.589	0.889	1.667
	C33	0.941	2.428	0.596	2.256	0.000	0.231	0.693	0.770	0.000	0.572	0.780	1.120
Mean		1.034	2.363	0.708	1.637	0.000	0.077	0.578	0.474	0.223	0.485	0.775	1.724
High-end	C26	1.071	2.142	0.796	1.300	0.000	0.454	0.000	0.887	0.454	0.643	0.891	1.577
	C27	1.020	1.861	0.750	1.230	0.000	0.000	0.347	0.735	0.256	0.855	1.228	1.307
	C28	0.895	1.962	1.018	1.632	0.000	0.000	0.000	0.693	0.549	0.553	0.000	1.784
	C34	1.367	2.978	1.163	2.607	0.000	1.938	1.343	1.118	0.416	1.202	0.850	1.546
	C35	1.351	3.209	1.175	2.822	0.000	0.726	0.430	1.126	0.666	1.185	0.847	1.514
	C36	0.956	2.839	0.615	2.217	0.000	0.231	0.462	0.774	0.173	0.725	0.865	1.797
	C37	1.107	2.496	0.708	1.983	0.000	0.000	0.000	0.885	0.347	0.866	1.326	1.328
	C38	1.448	3.205	1.329	2.463	0.000	0.355	0.764	1.610	0.385	1.206	0.716	1.782
	C39	1.783	3.548	1.275	2.731	0.621	0.574	1.588	1.895	0.968	1.602	1.059	2.055
	C40	2.320	3.981	2.036	2.870	0.000	0.636	2.070	2.684	0.139	2.520	0.952	1.773
Mean		1.332	2.822	1.086	2.186	0.062	0.491	0.701	1.241	0.435	1.136	0.873	1.646

In the 29 industries included in the specific data, the sub-sample analysis of the industry continues. In the 29 industries included in the specific data, the sub-sample analysis of the industry continues. Drawing on Li (2010), the manufacturing industry is divided into three categories: high-end, mid-end and low-end technology industries to capture the differences in the manufacturing industries of different technology categories, and increase the average value of each key indicator in 2011 at the beginning of the period and 2019 at the end of the period. Table 6 clearly shows that the average digital index of low-end manufacturing industry, mid-end manufacturing industry and high-end manufacturing industry is 0.955, 1.034 and 1.332 respectively. The digital transformation level of high-end manufacturing industries is obviously higher than that of mid-end and low-end industries, which is in line with the high-tech attributes inherent in digital transformation. High-tech industrial enterprises are the core participants of the digital economy. The high-end manufacturing industry is at the forefront of digital transformation, leading the digital transformation of different industries. The calculation results also show that, regardless of the average value of the digital index or the artificial intelligence, big data, and business model indexes, the index values at the end of the period are significantly larger than the corresponding index values at the end of the period. The transformation has significantly improved.

6.3. Analysis on the situation of manufacturing enterprises with different ownership

Next, we examine the differences in the value of digital transformation between manufacturing industries with different ownerships. In this study, the listed companies in the sample from 2011 to 2019 were classified as state-owned enterprises according to the wholly state-owned and state-controlled enterprises. The wholly privately-owned or privately-held enterprises are classified as private enterprises, and the wholly foreign-owned or foreign-controlled enterprises are classified as foreign enterprises. In the sample of 1,259 manufacturing enterprises, 507 are state-owned enterprises, 780 are private enterprises, and 53 are foreign-funded enterprises. The specific index results are listed in Table 7.

Table 7. Digital transformation index values of manufacturing enterprises with different ownerships.

Ownership Classification	Digital index	A Technology	B Technology	C Technology	D Technology	E mode
state-owned enterprise	1.891	1.380	0.257	1.151	0.763	1.393
Private Enterprise	2.108	1.575	0.574	1.319	0.981	1.416
Foreign companies	2.009	1.451	0.836	1.059	0.885	1.422

Table 7 and Figure 5 depict the specific index values and time trends of the digital transformation of manufacturing enterprises of different ownerships. It can be seen that the average value of the digital index and the average value of the artificial intelligence, big data, and business model indexes are the highest in private enterprises, followed by foreign investment, and state-owned enterprises. Enterprise transformation value is the lowest. In the cloud computing index value, private enterprises are the highest, followed by state-owned enterprises, and the average value of foreign capital transformation is the lowest. In the block chain index, foreign-funded enterprises are the highest, private enterprises are in the middle, and state-owned enterprises are the lowest. During the entire sample period, the overall transformation degree values of state-owned enterprises, private enterprises, and foreign-funded enterprises have increased by 100%–160%. Foreign-funded enterprises have experienced a large increase, and the overall fluctuations are also the most obvious. Although the development of state-owned enterprises is the slowest, the overall growth rate is the most stable. Finally, as of the end of the sample period, the digital transformation values of the three major types of manufacturing enterprises, state-owned enterprises, private enterprises and foreign-funded enterprises, have been very close, and the differences between different ownership systems have been continuously narrowed, showing a trend of high-quality catching up as a whole.

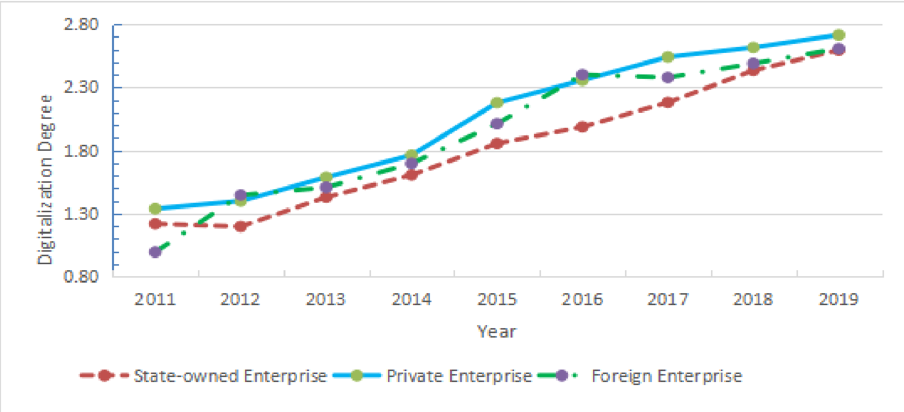


Figure 5. Time trend of digital transformation of manufacturing enterprises with different ownership.

7. Conclusions and suggestions

7.1. Conclusions

This research collects and organizes the annual reports of A-share listed companies from 2011 to 2019 on the http://www.cninfo.com.cn using the crawler function of Python 3.10, and obtains the texts of the annual reports through the Chinese word segmentation technology of the Jieba library to describe the digital transformation intensity of manufacturing enterprises. Using Kernel density estimation to analyze the disequilibrium and dynamic evolution of the manufacturing digitization degree in China and the three major regions. The main conclusions are as follows: (1) In general, the current pace of digital transformation of manufacturing enterprises has accelerated significantly, which is gradually driving China's manufacturing industry to a new track. The digital transformation of manufacturing has the characteristics of spreading from the eastern provinces to the central and western regions. (2) In terms of horizontal comparison, among the five types of "ABCDE" digital modules, the national artificial intelligence technology index has the largest value, the fastest development, and the block chain index value is the smallest, and there is still room for further improvement. (3) In terms of vertical comparison, there are inter provincial differences in the digitalization of manufacturing industry. Beijing, Shanghai, Guangdong and other leading provinces have certain stability, and Ningxia, Inner Mongolia, Chongqing and other central and western regions occasionally have high light moments. (4) In terms of nuclear density analysis, the digitalization of the manufacturing industry has obvious multi-peak forms, showing the phenomenon of multi-polarization of digital services. In the process of digitalization of the manufacturing industry, although the eastern region has a total advantage, it also has a balanced disadvantage. (5) Analysis of differences. In terms of technical attributes, the digital transformation level of the high-end manufacturing industry is obviously higher than that of the mid-end and low-end industries, and the high-tech industry is at the forefront of digital transformation. In terms of ownership attributes, private enterprises are the highest in digital transformation, followed by foreign investment, and state-owned enterprises are the lowest, showing a trend of high-quality catching up as a whole.

7.2. Suggestions

The emergence of digitalization promotes changes in the innovation pattern and triggers deeper changes in the economy and society, pointing out the development direction for the transformation and upgrading of the manufacturing industry. Accordingly, this study puts forward the following policy implications: (1) Continue to accelerate the digital transformation of the manufacturing industry. Digitalization provides a new track for the high-quality upgrade of the manufacturing industry, and constantly promotes the rapid development of key digital modules such as artificial intelligence, block chain, cloud computing, big data and enterprise business model. (2) Scientifically understand the imbalance in the digital transformation of the manufacturing industry in various provinces and regions, and there are differences in factor endowments, policy support, and location conditions among provinces and regions. (3) Enterprises in developed provinces are at the forefront of digital transformation of the manufacturing industry, but there are also bright spots in underdeveloped areas. In the future, in the road of in-depth transformation, risks, opportunities and challenges coexist. (4) Efforts should be made to reduce the multi-polarization problem of digital services, strengthen the construction of digital infrastructure, and actively explore the agglomeration effect of digital transformation within the region. (5) Prioritize the development of advanced manufacturing industries and build an innovative, coordinated, green, open and shared modern manufacturing industry system in the information age.

Acknowledgments

This research was funded by the National Natural Science Foundation of China (No. 72063034 & No. 72063035), Yunnan Provincial Department of Science and Technology Project (No. 2019FD117), Humanities and Social Sciences Project of the Ministry of Education (No. 17XJC790011), Research Fund Project of Yunnan Provincial Department of Education (No. 2019J0936), Introduction project of Yunnan University of Finance and Economics (No. 20190043).

Authors' Contributions

The authors confirm contribution to the paper as follows: Conceptualization, software, visualization: Guoqiong Long; data collection: Shuai Li, Shuai Li; analysis and interpretation of results: Chong Li,

Guoqiong Long; funding acquisition: Chong Li. draft manuscript preparation: Guoqiong Long, Chong Li. All authors reviewed the results and approved the final version of the manuscript.

Data Availability

The data used for this study are available and would be supplied upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

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