Effect Evaluation and Implementation Path of Digital Economy Empowering the Upgrading of Manufacturing Industry in Beijing-Tianjin-Hebei Region

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Abstract. On the base of panel data from 2012 to 2022, this article empirically examines the differential impact, mechanism, and path of the Digital Economy（DE）on the upgrading of the manufacturing industry in the Beijing-Tianjin-Hebei region. Research findings indicate that the DE significantly influences the upgrading of Beijing-Tianjin-Hebei's manufacturing industry; however, there exists regional and industry heterogeneity. The test for regional heterogeneity reveals that while promoting structural upgrades in various regions of Beijing-Tianjin-Hebei 's manufacturing industry, the DE has a stronger impact on enhancing the manufacturing industry chain in Tianjin and Beijing compared to Hebei Province.

Keywords: Digital Economy, Manufacturing upgrading, Intermediary effect, technological innovation

1 Introduction

The study focuses on investigating the influence of the DE in facilitating the upgrading of the manufacturing industry. Scholars explore the digital classics from different perspectives. The research on that theme has conclusions drawn different conclusions. Li Fuyi (2018) [1] proved that technological innovation exert a certain intermediary effect in the upgrading of manufacturing industry promoted by digital technology. Wang Shunan (2019) [2] found the DE exerts obvious influence on the progression of the traditional manufacturing industry through reforms in personalized market demand and production modes. Li Chunfa (2020) [3] argues that the unrestricted replication and dissemination of digital information accelerates the technological innovation cycle within companies, leading to reduced research and development costs and facilitating value chain upgrading. Shen Yunhong (2020) [4] proved that the development of the digital industry serves as a pathway for promoting the modernization and enhancement of Zhejiang Province's manufacturing industry, in line with the objectives of Digital Economy.

In summary, the existing literature has studied the theory of DE empowering manufacturing upgrading, which provides valuable reference for this article. However, there are few studies on that issue in the Beijing-Tianjin-Hebei region based on Digital Economy. In light of this,

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drawing upon the existing theoretical foundation of Digital Economy's role in empowering the manufacturing industry, the mechanism of the DE empowering the upgrading of the manufacturing industry in Beijing-Tianjin-Hebei is analyzed from a regional perspective. Through the panel data of the research region from 2012 to 2021, its heterogeneous impact, mechanism and implementation path are empirically tested.

2 Theoretical analysis and hypotheses

2.1 The direct impact of the Digital Economy Eon facilitating the advancement of the manufacturing industry.

First of all, computer information technology, cloud platforms, and big data brought about by the DE have greatly improved the innovation efficiency of manufacturing scientific researchers, shortened the technology research cycle of enterprises, increased the speed of technological innovation, and reduced enterprise costs. It improves the competitiveness of products in the market, thereby stimulating the improvement of the manufacturing structure. Secondly, the application of the digital technology has transformed traditional manufacturing production methods into smart manufacturing, promoted the extension of front-end and back-end links in the manufacturing value chain, and improved the production efficiency, product added value and profit margins of manufacturing company, reinforcing the advancement and modernization of the manufacturing industry, facilitating its manufacturing industry.

Finally, the advancement of digital technology fosters innovation in enterprise management models. Digital management breaks down the barriers between departments within an enterprise and between enterprises, and is benefit to treat the problems of untimely communication and limited geographical space between enterprises in the supply chain. It will continuously reduce the transaction costs, management and time costs of company, and improve the efficiency of that.

Assumption 1: The DE has emerged as a pivotal catalyst for the metamorphosis and advancement of the manufacturing industry.

2.2 The Digital Economy indirectly facilitates the enhancement of the manufacturing industry.

2.2.1 The influence of the Digital Economy on technological innovation.

Technological innovation is the cornerstone of manufacturing improvement. The DE is driven by digital innovation as its critical driving force. Digital technology is deeply integrated to realize intelligent reform of the manufacturing industry, improve the technological innovation capabilities of manufacturing enterprises, and promote the progression of the manufacturing industry. First of all, with the support of digital technology, enterprises track the behavior of informants to promote the creation of personalized markets. Liu Cuihua [5] found meet the growing personalized needs, increase the company core competitiveness, and subvert the traditional production thinking of "from factory to user", it will help promote the upgrading of manufacturing enterprises. Secondly, Yijiabin [6] found that the digital technology may bring about tremendous changes in the production methods of the manufacturing industry. Digital

technology can realize automated control of the manufacturing production process, improve resource allocation efficiency, optimize production processes, reduce production costs, and promote the progression of the manufacturing structure. Finally, Zhouyong[7]found the digitization of company management can help enterprises comprehensively promote the change and innovation of management models Digital management promotes the industrial ecological transformation of enterprises through the integration of business processes and even industry synergy and symbiosis, breaks down the barriers between departments within the enterprise and between enterprises, and improves the efficiency of enterprise resource management. Enterprises optimize management manner and improve enterprise efficiency, the aforementioned is favorable for facilitating the advancement of the manufacturing sector.

Assumption 2: The Digital Economy facilitates the technological innovation-driven upgrading of the manufacturing industry.

2.2.2 The impact of Digital Economy on resource allocation

The DE uses data elements as critical production factors, which have the characteristics of unlimited copying and being unaffected by wear and tear. First of all, Wangwenna[8]proved that data elements break the constraints of the limited supply of traditional production factors on enterprise development. They can be used by different entities on a global scale at the same time without any loss, showing the characteristics of increasing marginal returns, there by obviously promoting the efficiency of knowledge production, thus it reduces the cost and evolves into a key production factor to accelerate the progression of the manufacturing industry. Secondly, data circulation brings new business models such as personalized customization, convenience, intelligence, and networked collaboration, reducing information asymmetry and alleviating market failures. Weizhuangyu[9] proved that enterprises use information platforms to judge changes in the external environment and informants' needs, reduce information asymmetry, adopt flexible production methods, and effectively avoid blind resource allocation.

Assumption 3: The Digital Economy facilitates the process of upgrading of the Beijing-Tianjin-Hebei manufacturing industry by optimizing resource allocation.

3 Variable selection and model

3.1 Variable selection

This article considers the connotation of the DE and constructs a corresponding measurement index system from three aspects: infrastructure, and industrial digitization, as illustrated in Table 1.

Table 1 Beijing-Tianjin-Hebei DE development level indicator system

First-level indicator	Second-level indicators	Third-level indicators
Beijing-Tianjin-Hebei DE development	infrastructure index	Mobile phone penetration rate
		Internet penetration rate

index indicator		Number of Internet broadband users
	Digital industrialization	The added value of core industries of the DE as a proportion of GDP
		Scale of electronic information industry
		Scale of software and information technology services industry
	Industrial digitalization	Proportion of industrial enterprises above designated size that have fully digitized key business links
		Added new industrial Internet platform
		Added new smart factories and digital workshops
		Cross-border e-commerce transaction volume
		online retail sales

The entropy weight method is used to evaluate the development level of DE in the Beijing-Tianjin-Hebei region. as shown in Table 2.

The EWM is a commonly utilized method for weighting multiple evaluation indexes, which uses information entropy to determine the weight values of each index, thereby better reflecting the importance of evaluation indexes in decision-making. The information entropy is calculated as:

$$E_j = -\sum_{i=1}^{n} \frac{Y_{ij}}{\sum_{i=1}^{n} Y_{ij}} \tag{1}$$

The calculation of weight is a key step in information entropy, and the weight of each index can be calculated using Formula (2):

$$W_j = \frac{1 - E_j}{\sum_{j=1}^{m} \left(1 - E_j\right)} \tag{2}$$

The EWM is a commonly used multi-index decision-making method used to determine the weight of each index in the comprehensive score and ultimately calculate the comprehensive score. The comprehensive score is determined:

$$\mathrm{DE}_i = -\sum_{j=1}^{m} \left(W_j X_{ij}\right) \tag{3}$$

Table 2 Beijing-Tianjin-Hebei DE development level

Years	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Beijing	0.5578	0.9387	1.9283	2.0179	2.0831	2.2011	2.4119	2.9132	3.012	3.2671	3.4135
Tianjin	0.1747	0.2298	0.4368	0.4482	0.5012	0.4931	0.5932	0.6801	0.7122	0.7728	0.8371
Hebei	0.2089	0.2475	0.6182	0.3119	0.5816	0.6821	0.7481	0.7688	0.7801	0.8102	0.9035

Regarding the level of manufacturing upgrading (MFG) in the study area, we follow the definition of manufacturing upgrading in existing research. Drawing on the research methods of Zhao xidong [10], this paper uses two indicators: "Manufacturing Industry Structure Upgrade (MR)" and "Manufacturing Industry Chain Upgrade (MA)" to weigh the advancement and modernization of the manufacturing sector. The manufacturing industrial structure upgrading index is: MR=1×MR1+2×MR2+3×MR3. The larger the MR value, the more reasonable the MI structure upgrading is. Among them, MR1 is the ratio of the output value of labor-intensive industries in the total output value of the manufacturing industry, representing the development level of labor-intensive industries. MR2 is the ratio of the output value of capital-intensive industries in that, representing the development level of capital-intensive industries. MR3 refer to the percentage of the output value of technology-intensive industries in that , representing its development level. The manufacturing industry chain upgrading index is: MA=MR3/MR2, which reflects the process of upgrading the manufacturing industry chain to high added value.

Referring to existing research this study adds the control variables to the model: PGDP, FDI, GOV, urbanization rate (URB). In order to explore the realization path of the digital technology empowering the improvement of the manufacturing industry in Beijing-Tianjin-Hebei, this article introduces two intermediary variables: technological innovation capability (TI) and resource allocation (RA). Technological innovation capability (TI) is measured by the logarithm of the patent applications number in the study area. Resource allocation (RA) is expressed by the logarithm of capital stock and human capital stock in that region.

3.2 Data Sources

In view of the authenticity of the data, Benli selected panel data from the three regions of study area from 2012 to 2022 to explore the issue of DE empowering that process. Among them, the original data of digital infrastructure investment intensity, digital technology application index, and digital business model come from the "China Statistical Yearbook", "China Industrial Economic Statistical Yearbook", "China Industrial Statistical Yearbook", "China Internet Development Statistical Report", and "China Electronic Information Industry Statistical Yearbook". The statistical results of the parameters after standardization as illustrated in Table 3.

Table 3 Descriptive statistical results of variables after standardization

variable	Average value	Standard deviation	Minimum value	Maximum value
（MR）	1.961	0.193	1.542	2.356
（MA）	0.894	0.991	0.053	4.468
DE	1.078	0.184	0.507	2.156
PGDP	9.639	0.435	8.947	11.764
FDI	2.058	1.993	0.139	9.973
GOV	0.267	0.112	0.125	0.671
URB	4.291	0.216	3.657	4.769
TI	8.741	1.389	5.975	12.372
RA	8.487	0.712	6.734	10.215

3.3 Model development.

3.3.1 Baseline regression model

The impact of the DE on the upgrading of the manufacturing industry in the Beijing-Tianjin-Hebei region was analyzed through the establishment of a regression model. The measurement model is as follows:

$$MFG_{i,t} = \alpha_0 + \alpha_1 DE_{i,t} + \alpha_j X_{i,t} + \delta_t + u_i + \varepsilon_{i,t} \quad (4)$$

Among them, i and t represent region and time, MFG represents the level of manufacturing upgrading in Beijing-Tianjin-Hebei, DE represents Beijing-Tianjin-Hebei Digital Economy, X represents control variables, δ_t represents time fixed effects, u_i represents individual fixed effects, $\varepsilon_{i,t}$ represents random error.

3.3.2 Mediating effect model

The present article employs the intermediary effect application method, constructs an intermediary effect model, and validates the fundamental pathway through which the DE empowers the upgrading of the manufacturing industry in Beijing-Tianjin-Hebei.

$$M_{i,t} = \gamma_0 + \alpha\gamma_1 DE_{i,t} + \gamma_j X_{i,t} + \delta_t + u_i + \varepsilon_{it} \quad (5)$$

Among them, M is the intermediary variable, including two aspects: technological innovation (TI) and resource allocation (RA).On the basis of model (1), (2) is added to build a mediating effect model.

$$MFG_{i,t} = \beta_0 + \alpha\beta_1 DE_{i,t} + \rho M_{i,t} + \beta_j X_{i,t} + \delta_t + u_i + \varepsilon_{it} \quad (6)$$

Equation (2) is the impact of the DE on technological innovation and resource allocation in the manufacturing industry in the Beijing-Tianjin-Hebei region. Equation (6) tests the impact of Digital Economy, technological innovation, and resource allocation on the upgrading of the manufacturing industry in Beijing, Tianjin, and Hebei.

4 Results and discussion

4.1 Regression results

Table 4 Regression results

Variable	MR	MR	MA	MA
DE	0.498*** (0.061)	0.202*** (0.084)	2.685*** (0.311)	1. 70*** (0.429)
PGDP		0. 073** (0.037)		0.306* (0.185)
FDI		0.019*** (0.005)		0.088*** (0.026)
GOV		0.334*** (0.114)		0.142* (0.077)
URB		1.211***		0.174***

		(0.043)		(0.037)
Constant term	1.798*** (0.016)	1.247*** (0.384)	0.391*** (0. 091)	-2. 069* (2.102)
Regional effect	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes
R2	0.191	0.389	0.211	0.378
N	205	205	205	205

Note: ***（1%）, **（5%）, *（10% ）levels respectively, The same below.

According to the result of benchmark regression results in Table 4, it was concluded that when the development level of the DE enhances by 1%, the manufacturing industry structure upgrading index increases by 0.20%, and the manufacturing industry chain upgrading index increases by 1.7%. The findings demonstrate a positive association in the level of DE development of the manufacturing industry in Beijing-Tianjin-Hebei. The aforementioned statement aligns with the first research hypothesis, suggesting that the DE exerts a substantial influence on that process in Beijing-Tianjin-Hebei.

4.2 Stability test

To confirm the reliability of the above results, this research tests the stability of the model by considering adding control variables and not adding control variables during linear regression. From the stability test results in Table 5, it was concluded that the coefficients of the DE are consistent with the benchmark regression coefficients in Table 4, with slight differences Therefore, the regression results of this article are stable.

Table 5 Stability test results

Variable	MR	MR	MA	MA
DE	0.197*** (0.084)	0.15*** (0.426)	1.207** (0.086)	0.103*** (0.441)
Constant term	1.205*** (0.419)	-1.968* (2.145)	1.164*** (0.369)	-1.022* (2.091)
Regional effect	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes
R2	0.397	0.369	0.377	0.68
N	205	205	205	205

4.3 Heterogeneity test

The findings in Table 6 demonstrate the presence of regional heterogeneity regarding the impact of the DE on the upgrading of the manufacturing industry within the research region. The coefficient of DE upgrading the industrial structure of Beijing's manufacturing industry is 0.082, which is significant at the 10% level. The regression coefficient of manufacturing industry chain upgrading is 3.215, which is significant at the 1% level. It shows that the DE is conducive to the upgrading of the manufacturing industry in Beijing. The Digital Economy’s upgrading index of the manufacturing industry structure in Tianjin is 0.259, which is significant at the 5% level. The manufacturing industry chain upgrade index in the region is

3.070, which is significant at the 1% level. The aforementioned statement demonstrates the profound impact of the DE on facilitating the transformation and advancement of Tianjin's manufacturing industry. The regression coefficient of DE on the upgrading of manufacturing structure in Hebei is 0.233, which exhibits statistical significance at the 10% level. The regression coefficient of the manufacturing industry chain upgrade is 0.359, which fails the significance test, indicating that the DE is effective in upgrading the manufacturing industry structure in Hebei.

Table 6 Heterogeneity test results

Variable	Regional heterogeneity						Industry heterogeneity		
	Beijing		Tianjing		Hebei		MR1	MR2	MR3
	MR	MA	MR	MA	MR	MA			
DE	0.082*	3.215**	0.259**	3.070**	0.233*	0.359	0.619	3.767**	7.216***
	(0.108)	(0.857)	(0.248)	(0.986)	(0.129)	(0.618)	(4.219)	2.933	(1.672)
PGDP	0.161***	0.003*	0.054*	0.059**	0.072*	0.392	2.011*	1.795**	5.849***
	(0.049)	(0.341)	(0.118)	(0.468)	(0.059)	(0.286)	(1.820)	(1.978)	(1.140)
FDI	0.021***	0.095*	0.010*	0.137**	0.019*	0.051	-0.190*	0.119*	0.125*
	(0.006)	(0.048)	(0.009)	(0.029)	(0.011)	(0.053)	(0.235)	(0.140)	0.077
GOV	1.159***	-0.367	0.476**	2.817**	0.540**	-3.397**	-6.875***	-4.991	2.123**
	(0.219)	(1.539)	(0.421)	(1.657)	(0.168)	(0.807)	(5.650)	(9.281)	(5.286)
URB	-0.034***	-0.215**	-0.128**	0.079*	0.451*	-0.474	1.103**	3.874	1.889***
	(0.048)	(0.377)	(0.089)	(0.357)	(0.81)	(0.394)	(2.095)	(1.697)	(0.963)
Constant term	0.269*	1.570**	1.249**	-2.712**	2.695**	-2.916	5.395***	2.589**	-4.067***
	(0.570)	(0.368)	(1.279)	(1.038)	(0.631)	(3.307)	(1.949)	(2.147)	(1.138)
Regional effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R2	0.789	0.590	0.139	0.438	0.160	0.295	0.380	0.478	0.628
N	65	65	60	60	80	80	205	205	205

The influence of the DE on that process in Beijing-Tianjin-Hebei is demonstrated by Table 6. The regression of coefficient technology-intensive manufacturing is 7.216, which is significant at the 1% level, capital-intensive manufacturing is 3.767, which is significant at the 1% level, labor-intensive manufacturing is 0.619, which fails the significance test. The DE exerts the most significant impact on the upgrading of technology-intensive manufacturing industries, followed by capital-intensive manufacturing industries, while its effect on labor-intensive manufacturing industries is comparatively smaller.

4.4 Mechanism of action mediation effect test

The present study employs the intermediary effect model to examine whether technological innovation and resource allocation, driven by the Digital Economy, facilitate the upgrading of the manufacturing in Beijing-Tianjin-Hebei region. From the benchmark regression results in Table 4, MR (0.202) and MA (2.685) are both significant at the 1% level. As can be seen from Table 7, the regression coefficients of DE on technological innovation and resource allocation are 0.016 and 1.079 respectively, both significant at the 1% level. It shows that the DE has a mediating effect on technological innovation and resource allocation.

For the reasonable industrial structure of the manufacturing industry in the Beijing-Tianjin-Hebei region, the regression coefficient of technological innovation in Table7 is 0.025 and passes the 5% significance test. The intermediary effect of technological innovation is 0.104, indicating that technological innovation plays an important role in the upgrading of the MR in Beijing-Tianjin-Hebei. The impact of resource allocation on the upgrading of the MA in the Beijing-Tianjin-Hebei, but does not pass the significant test. After further conducting the Sobel test, it was found that the P value was 0.69>0.05, which failed to pass the Sobel test, indicating that the mediating effect of the resource allocation intermediary variable was not significant.

According to columns 5 and 6, the influence of technological innovation and resource allocation on MA in the Beijing-Tianjin-Hebei system is uniformly positive through significance test. The mediating effect of technological innovation is 0.474. The mediating effect of resource allocation is 0.106. In order to ensure the stability of the test results, Sobel test was performed, and the P values were 0.016 and 0.029 respectively, both of which were less than the critical value (0.05). It is verified that technological innovation and resource allocation play the role of intermediary variables in the upgrading of the MA in the Beijing-Tianjin-Hebei region.

Technological innovation and resource allocation serve as effective means for promoting the upgrading of the manufacturing industry in Beijing-Tianjin-Hebei within the Digital Economy. At this point, research hypotheses 2 and 3 have been confirmed.

Table 7 Mediation effect test results

Variable	TI	RA	MR	MR	MA	MA
DE	4.016*** (0. 419)	1.079*** (0. 238)	0.19* (0.094)	0.209* (0.091)	1.297*** (0.490)	1. 679*** (0.467)
TI			0.025** (0.010)		0.018** (0.061)	
RA				0.020 (0.019)		0.097* (0.102)
Mediating effect			0.104		0.474	0.106
Proportion			44.44%	—	26.48%	5.92%
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Regional effect	Yes	Yes	Yes	Yes	Yes	Yes

Time effect	Yes	Yes	Yes	Yes	Yes	Yes
P(Sobel)			0.001	0.69	0.016	0.029
N	205	205	205	205	205	205

5 Conclusions and recommendations

5.1 Conclusions

(1) The DE exerts a substantial impact on the upgrading of the manufacturing industry in Beijing-Tianjin-Hebei; however, regional disparities and variations across industries exist.

(2) The results of the regional heterogeneity test indicate that the DE significantly influences the upgrading of the manufacturing industry structure in the Beijing-Tianjin-Hebei region. However, its impact on the upgrading of the manufacturing industry chain is more pronounced in Beijing-Tianjin than in Hebei.

(3) Industry heterogeneity test results prove that the DE has the greatest impact on technology-intensive manufacturing in the Beijing-Tianjin-Hebei region, followed by capital-intensive manufacturing, and labor-intensive manufacturing the least.

(4) The test of the mechanism of action demonstrates that technological innovation and resource allocation are two crucial pathways for promoting the upgrading of the manufacturing industry in Beijing-Tianjin-Hebei region. Notably, technological innovation plays a more significant role as an intermediary factor in driving this transformation.

5.2 Recommendations

1.Deeply integrate and develop the DE and manufacturing in a targeted manner. In the labor-intensive manufacturing industry, priority should be given to launching digital transformation pilots in key enterprises, using digital technology to transform the production and management methods of traditional manufacturing, optimizing production processes, improving production efficiency, etc. to accelerate the progression of labor-intensive manufacturing. In the capital-intensive manufacturing industry, existing production equipment should be transformed and upgraded, and intelligent integrated production lines should be built to improve enterprise production efficiency and promote intelligent production in the manufacturing industry. For technology-intensive manufacturing industries, we should strengthen the integration of "industry and research", stimulate digital technology innovation capabilities, shorten the technology research cycle, upgrade the industrial chain, improve market competitiveness, and accelerate the progression of the manufacturing industry.

2.The Digital Economic indirectly affects the upgrading of the manufacturing industry through technological innovation. We should accelerate breakthroughs in key technologies in key areas such as artificial intelligence, big data, cloud computing, and network security, strengthen independent training of talents, and stimulate the vitality of independent innovation of talents.

3.Optimize the allocation of Digital Economic resources. While Hebei province and two cities with differences in resource allocation and technological innovation implement heterogeneous development. Beijing and Tianjin work together to strengthen the development of manufacturing industry clusters, increase investment in digital technology, promote the

manufacturing value chain of Beijing and Tianjin to move towards the mid-to-high end. Hebei Province should strengthen the construction of Digital Economic infrastructure to promote the development of regional Digital Economic.

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