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Research on the Efficiency of Service-Oriented Manufacturing in Beijing-Tianjin-Hebei under Digitalization

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Abstract: Against the backdrop of the new generation of information technology and the development trend of manufacturing servitization, this paper constructs comprehensive evaluation indicators for the level of digital development and the development level of productive service industries in the Beijing-Tianjin-Hebei region based on the entropy weight method. It also conducts a descriptive analysis of the digital development level in the Beijing-Tianjin-Hebei region. Further, by constructing a moderating effect model, this paper explores the influence mechanism of the digitalization level of the manufacturing industry on improving the efficiency of the manufacturing industry under the service-oriented manufacturing model in the Beijing-Tianjin-Hebei region. The research results show that service-oriented manufacturing can improve manufacturing efficiency, while the regional digitalization level plays a positive moderating role in this process.

Keywords: Manufacturing, Service-oriented Manufacturing, Digitalization, Moderating Effect

1. Introduction

With the acceleration of global economic integration, the flow of resources and factors between countries and regions has increased, and under the pressure of domestic and international competition, higher requirements have been put forward for the development level of China's manufacturing industry to achieve an upgrade in the global value chain. As an important pillar of the national economy, the development of the manufacturing industry plays a crucial role in promoting economic growth, increasing employment, and enhancing national competitiveness [1]. However, traditional manufacturing faces multiple challenges such as resource and environmental constraints, rising labor costs, and intensified market competition, making transformation and upgrading an inevitable choice. Among them, service-oriented manufacturing, as a new development model of the manufacturing industry, can provide more value-added services on the basis of traditional manufacturing by integrating upstream and downstream resources of the industrial chain. Additionally, this development model can achieve deep integration of manufacturing and service industries, increase the added value of manufacturing, enhance the profitability and market competitiveness of manufacturing enterprises, and better meet consumers' personalized and diversified needs. Improving the level of digitalization can not only increase production efficiency, reduce production costs, but

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also improve product quality and shorten product development cycles. Under the dual trends of manufacturing digitalization and servitization, this project focuses on the Beijing-Tianjin-Hebei region, analyzing the current situation of the manufacturing industry and the development level of service-oriented manufacturing. It measures the digitalization level of regional manufacturing through the entropy weight method and further explores the influence mechanism of the digitalization level of the regional manufacturing industry on improving manufacturing efficiency under the service-oriented manufacturing model, based on previous research.

2. Theoretical Analysis and Research Hypotheses

2.1. Service-Oriented Manufacturing and Manufacturing Efficiency

Based on the research findings of scholars like Guo Ran and others, it has been discovered that the service-oriented manufacturing model can enhance manufacturing efficiency through three pathways: promoting technological innovation, saving manufacturing costs, and reducing transaction costs [2].

Accordingly, this paper proposes Hypothesis H1:

H1: The development of a service-oriented manufacturing model can improve the manufacturing efficiency in the Beijing-Tianjin-Hebei region.

2.2. The Moderating Effect of the Digital Development Level of Manufacturing on the Relationship Between Service-Oriented Manufacturing and Manufacturing Efficiency

The improvement of the digital development level in regional manufacturing can promote the deep integration of products and services through the application of digital technology, drive innovation in service-oriented manufacturing business models, and build information platforms. These methods can help service-oriented manufacturing better enhance regional manufacturing efficiency through the aforementioned three pathways.

Accordingly, this paper proposes Hypothesis H2:

H2: The digital development level can influence the process by which the service-oriented manufacturing model affects manufacturing efficiency in the Beijing-Tianjin-Hebei region.

3. Research Design

3.1. Variable Definition and Data Description

The research sample of this study includes panel data from Beijing, Tianjin, and Hebei provinces from 2013 to 2022. The data are sourced from the corresponding years' editions of the "China Statistical Yearbook," "China Industrial Statistical Yearbook," and "China Science and Technology Statistical Yearbook." Additionally, to improve data continuity and completeness, linear interpolation methods were used to estimate missing data, ensuring consistency and accuracy for subsequent analyses.

3.1.1. Dependent Variable: Comprehensive Manufacturing Output Level Based on the Entropy Weight Method (op)

This study aims for the dependent variable to reflect industrial efficiency. Referring to the research methods of Wang Yun and Sun Xiaohua [3] on manufacturing efficiency, the measurement model of total factor productivity includes environment and resources. The expected output (i.e., industrial added value) and unexpected output (i.e., total emissions of wastewater and waste gas) are selected for measuring green productivity, and the data are measured using the entropy weight method to obtain a comprehensive indicator reflecting the output level in the Beijing-Tianjin-Hebei region.

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3.1.2. Independent Variable: Comprehensive Output Level of Productive Service Industries Based on the Entropy Weight Method (ser)

Referring to Guo Ran's research, the output level of the service industry determines the development degree of service-oriented manufacturing. Therefore, this study selects the added value of service industries related to productive service-oriented manufacturing as the independent variable to analyze the improvement of manufacturing efficiency by service-oriented manufacturing. Specifically, the added value of wholesale and retail, transportation and postal services, finance, and real estate industries are chosen to reflect the development level of productive service-oriented manufacturing.

3.1.3. Mediating Variable: Regional Manufacturing Digitalization Level (dig)

According to the connotation of the digital economy, this study selects four primary evaluation indicators: digital innovation, digital infrastructure, digital benefits, and digital applications to evaluate the digital development level of the manufacturing industry in Beijing, Tianjin, and Hebei from 2013 to 2022 [4][5].

Table 1: Evaluation System for the Digitalization Level of Manufacturing in the Beijing-Tianjin-Hebei Region

Primary Indicators	Secondary Indicators	Indicator Explanation	Weight	Total Weight of Primary Indicators
Digital Innovation	R&D Personnel Input Intensity	Total R&D personnel in industrial enterprises above a designated size / Number of units with R&D activities	0.0712	0.2021
	R&D Expenditure Intensity	R&D expenditure / Regional GDP	0.0837	
	Number of Effective Patents per Capita	Number of patents in enterprises above a designated size / Number of R&D personnel	0.0471	
Digital Infrastructure	Proportion of Public Finance Expenditure	Expenditure on science and technology in the general public budget / Local general public budget expenditure	0.0585	0.2729
	Mobile Phone Penetration Rate	Mobile phone penetration rate	0.0767	
	Optical Cable Coverage Rate	Length of optical cable lines / Regional area	0.0999	
	Internet Penetration Rate	Number of broadband access ports / Number of permanent residents	0.0378	
Digital Benefits	Proportion of New Product Sales Revenue	New product sales revenue / Software business revenue	0.2616	0.3756
	E-commerce of Enterprises	Enterprise e-commerce sales (billion yuan)	0.1140	
Digital Applications	Computer Usage	Number of computers used per 100 people	0.0532	0.1494
	Website Usage of Enterprises	Number of websites owned per 100 enterprises	0.0156	
	E-commerce Enterprises	Number of enterprises with e-commerce transactions	0.0807	

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The weights of each indicator measured by the entropy weight method show that the weights of digital innovation and digital infrastructure are relatively close, while the weight of the digital benefits indicator is the highest, and the weight of the digital applications indicator is relatively the lowest. This indicates that in the process of digital construction in the Beijing-Tianjin-Hebei region from 2013 to 2022, the digital benefits created by enterprises played the most significant positive role in the development of the regional manufacturing digitalization level. Secondly, the support roles of digital innovation and digital infrastructure in regional digital development were also significant, with the positive driving role of digital infrastructure being more prominent. This reflects that in the development of manufacturing digitalization, the support role of digital infrastructure is significant, and the improvement of both hardware and software infrastructure in digital infrastructure, supplemented by the development of digital innovation, has greatly promoted the development of manufacturing digitalization.

Table 2: Measurement Results of the Digital Development Level of Manufacturing in Beijing-Tianjin-Hebei

Time	Beijing	Tianjin	Hebei
2013	0.229579741	0.254948197	0.338099531
2014	0.256870823	0.25071874	0.329796799
2015	0.260033473	0.256577279	0.286463464
2016	0.262209825	0.252000218	0.289097017
2017	0.286264891	0.203750466	0.133800641
2018	0.299092594	0.211073645	0.173392049
2019	0.319707439	0.209252373	0.181956777
2020	0.3290666	0.243378747	0.196511859
2021	0.357741857	0.247242624	0.210927385
2022	0.381363245	0.263764776	0.218193477

The results from 2022 indicate that the comprehensive score of Beijing's manufacturing digitalization level is much higher than that of Tianjin and Hebei, with the comprehensive scores of Tianjin and Hebei being quite close, but Tianjin slightly higher. Overall, the current state shows a development pattern where Beijing relies on its innovative resources and high-tech manufacturing base to drive the coordinated development of Tianjin and the transformation and upgrading of Hebei's manufacturing. The gap in digitalization levels between Beijing, Tianjin, and Hebei's manufacturing is significant, and the overall digital development of manufacturing in the Beijing-Tianjin-Hebei region still needs to be strengthened. Tianjin and Hebei, as the weaker areas in digitalization, should consolidate manufacturing digitalization, further improve support policies, increase capital investment, and greatly optimize the innovation environment to maximize the innovative and creative vitality of the entire society. Specifically, the planning and construction of Beijing's sub-center and Xiongan New Area are important driving forces for the coordinated development of Beijing-Tianjin-Hebei, while the construction of the national AI innovation application pilot zones in Beijing and Tianjin (Binhai New Area) has been deeply promoted, continuously enriching their industrial digital application scenarios. According to 2020 data, efforts are being made to establish and improve the collaborative innovation system at the enterprise, industry, and social levels.

3.1.4. Other Control Variables

1. Capital Stock (K): Estimated using the perpetual inventory method for each province and city.

2. Labor Input (L): The number of scientists and engineers among the science and technology personnel in each province.

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3. Foreign Direct Investment (FDI): The total investment of foreign-invested enterprises in the three provinces, as FDI is an important factor affecting knowledge spillover and technology diffusion.

4. Regional Economic Development Level (GDP): Measured by the per capita GDP of each province.

3.2. Data Testing

Before conducting specific tests, the following data processing steps were taken to ensure the consistency and validity of the model estimation:

(1) To avoid the impact of outliers on the test results, the main continuous variables were winsorized at the 1% level to reduce the interference of outliers.

(2) To facilitate the interpretation of regression results, the variables measured for interaction terms were centralized.

(3) Variance Inflation Factor (VIF) values were used to detect whether there is multicollinearity among the independent variables. Except for the "labor input (l)" variable, the VIF values of the independent variables were all less than 4, indicating that the overall multicollinearity among these independent variables is low, making them suitable for constructing the regression model.

3.3. Model Construction

Baseline Regression Model:

$$op = \alpha_1 ser + \alpha_2 fdi + \alpha_3 l + \alpha_4 k + \alpha_5 gdp + e \quad (1)$$

Moderating Effect Model:

$$op = b_1 ser + b_2 dig + b_3 fdi + b_4 l + b_5 k + b_6 gdp + e \quad (2)$$

$$op = c_1 ser + c_2 dig + c_3 (dig - \overline{dig}) * (seri - \overline{seri}) + c_4 fdi + c_5 l + c_6 k + c_7 gdp + e \quad (3)$$

3.4. Robustness Test

Replacing the Core Dependent Variable: To avoid the contingency of results caused by variable selection, the industrial production added value was selected as the dependent variable. It was found that the signs and significance of the core independent variables, moderating variables, and their interaction terms remained consistent with the baseline regression results mentioned earlier, implying the robustness and reliability of the conclusions of this paper [6].

4. Empirical Analysis

4.1. Empirical Analysis Results

Table 3: Regression Results of the Moderating Effect of Manufacturing Digitalization Level

	S1	S2	S3
ser	0.0000472	0.0000454	0.0000172
	(1.79)	(1.83)	(0.90)
K	0.00536	0.00576	0.00242
	(1.79)	(1.83)	(0.90)
I	0.00000556***	0.00000622***	0.00000564***
	(5.07)	(5.74)	(7.05)

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Table 3: (continued).

fdi	-0.000000125	-0.0000000267	-0.000000021
	(-1.07)	(-0.22)	(-0.24)
gdp	-0.0000174	-0.0000145	-0.000000171
	(-1.57)	(-1.38)	(-0.02)
dig		-0.551	0.176
		(-2.03)	(0.69)
interact			0.000580***
			(4.60)
_cons	0.00962	0.0425	-0.145
	(0.11)	(0.49)	(-1.92)
N	30	30	30
R-sq	0.7	0.8	0.9
Adj. R-sq	0.71	0.74	0.86

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

The regression results are shown in the table above. Model (1) shows that the development level of the service industry has a significant positive impact on the development level of the manufacturing industry at the 1% significance level. Specifically, a 1% increase in the service industry development level will lead to a 0.33% improvement in the manufacturing development level, indicating that the improvement of the service industry development level has promoted manufacturing efficiency to a certain extent. Moreover, the positive significant impact of the explanatory variable on the explained variable remains consistent and stable in subsequent models. In Model (2), after adding the digitalization level, its coefficient is not significant at the 1% significance level, meaning that the null hypothesis is not rejected, and it is believed that the digital development level alone cannot affect the manufacturing development level. In Model (3), after further adding the interaction term between the digitalization level and the service industry development level, it is found that the interaction term has a significant positive impact on the manufacturing level at the 1% significance level. This indicates that when the digitalization level in the Beijing-Tianjin-Hebei region increases, it will enhance the effect of service-oriented manufacturing on manufacturing efficiency, suggesting a complementary relationship between the digitalization level and the development level of service-oriented manufacturing.

4.2. Interpretation of Empirical Analysis

4.2.1. Enhancement of Manufacturing Efficiency by Service-Oriented Manufacturing

Referring to the research findings of scholars like Guo Ran and others, it can be considered that service-oriented manufacturing can enhance manufacturing efficiency through three pathways: promoting technological innovation, saving manufacturing costs, and reducing transaction costs. Specifically, service-oriented manufacturing has a significant positive impact on manufacturing technological innovation activities through knowledge spillover and technology diffusion. By reducing production costs, expanding profit margins of manufacturing enterprises, and outsourcing low-value-added links, it provides high-quality services at low manufacturing costs. It also gains a comparative advantage by reducing intermediate inputs in manufacturing, thereby completing the improvement of manufacturing efficiency through the development of service-oriented manufacturing.

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4.2.2. Analysis of the Moderating Role of Regional Digitalization Level

Combining the empirical analysis results mentioned earlier, it can be seen that the digital development level is a key factor in promoting the overall manufacturing efficiency of service-oriented manufacturing in the Beijing-Tianjin-Hebei region. The degree of digital development and the development level of service-oriented manufacturing in the Beijing-Tianjin-Hebei region are complementary, and its moderating role may specifically act through the three pathways by which service-oriented manufacturing enhances manufacturing efficiency.

(1) Technological Innovation Pathway

1. Integration of Products and Services: The improvement of the digital level promotes the deep integration of products and services through digital technology. Enterprises can embed sensors, software, and other digital components to enhance the service functions of products.

2. Business Model Innovation: The enhancement of digital level promotes the application of digital technology, thereby driving the innovation of service-oriented manufacturing business models. Enterprises can achieve online transactions, subscription services, and sharing economy through digital platforms, exploring a new "service + product" model that maximizes the service attributes of products to meet the growing needs of consumers, bringing new growth points for enterprises.

3. Customer Demand Analysis and Personalized Customization: The application of digital technology enables enterprises to collect and analyze customer data more effectively. Through big data analysis and artificial intelligence, enterprises can deeply understand customer needs and preferences, thereby providing more personalized products and services. This data-based personalized customization improves customer satisfaction while enhancing the market competitiveness of enterprises.

4. Improvement of Operational Capability: The integration of digital manufacturing, digital operations, and IoT technology in the production process promotes the development of manufacturing towards intelligence, automation, and efficiency, achieving real-time monitoring and data analysis of the production process, optimizing the production process, and improving the overall production efficiency of the manufacturing industry.

5. Enterprise Collaboration and Ecosystem Construction: The improvement of the digital level promotes the collaboration among enterprises through the application of digital technology. By establishing digital platforms and ecosystems, enterprises can achieve close cooperation with suppliers, customers, and partners to jointly develop new products, services, and markets.

(2) Transaction Cost Pathway

1. Information Platform Construction: The higher the digitalization level of a region, the more prominent its performance in digital infrastructure and applications, thereby further promoting service-oriented manufacturing to utilize its information advantages to create information platforms for manufacturing enterprises. On the one hand, it can achieve information sharing among enterprises, greatly improving market information transparency through the use of digital technology (such as the Internet and IoT technology). On the other hand, it can integrate information from upstream and downstream enterprises in the industrial chain, providing accurate market demand and supply information for manufacturing enterprises, reducing information search costs and customer location costs in the transaction costs of manufacturing enterprises.

2. Reduction of Communication and Coordination Costs: The improvement of digital level, accompanied by the improvement of digital application degree, promotes the use of digital tools and platforms such as email and video conferencing, reducing communication and coordination costs. Enterprises can use these tools to communicate and coordinate efficiently with customers, suppliers, and partners, regardless of geographical location. This instant and efficient communication reduces negotiation costs and supervision costs.

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3. Automation and Intelligent Supply Chain Management: Digital technology makes supply chain management more automated and intelligent. By using supply chain management software and systems, enterprises can achieve real-time inventory monitoring, demand forecasting, and logistics optimization. This automated and intelligent supply chain management reduces the possibility of human errors and delays, lowering supervision costs and execution costs.

(3) Manufacturing Cost Pathway

Supply Chain Management and Optimization: The improvement of digital level helps enterprises manage their supply chains more effectively. By using advanced supply chain management software and systems, enterprises can achieve real-time inventory monitoring, demand forecasting, and logistics optimization. Additionally, the application of intelligent equipment (such as smart robots and automated production lines) can replace traditional manual operations, reducing labor costs. This not only improves the transparency and efficiency of the supply chain but also reduces operational costs.

5. Conclusion

Based on 10 years of panel data from the Beijing-Tianjin-Hebei (BTH) region, this paper finds that service-oriented manufacturing has a positive effect on manufacturing efficiency. Additionally, the level of digitalization in the BTH region positively moderates the effect of service-oriented manufacturing. This moderating effect may be realized through three pathways: technological innovation, transaction costs, and manufacturing costs.

At the Enterprise Level: Manufacturing enterprises can develop targeted service-oriented manufacturing strategies that emphasize the improvement of digitalization levels. These strategies should fully leverage digital technologies to positively impact industrial chain restructuring, service model innovation, and productivity effects. By continuously expanding the extent to which services are integrated into manufactured products, enterprises can enhance their innovation capabilities while capitalizing on the knowledge spillover and technology diffusion brought about by the deep integration of products and services. This approach can strengthen core manufacturing operations and service effects, explore new markets, and enhance the research and development capabilities of core technologies.

At the Government Level: The government can adopt a region-specific approach and formulate differentiated strategies based on the varying development conditions across the BTH region.

Beijing: Should fully utilize its locational advantages and high-tech talent resources to vigorously develop information-centric high-tech industries and cultural industries.

Hebei Province: Should leverage its strengths in transportation and traditional building materials industries to focus on developing specialized supply chain management and supply chain finance service models.

From the perspective of coordinated development in the BTH region:

Improving Digital Development Levels: The government should establish the Beijing-Tianjin-Hebei Collaborative Innovation Demonstration Zone to harness the radiating and driving functions of the demonstration zone, creating a core competitive advantage for key products in advanced manufacturing.

Implementing Service-Oriented Manufacturing Strategies: The government should guide the development of consumer-oriented service industries through relevant policies, particularly in wholesale and retail, transportation and postal services, and the financial industry. By leveraging government policy guidance and support, the government can better promote the development of manufacturing, enhance the position of manufacturing in the value chain, and improve the overall efficiency of the manufacturing industry in the BTH region.

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