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Study on the Effect of Industrial Internet Development on the Chinese Manufacturing Productivity Improvement

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Abstract

Firstly, data resource allocation coefficient is introduced into the analytical framework to construct a theoretical model of the impact of data factor allocation on total factor productivity (TFP), and then the panel data of 30 provinces and cities in China from 2012 to 2020 are utilized to measure the level of the development of the Industrial Internet, and the stochastic frontier analysis (SFA) method is used to estimate the provincial TFP in the manufacturing industry. Then the effect of Industrial Internet development on Chinese manufacturing productivity is empirically tested based on the fixed effect model, and finally the heterogeneity analysis is carried out from the perspective of regional location of enterprises. The results show that the level of Industrial Internet development in China shows an overall upward trend and has a significant enhancement effect on manufacturing TFP, but its enhancement effect is regionally heterogeneous. The conclusion of the study has positive insights for China to further promote the development of Industrial Internet and facilitate the transformation and upgrading of manufacturing industry.

Keywords

Industrial Internet; Total Factor Productivity; Manufacturing Industry.

1. Introduction and Literature Review

The report of the twentieth CPC National Congress points out that "we will accelerate the construction of a new development pattern and strive to promote high-quality development. Accelerate the development of the digital economy and promote the deep integration of the digital economy and the real economy". The term "digital economy" refers to a set of economic activities that use digitized knowledge and information as the primary production inputs, a contemporary information network as the key delivery mechanism, and effective information and communication technology use as the primary force behind efficiency enhancement and economic structure optimization. Manufacturing is key area for the development of the real economy and a core component of the multi-level industrial system. China has explicitly incorporated the strategy of accelerating the promotion of a competitive manufacturing country into the "14th Five-Year Plan" and the 2035 Vision Outline. The in-depth integration of the digital economy and manufacturing industry has become an important driving force in promoting changes in the quality, efficiency and dynamics of China's economic development.

As an important engine of the digital economy, the Industrial Internet drives the flow of technology, capital and talent with the flow of information, reduces the barriers to information flow, accelerates the flow of resource elements, promotes the optimal allocation of resources. In November 2017, the State Council issued the "Guiding Opinions on Deepening the "Internet+Advanced Manufacturing "and Development Industrial Internet", which promotes the Industrial Internet in three major aspects: network, platform and security, thus providing a foundation for the realization of intelligent manufacturing and service-oriented manufacturing. Industrial Internet can realize the efficient sharing of production factors and service factors through the interconnection of data in the whole region, promote the digital transformation of enterprises. In order to further advance the development of the Industrial Internet and the high-quality development of the manufacturing industry, it is of great theoretical and practical significance to investigate the impact of the Industrial Internet on the productivity improvement of China's manufacturing industry.

With the transformation of the economic development mode and the explosive growth of the digital economy, scholars at home and abroad have conducted research on related issues. The widespread application of information and communication technology is considered to be one of the important factors that enabled the sustained growth of total factor productivity in developed countries such as the United States from the 1990s to the early 2000s. Jorgenson (2016) measured the contribution of information technology capital to the economic growth of the United States, and found that its contribution was significant. Based on network externalities and the endogenous growth theory, Yen and Howard (2014) noted that there is a considerable positive relation between information technology and total factor productivity in terms of the quality of economic development. Thompson (2007) found the role of information technology investment and information technology industry in enhancing the productivity of manufacturing industry. According to Cha and Zuo's (2017) research, there is a spatial spillover effect and that the level of information technology significantly improves industrial structure upgrading. Jing and Sun (2019) discussed the digital economy acting on the macro-economy through three pathways: new factor inputs, new factor allocation efficiency and new total factor productivity at the theoretical level. Ma and Ning (2020) used factor allocation as a mediator to examine the connection between the digital economy and manufacturing quality. Through empirical investigation, Xiao (2019) came to the conclusion that the rise of total factor productivity can be considerably aided by the digital economy.

The definition of factors of production in the information age is no longer limited to traditional labor, capital and land, etc. The Fourth Plenary Session of the 19th Central Committee (PRC) explicitly proposed that "data can be used as factors of production to participate in the distribution of value". Dewan (2000) points out that data is a fundamental resource of the digital economy and a new driving force for economic growth. On the one hand, in the process of the development of the digital economy data has not only gained the same status as traditional factors such as capital and labor, but its productive attributes in economic activities have been continuously strengthened. Data resources can directly empower manufacturing industry development , improve the quality control and manufacturing capabilities of enterprises, enhance the automation and intelligent production level of enterprises, and optimize the manufacturing process; on the other hand, data elements can also indirectly boost the high-quality development of the manufacturing industry by influencing the resource allocation and efficiency of human resources, capital, science and technology innovation and other factors (Zhang, 2017). Data factors can improve the established ratio of factor inputs and enhance the overall factor allocation level through the integration with traditional factors of production (Li, 2021).

From the literature review, there is less literature involving Industrial Internet research, and most of the research focuses on the study of the impact of the internet on the upgrading of the manufacturing industry. Li et al. (2017) believe that the Industrial Internet covers cloud computing, big data and other technologies, which can reduce the production cost and improve the efficiency of industrial production. According to Wang (2019), the Industrial Internet may help the manufacturing sector advance by optimizing resource allocation, enhancing the production process, and promoting the innovation of business models. Tang and Li (2020) believe that the Industrial Internet is of positive significance in solving the problem of locking China's manufacturing industry at the low end of the global value chain, and can effectively promote the improvement of manufacturing value creativity. Cai and Qi (2021) pointed out that the Industrial Internet can help manufacturing enterprises digitize their production processes, and ultimately promote the digital transformation of the manufacturing industry from point to point, and enhance the overall competitiveness of China's manufacturing industry.

2. Theoretical Model and Hypothesis

This paper introduces three different variables denoting the final product market, data factor market, and traditional factor market and defines the competitive equilibrium within the framework of Hsieh and Klenow's (2009) study, which in turn discusses the impact of data factor allocation on total factor productivity in the manufacturing industry.

HK is based on the framework of the monopolistic competition model, which assumes that firms within industries are heterogeneous and face different price distortions. In this paper, it is assumed that N different sub-industries within the manufacturing industry have different production functions, while firms within the same sub-industry have the same production function, such that each sub-industry can be considered to be replaced by a representative firm. Firms are price takers in the factor market, and the prices of basic factors under the perfect competition model are p_{DR} , p_{KL} respectively. Starting from the Cobb-Douglas (CD) production function, there are:

$$V_i = F_i(\mathrm{DR}_i, \mathrm{KL}_i) \equiv A_i \mathrm{DR}_i^{\partial_i} KL_i^{1-\partial_i} \tag{1}$$

where V_i represents output, A_i represents technological progress of individual firms, i.e. total factor productivity. DR and KL represent data factor inputs and traditional factor inputs, respectively, and ∂^i represents the output elasticity of data factors.

Industries face different distortionary tax rates representing differences in the degree of factor mismatch, and for simplicity, the degree of data factor mismatch is denoted by τ_i, assuming that factor allocation distortions exist mainly in the data factors. The larger the value of τ_i, the more pronounced the degree of data factor mismatch. The profit function of a representative firm can be expressed as:

$$\pi_i = p_{yi} V_i - (1+\tau_i) p_{\mathrm{DR}} \mathrm{DR}_i - p_{\mathrm{KL}} \mathrm{KL}_i \tag{2}$$

Industrial Internet development is conducive to reducing the cost of data element search and transaction costs, and then enhance the efficiency of data allocation, therefore, the higher the level of Industrial Internet development II , the lower the data factor mismatch level τ_i ,and tends to show the law of diminishing marginal effect, i.e., $\tau'_i(II) < 0$,then the profit function can be rewritten as:

$$\pi_i = p_{yi} V_i - \sum (1+\tau_i(\mathrm{II}_i)) p_{\mathrm{DR}} \mathrm{DR}_i - p_{\mathrm{KL}} \mathrm{KL}_i \tag{3}$$

The profit maximization objectives of the firm are as follows:

$$Max \pi_i = p_{yi} V_i - \sum (1+\tau_i(\mathrm{II}_i)) p_{\mathrm{DR}} \mathrm{DR}_i - p_{\mathrm{KL}} \mathrm{KL}_i \tag{4}$$

$$S.t. \ \sum_{i=1}^{n} K\mathrm{L}_i = K\mathrm{L}, \ \sum_{i=1}^{n} \mathrm{DR}_i = \mathrm{DR}$$

Based on the principle of chasing the minimized cost under the given output, the cost minimization objectives of the enterprise are as follows:

$$MinC_i = \sum (1+\tau_i(\mathrm{II_i}))p_{\mathrm{DR}}\mathrm{DR}_i + p_{\mathrm{KL}}\mathrm{KL}_i \tag{5}$$

$$S.t.\ V_i = A_i D\mathrm{R}_i^{\partial_i} KL_i^{1-\partial_i}$$

The optimal number of inputs for data and traditional factors under the cost minimization constraint can be found by constructing a Lagrange multiplier equation for the cost function:

$$\mathrm{DR}_i = \left[\frac{\partial_i P_{KL}}{(\partial_i - 1)\sum (1+\tau_i(\mathrm{II_i}))p_{\mathrm{DR}}} \right]^{\partial-1} \frac{V_i}{A_i} \tag{6}$$

$$\mathrm{KL}_i = \left[\frac{(\partial_i - 1)P_{DR}}{\partial_i \sum (1+\tau_i(\mathrm{II_i}))p_{KL}} \right]^{\partial} \frac{V_i}{A_i} \tag{7}$$

With constant returns to scale, substituting the above equation into the cost function (5) and deriving it for output yields the marginal cost MC_i expression:

$$MC_i = F\left[\sum (1+\tau_i(\mathrm{II_i}))p_{\mathrm{DR}} \right]^{\partial} p_{\mathrm{KL}}{}^{1-\partial} A_i^{-1} \tag{8}$$

$$\mathrm{F} = \left(\frac{\partial}{1-\partial} \right)^{1-\partial} + \left(\frac{\partial}{1-\partial} \right)^{\partial} \tag{9}$$

According to the general definition of total factor productivity TFP, substituting equation (8) into the firm's profit function (4), the expression for total factor productivity can be obtained as.

$$TFP_i \equiv \mathrm{A}_i = \frac{Fp_{vi} p_{DR}{}^{\partial} p_{KL}{}^{1-\partial}}{\sum (1+\tau_i(\mathrm{II_i}))^{\partial}} \tag{10}$$

The marginal total factor productivity effect of industrial internet development can be obtained by taking the first order derivative of the above equation with respect to II :

$$\frac{\partial\left(\mathrm{TFP}\right)_i}{\partial\left(II\right)_i}=\frac{-\tau_i{}^{,}Fp_{vi}p_{DR}{}^{\partial}p_{KL}{}^{1-\partial}}{\sum(1+\tau_i(\mathrm{II}_{\mathrm{i}}))^{\partial+1}} \tag{11}$$

In the above equation, the values of F , P_{vi} and P_{DR} are all greater than 0. Meanwhile, according to the previous analysis of $\tau'_{\mathrm{i}}(II)<0$, therefore, $\partial\left(TFP\right)_i/\partial\left(II\right)_i>0$ .This indicates that the development of Industrial Internet can lead to positive marginal total factor productivity changes, that is, the development of Industrial Internet contributes to the improvement of TFP in the manufacturing industry.

The development of Industrial Internet helps to realize the optimal allocation of data factors, reduce the degree of allocation distortion, and thus improve the TFP of manufacturing industry. On the one hand, data factors themselves have the characteristics of high penetration and high synergy, relying on the Industrial Internet platform can realize more efficient factor matching, and strengthen the integration with traditional factors of labor and capital; on the other hand, the networked characteristics of the development of Industrial Internet provides an important carrier for the flow transfer and clustering application of data factors, which contributes to the efficient circulation and optimal allocation of data elements. On the other hand, the networked character of Industrial Internet development provides an important carrier for the flow transfer and agglomeration application of data elements, which contributes to the efficient circulation and optimal allocation of data factors. The first hypothesis of this paper can be put forward as follows:

Hypothesis: The development of Industrial Internet helps to increase the TFP in manufacturing industries.

3. Research Design

3.1. Evaluation Indicators of Industrial Internet Development

Table 1. Evaluation Index System of Industrial Internet Development

Primary indicators	Secondary indicators	unit (of measure)
	X1 Length of fiber-optic cable lines/area occupied by provinces and municipalities	Kilometers per 10,000 square kilometers
	X2 Internet broadband access ports/coverage by province and city	10,000 per 10,000 square kilometers
	X3 Internet penetration	%
	X4 Railroad mileage/area covered by provinces and cities	10,000 km/10,000 km2
	X5 Number of Internet broadband access subscribers/year-end resident population	Tens of thousands/tens of thousands
	X6 Total length of postal routes/area covered by provinces and municipalities	10,000 km/10,000 km2
	X7 Total telecommunications operations	billions
	X8 Revenue from software operations	billions
	X9 Employment in urban units of the information transmission, software and information technology services industry	all the people
	X10 Income from information technology services	ten thousand dollars
	X11 Embedded systems software revenue	ten thousand dollars
	X12 Revenue from software products	ten thousand dollars

Drawing on existing research (Lu and Cheng, 2022), this paper adopts 2 first-level indicators and 12 second-level indicators to measure the level of Industrial Internet development, and applies the entropy weight method to determine the weights. The first-level indicators comprise the development of the information industry and the infrastructure of the Industrial Internet platform. The specific indicator system is shown in Table 1. Limited to the availability and completeness of data, as well as the development of Industrial Internet, this paper excludes the relatively backward province of Tibet, and finally takes the panel data of 30 provinces and cities in China from 2012 to 2020 as the measurement sample of this paper. The original data on the development level of Industrial Internet comes from the national statistical yearbooks and provincial and municipal statistical yearbooks in the past years, and in order to reduce the possible impact of price fluctuations, the variables involving prices are converted to the price level of 2012 based on the corresponding price indexes.

3.2. Measure of Manufacturing TFP

Based on the stochastic frontier analysis (SFA) method, this paper establishes the transcendental production function as follows, and estimates the total factor productivity of interprovincial manufacturing industry through coefficient estimation and its significance test:

$$\ln y_{it} = \beta_0 + \beta_1 \ln K_{it} + \beta_2 \ln L_{it} + \beta_3 T + \frac{1}{2}\beta_4 \ln K_{it}^2 + \frac{1}{2}\beta_5 \ln L_{it}^2 + \frac{1}{2}\beta_6 T^2 + \beta_7 \ln K_{it} \times \ln L_{it} + \beta_8 \ln K_{it} \times T + \beta_9 \ln L_{it} \times T + (v_{it} - \mu_{it}) \quad (12)$$

Among them, the output indicator y_{it} adopts the gross industrial output value to measure, and uses the GDP deflator of the host province for deflating and constant price treatment. The input indicator of labor input L_{it} chooses industrial employees to measure, and the average annual balance of industrial net fixed assets is used to proxy for the capital stock indicator K_{it} and deflated by the price index of investment in fixed assets of the host province.

3.3. Model Specification and Variables Definition

In order to test the impact of Industrial Internet development level on manufacturing TFP, this paper constructs the following benchmark model for empirical analysis:

$$TFP_{it} = \beta_0 + \beta_1 II_{it} + \sum_j \beta_j Control_{it} + \lambda_i + \lambda_t + \varepsilon_{it} \quad (13)$$

Where i denotes province and city, t denotes year, TFP_{it} represents the overall total factor productivity level of manufacturing industry in the year t of province and city i, II_{it} denotes the index of Industrial Internet development, and the estimated coefficient β_1 measures the intensity of the impact of the level of Industrial Internet development on the TFP of manufacturing industry. If β_1 is significantly greater than 0, it indicates that industrial Internet development has a positive promotion effect on manufacturing TFP, and if β_1 is significantly less than 0, it indicates that Industrial Internet development inhibits the improvement of manufacturing TFP. $Control_{it}$ denotes a set of control variables, including: the level of economic development (GDP), the level of science and education investment (SCE), the level of foreign investment (FDI) and the level of fiscal revenue (FD). λ_i and λ_t represent individual effect and time effect respectively, while ε_{it} represents the random error.

The explanatory variable is the TFP level of manufacturing industry (TFP_{it}), which can be estimated by the SFA method, and the explanatory variable is the Industrial Internet development index (II_{it}), which is measured in the prior subsection.

In order to control the influence of other factors on the explanatory variables, this paper refers to previous research (Huang et al., 2019) and controls for the following variables: (1) the level of economic development, defined as GDP per capita, taking the natural logarithm; (2) the level of science and education investment, measured by the share of education and science and technology investment in GDP; (3) the level of foreign investment, measured by the share of foreign investment in GDP; and (4) the level of fiscal revenue level, measured using the share of fiscal revenue in the general budget to fiscal expenditure in the budget.

3.4. Sample Selection and Data Sources

This paper takes the panel data of 30 provinces and cities in China from 2012 to 2020 as the research sample, and Tibet is excluded due to too much missing data. The data are mainly from the national statistical yearbooks, provincial and municipal statistical yearbooks and economic census data bulletins of past years. Variables involving prices in the paper are converted to the price level in 2012, and missing data are filled in by the mean value method or growth rate method. In order to prevent outliers from affecting the results, the variables are indented by 1%.

4. Empirical Results

4.1. Baseline Results

Table 2. Baseline regression and robustness checks

Variable	(1)	(2)	(3)
	OLS	FE	difference GMM
II	0.027***	0.046***	0.035***
	(0.010)	(0.015)	(0.012)
L1.TFP			0.872***
			(0.09)
GDP	0.402***	0.371***	
	(0.118)	(0.115)	
SCE	0.215**	0.108**	
	(0.092)	(0.044)	
FDI	0.122**	0.103**	
	(0.058)	(0.046)	
FD	0.052*	0.057*	
	(0.030)	(0.030)	
Year	Yes	Yes	Yes
Province	Yes	Yes	Yes
AR(1)			0.012
AR(2)			0.231
Sargan Test			0.299
R^2	0.201	0.352	
N	270	270	270

Note: ***, **,* represent 1%, 5%, and 10% significance levels, respectively.

Prior to the estimation of model (4), this paper uses the results of the Hausman test as the basis for model selection, which suggests that the choice of the Fixed Effects Model (FE) is appropriate, and the results of the benchmark regressions are reported in Table 2. In particular, column (1) shows the OLS regression analysis for the full sample and column (2) shows the results of the fixed effects regression analysis. The results show that the coefficient of the impact of the core explanatory variable Industrial Internet development on manufacturing TFP is positive and passes the test at the 1% significance level. Therefore, the regression results support the hypothesis, indicating that Industrial Internet development can significantly increase the level of manufacturing total factor productivity. In terms of the degree of the impact, the regression coefficient of Industrial Internet is 0.046, indicating that for every 1% increase in the index of Industrial Internet development, manufacturing TFP will increase 0.046. All other control variables pass the significance test, indicating that the selection of control variables in the model is reasonable.

4.2. Robustness Checks

In order to test the impact of Industrial Internet development on manufacturing TFP, we need to consider the possible endogeneity between the variables. The impact effect of Industrial Internet tends to have a long lag period, i.e., the level of Industrial Internet development in the current period is unlikely to have a significant effect in the current period. In order to overcome the estimation bias caused by the endogeneity problem, this paper adopts the difference GMM to check the robustness of the model in order to improve the precision of the analysis results.

Considering the effect of lagged period of the explanatory variables on the current period, the lagged period of the explanatory variables is added as an explanatory variable here, and the dynamic panel data regression model is established as follows.

$$TFP_{it} = \beta_0 + \beta_1 TFP_{i,t-1} + \beta_2 II_{it} + \sum_j \beta_j Control_{it} + \lambda_1 + \lambda_t + \varepsilon_{it} \tag{14}$$

Where $TFP_{i,t\text{-}1}$ denotes the total factor productivity of the manufacturing industry lagged one period, and other variables represent the same meaning as model (13). In this paper, the second-order lagged term of the explanatory variable II_{it} is selected as the instrumental variable of the difference equation. The p-value of Sargan's over-identification test is 0.299, indicating that the use of the tool variable is reasonable.

The results of difference GMM in column (3) of Table 2 show that the regression coefficient of Industrial Internet is 0.035 and significant at 1% level, indicating that the development of Industrial Internet has a significant positive impact on manufacturing TFP, indicating that the estimation results are basically robust.

4.3. Analysis of Regional Heterogeneity

There are obvious differences in the development of Industrial Internet in different regions of China. In order to explore whether there are also differences in the impact of the development of Industrial Internet on manufacturing TFP in different regions, this subsection analyzes the regional heterogeneity of the role of Industrial Internet by using the fixed-effects model. The regression results show that, as shown in Table 3, columns (1)-columns (3), the role of Industrial Internet development on manufacturing TFP has obvious regional differences, and Industrial Internet development has a significant role in enhancing the manufacturing TFP in the eastern, middle, and western regions, and this enhancement effect presents a trend of decreasing in the west, middle, and eastern regions in that order. Although the level of Industrial Internet development in China's middle and western regions is weak, its effect on the role of TFP enhancement in manufacturing is nevertheless significant. Therefore, the middle and western regions should seize the opportunity to vigorously develop the Industrial Internet platform, promote the digital transformation of the manufacturing industries, so to promote economic development.

Table 3. Additional analysis of regional heterogeneity

	(1)	(2)	(3)
	Eastern Region	Middle Region	Western Region
II	0.036***	0.043**	0.057***
	(0.012)	(0.020)	(0.019)
Controls	Yes	Yes	Yes
Year	Yes	Yes	Yes
Province	Yes	Yes	Yes
R2	0.450	0.476	0.321
N	108	81	81

Note: ***, **,* represent 1%, 5%, and 10% significance levels, respectively.

5. Conclusion and Implications

Taking the panel data of 30 provinces and cities in China from 2012 to 2020 as a sample, this paper empirically examines the impact of Industrial Internet development on manufacturing TFP by using fixed-effects model on the basis of constructing an indicator system to measure the level of Industrial Internet development, and further analyzes it based on regional heterogeneity. The study found that: the level of Industrial Internet development in China shows an overall upward trend, and has a significant enhancement effect on the total factor productivity of the manufacturing industry, but there are obvious differences in the promotion effect in different regions.

The results presented in this paper have the following policy implications: first, strengthen the construction of information infrastructure, enhance the capacity of data resource allocation. Through the Industrial Internet platform to carry out science and industry docking, to help enterprises to solve the constraints of talent, technology and other constraints, to better boost the digital transformation of manufacturing enterprises. Second, the data sources in the industrial production network are diversified, and due to the lack of unified data standards, a large number of data silos have been formed, and the lack of clarity in the data transaction process has also made it difficult to realize the value of the data. Third, it is to promote the construction of Industrial Internet in backward areas and narrow regional development differences. Due to the differences in resource endowment and geographic location, China's regional economic development shows an unbalanced situation. Industrial Internet, as an innovation of the deep integration of digital economy and manufacturing industry, utilizes data analytics and other technologies to fully release production potential, thus better improving production efficiency and creating new opportunities for promotion the digital transformation of the manufacturing industries. Therefore, the midwest regions should accelerate the development of the Industrial Internet, give full play to the advantages of latecomers, and narrow the gap with developed regions.

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