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Original Paper

Research on the Influence of Industrial Intelligence on the Activity of Innovation and Entrepreneurship

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Abstract

Drawing on China's panel data across 30 provinces between 2011 and 2021, this paper explains the impact of industrial intelligence on the activity of innovation and entrepreneurship from two aspects: baseline regression estimation results and nonlinear effects. In this paper, the installation density of industrial robots is used to measure industrial intelligence, and the threshold regression model and panel fixed effect model are used to study the complex relationship between industrial intelligence and innovation and entrepreneurship at the national, eastern, central, and western levels. It is found that the development of industrial intelligence plays a significant positive role in the improvement of innovation and entrepreneurship activity and presents the characteristics of "Midwest > East"; industrial intelligence has a significant threshold effect on the activity of innovation and entrepreneurship. When the region has a strong talent agglomeration, industrial intelligence has a greater effect on the promotion of innovation and entrepreneurship activity.

Keywords

industrial intelligence, innovation and entrepreneurship activity, talent agglomeration, threshold effect

1. Introduction

In recent years, scientific and technological innovation represented by industrial intelligence (hereinafter referred to as Indt) has become a new focus of international competition, and developed countries such as the United States, Germany, and Japan have put forward strategies such as "Industry 4.0" and "industrial value chain". The Chinese government has seized the opportunities of The Times, placed a high value on the creation of Indt, and has released many policies such as "China Manufacturing 2025" and "14th Five-Year Plan" intelligent manufacturing Development Plan,

emphasizing the important role of Indt in manufacturing power. After years of growth, China is now home to the world's largest robot market. According to figures from the International Federation of Robotics (IFR), China sold 290,258 industrial robots in 2022, accounting for a 52.5% share of the global market.

Innovation and entrepreneurship play a key role in promoting new growth drivers and promoting high-quality economic development. In addition, the improvement of the activity of innovation and entrepreneurship (hereinafter referred to as Aie) is crucial for stabilizing and ensuring employment and promoting common prosperity (Wang et al., 2023). The swift development of Indt may have an impact on the Aie. With the development of Indt, more and an increasing number of businesses have begun to focus on research and development and application. At the same time, relying on artificial intelligence technology, Indt has certain self-learning attributes, which can be deeply integrated with the traditional manufacturing industry, promote the transformation of traditional production methods to intelligence, and generate new market demand (Cheng et al., 2024), such as robot maintenance and operation training, providing entrepreneurs with new business opportunities and stimulating innovation vitality. Based on this, Indt can promote the Aie, and further, how does Indt affect the Aie? At the same time, Taking into account the characteristics of regional heterogeneity in China, the paper analyzes the characteristics and rules of Indt on the Aie.

At present, the research on Indt and the Aie is increasing. In terms of Indt, existing literature mainly focuses on three aspects: First, the impact of Indt on labor employment, which discusses the promotion of high-quality employment by Indt, the total number of jobs affecting the labor market, employment structure (Wang et al., 2022) and labor skill structure (Zhao & Gao, 2024). The second is the impact of Indt on the ecological environment. Relevant studies believe that Indt can drastically lower the intensity of carbon emissions (Huang et al., 2021) and promote the improvement of regional green ecological efficiency (Deng & Xiao, 2023). The third is the impact of Indt on the economy. Indt can promote high-quality economic development (Chen et al., 2020), the upgrading of industrial structures (Tang et al., 2022), and expand the urban-rural income gap (Chen & Sun, 2022). In terms of innovation and entrepreneurship activity, existing studies mainly focus on measurement methods and influencing factors, among which the influencing factors are mainly policy support (Bai et al., 2022), digital economy (Wang et al., 2023), new infrastructure (Wang et al., 2024) and so on. However, there are few studies on the effect of Indt on the Aie. Given this, this paper selects panel data from 2011 to 2021 to study the relationship between the two.

The contribution of innovation in this paper may be as follows: First, the entropy weight method is used to measure the Aie, to enrich the research in related fields; Second, the nonlinear effect of Indt on the Aie is analyzed. Third, based on the heterogeneity of China's provincial heterogeneity, this paper examines the heterogeneity of Indt on regional Aie and puts forward relevant policy suggestions to lay a solid theoretical foundation for promoting Indt and enhancing innovation and entrepreneurship activity.

2. Theoretical Analysis and Research Hypothesis

2.1 Direct Conduction Mechanism and Research Hypothesis

Innovation and entrepreneurship activity are crucial to enhancing the soft power of urban development and promoting the real economy to drive urban development (Liu et al., 2021). Indt directly affects the Aie by promoting industrial upgrading and releasing innovation and entrepreneurship resources.

On the one hand, Indt realizes the intelligence and efficiency of traditional production methods, improves the quality of products and production efficiency, which provides great space for innovation and entrepreneurial activities. The application of intelligent technology can fully cover the production process, and timely supervision can further improve production efficiency, effectively reduce the waste of resources, and further reduce the cost of innovation and entrepreneurship. In addition, to obtain benefits and improve productivity, enterprises will increase technological investment and drive technological progress, promote more innovation and entrepreneurship activities, and promote the improvement of Aie.

On the other hand, Indt has accelerated the release of labor in traditional and backward industries, and promoted the improvement of labor skills in related industries, which has activated innovation and entrepreneurial resources such as production factors and capital, and provided resources for the improvement of innovation and entrepreneurial activity. In addition, the widespread application of Indt has stimulated broader participation of market players, driving an increase in innovation and entrepreneurial activities. At the same time, by optimizing resource allocation and technology integration (Liu & Chen, 2021), Indt significantly improves the efficiency of resource allocation, deepens the integration of innovation and entrepreneurship, and thus significantly improves the overall Aie.

Hypothesis 1: Indt can directly promote the improvement of Aie.

2.2 Nonlinear Conduction Mechanism and Research Hypothesis

Talent is a key component that propels industrial innovation and is essential to the advancement of superior economic development. In light of China's uneven provincial development, the influence of Indt on the Aie may be different. Talents can bring scale effect, information sharing effect, knowledge spillover effect, and other agglomeration effects to bring vitality to innovation and entrepreneurship (Jiang et al., 2023). When the concentration level of talents is at an appropriate level, the concentration talents can not only optimize the local scientific and technological innovation environment, but also accelerate the commercialization process of knowledge, accelerate the transformation of technology, and promote the development of the industrial chain, which offers crucial support for the development of Aie. A moderate concentration of talents can also attract the further concentration of surrounding talents so that the influx of high-quality resources and production factors can effectively promote the integration and sharing of resources, improve research and development efficiency and resource utilization, boost the development of Indt, and then promote the improvement of Aie.

Hypothesis 2: Talent agglomeration has a threshold effect on the Aie promoted by Indt.

3. Model Building and Variable Measurement

3.1 Model Building

This paper studies the impact of Indt on innovation and entrepreneurship activity, and constructs the following benchmark regression model on the basis of theoretical analysis:

$$Aie_{it} = \alpha_0 + \alpha_1 Indt_{it} + \alpha_n X_{it} + \lambda_i + \varepsilon_{it} \quad (1)$$

Among them, i and t are the province and year respectively, and the Aie_{it} represents the activity of innovation and entrepreneurship, the $Indt_{it}$ represents industrial intelligence, and the X_{it} represents a series of control variables that may affect the Aie, including the level of economic development ($pgdp_{it}$), industrial structure (str_{it}), scientific research capacity (put_{it}), and urbanization level ($city_{it}$). In addition, in Eq. (1), α_0 represents the intercept term, λ_i represents the unobservable individual fixed effect, and ε_{it} is the random perturbation term.

Furthermore, this paper takes talent agglomeration (hereinafter referred to as Hum) as the threshold variable to test the threshold effect between Indt and Aie, and establishes a threshold model as follows:

$$Aie_{it} = \mu_i + \theta_1 Indt_{it} \cdot I(threshold_{it} \le \gamma) + \theta_2 Indt_{it} \cdot I(threshold_{it} > \gamma) + \theta_n X_{it} + \varepsilon_{it} \quad (2)$$

Among them, μ_i is the intercept term, θ_1 and θ_2 are the parameters to be evaluated, θ_n is the parameter vector to be evaluated, γ is the threshold value, I(•) is the indicator function, the corresponding condition is 1 when it is true, otherwise it is 0, and the other variables are the same as Eq. (1).

3.2 Variable Measures

3.2.1 Explanatory Variables

Innovation and Entrepreneurship Activity. Drawing on the research of Li (2021) and Lv et al. (2022), this paper divides the innovation and entrepreneurship activity into innovation activity and entrepreneurship activity, and comprehensively considers the scientificity, dynamics, rationality, and constructs the regional innovation and entrepreneurship activity index in the following Table.

Table 1. Evaluation Index System of Innovation and Entrepreneurship Activity

Primary index	Secondary index	Three-level index	Calculation mode
Innovation and entrepreneurship activity	Innovation activity	Capital input	Intensity of R&D expenditure
			The share of government funds in total internal R&D expenditure
		Talent input	R&D full-time equivalent per capita in enterprises above designated size
			The proportion of R&D

			personnel in the total labor force
		Technology trading	Share of total technology market transactions in GDP Technology market The proportion of technology inflow into regional contracts in GDP
		Patent output	10,000 patent applications The number of patents applied by enterprises with R&D activities and above designated size
	Entrepreneurial activity	Enterprise entrepreneurship	Number of new businesses per 10,000 people Number of new private businesses created per 10,000 people
		Individual entrepreneurship	The proportion of self-employed workers in the total population（%） The proportion of self-employed workers in the total labor force（%）

3.2.2 Explanatory Variables

Industrial intelligence. In this paper, we draw on the calculation method of Yan et al. (2020) to characterize the installation density of industrial robots, and the specific calculation formula is as follows:

$$Indt_{it} = \sum_{j=1}^{n} \frac{lab_{ijt}}{lab_{it}} \times \frac{rob_{jt}}{lab_{jt}} \quad (3)$$

Among them, lab_{ijt} represents the number of employees in industry j in region i in year t, rob_{jt} represents the number of robot installations in industry j in year t, lab_{it} represents the number of employees in year t in region i, and lab_{jt} represents the number of employees in industry j in year t.

3.2.3 Threshold Variables

Talent agglomeration. Referring to the research of scholar Xie (2022), this paper gauges the degree of

talent agglomeration using the location entropy index, and the calculation formula is: $Hum_{it} = \frac{K_{it}/T_{it}}{\sum_i K_{it}/\sum_i T_{it}}$, where K_{it} represents the number of science and technology practitioners in year t in province i, and T_{it} represents the total population of province i in year t.

3.2.4 Control Variables

Referring to the existing literature (Zhao et al., 2023; Sun, 2024), the control variables chosen for this paper are as follows: (1) The level of economic development (pgdp) is represented by GDP per capita. (2) The industrial structure (str) is characterized by the ratio of the tertiary industry to the secondary industry. (3) Scientific research capacity (put) is characterized by the logarithm of scientific and technological expenditure. (4) The level of urbanization (city) is measured by the proportion of urban population in the total population.

3.3 Sources of Variables

This paper uses panel data from thirty Chinese provinces as its research sample, the time span is 2011-2021, and the original data are mainly from the China Statistical Yearbook, the China Labor Statistics Yearbook, and the International Federation of Robotics (IFR), and some of the missing data are supplemented by linear interpolation. The descriptive statistical results of each variable are shown in Table 2.

Table 2. Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Aie	330	8.468	1.521	4.712	12.190
Indt	330	0.149	0.116	0.039	0.683
pgdp	330	10.831	0.451	9.682	12.142
str	330	1.246	0.705	0.518	5.297
put	330	4.348	1.059	1.324	7.064
city	330	0.596	0.121	0.350	0.896

4. Theoretical Analysis and Research Hypothesis

4.1 Baseline Regression Results

Based on the results of Hausman's test, a fixed-effect model was used for benchmark regression analysis. Table 2 shows the benchmark regression results of Indt on Aie, in which model (1) is the national full-sample estimation result, model (2) is the estimation of the eastern region, and model (3) is the sample estimation result of the central and western regions. As shown in model (1), the influence coefficient of Indt on Aie is 2.066, which is significant at the level of 1%, indicating that the development of Indt is extremely beneficial to the improvement of Aie in general, and this conclusion is consistent with hypothesis 1 of this paper, that is, Indt can directly promote the improvement of

innovation and entrepreneurship activity. The growth of Indt fosters the energy of innovation and entrepreneurship and offers an atmosphere that supports them.

In terms of control variables, the improvement of economic development level has a positive effect on the Aie, and its impact coefficient is 1.310, which may be since the improvement of economic development level can provide economic support for innovation and entrepreneurship, thereby improving the Aie; Every unit of industrial structure will promote the increase of innovation and entrepreneurship activity by 0.550 units, indicating that the transformation of industrial structure is conducive to the improvement of Aie; The impact coefficient of urbanization level on Aie is 7.064, indicating a significant positive relationship at the 1% level. This suggests that improved innovation and entrepreneurship activities are more likely to occur in areas with higher levels of urbanization and more developed infrastructure.

Table 3. Benchmark Regression Results of the Influence of Indt on Aie

Variable	(1)	(2)	(3)
	Full sample	Eastern Region	Midwest Region
Indt	2.066***	1.354***	2.095**
	(0.594)	(0.495)	(0.917)
pgdp	1.310***	2.745***	0.191
	(0.362)	(0.329)	(0.275)
str	0.550***	0.167	0.552***
	(0.153)	(0.114)	(0.096)
put	0.066	-0.109	0.132*
	(0.136)	(0.115)	(0.071)
city	7.064***	4.405***	12.381***
	(1.763)	(1.313)	(1.597)
Constant	-11.213***	-24.607***	-1.943
	(3.044)	(2.844)	(2.175)
N	330	121	209
R^2	0.941	0.937	0.955

4.2 Baseline Regression Results

Before performing threshold regression, this paper tests the existence of the threshold effect of the model. Talent agglomeration was selected as the threshold variable, and the threshold value was tested for the critical value, as shown in Table 4, after repeated sampling by Bootstrap, the results showed that the talent agglomeration passed the significance test of the single threshold effect, but did not pass the double threshold test, which verified the hypothesis 2 proposed in this paper: there is a threshold effect

of talent agglomeration on the activity of Indt to Aie. To observe the estimation and confidence interval of the threshold value more clearly, the threshold value is identified by using the least squares likelihood ratio statistic LR, which is the value taken when the LR is zero, and then the likelihood ratio function plot of the threshold value is plotted, as shown in Figure 1.

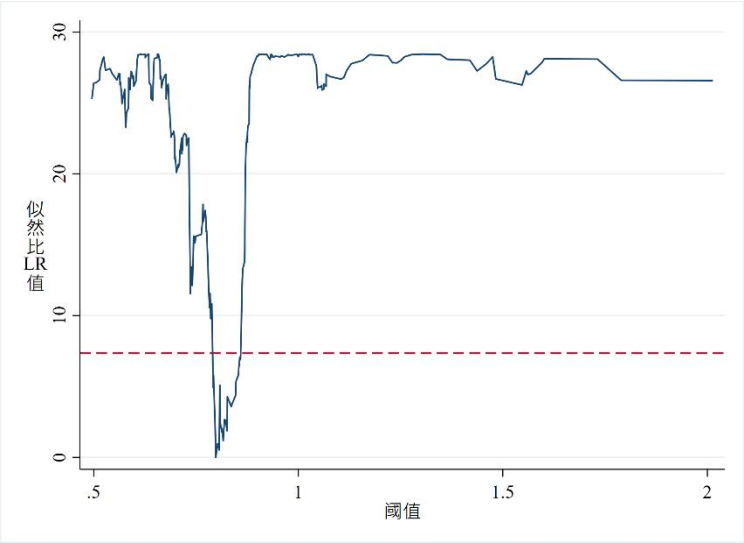

Figure 1. Likelihood Ratio Function of Talent Concentration (Hum)

Table 5 shows the threshold regression results of Indt affecting Aie. From the test results, It is evident that in cases where the level of talent aggregation falls below the 0.7984 threshold, the influence coefficient of Indt on innovation and entrepreneurship activity is positive but not significant, and when the degree of talent concentration is higher than the threshold value of 0.7984, the influence coefficient of Indt on innovation and entrepreneurship activity is 2.176 and is significant under the condition of 1%. The possible reasons are: on the one hand, Indt needs to have a certain maturity and stability in the application and promotion to play a role. When the degree of talent concentration is low, it is difficult to meet the technical needs in the process of industrial intelligence development, and the development of Indt is imperfect, and its impact on innovation and entrepreneurship activity is very little to be ineffective. On the other hand, based on the needs of innovation and entrepreneurship development, Indt must meet the needs of high standards, and only when the talent gathering reaches a higher threshold can the effective drive of innovation and entrepreneurship activity be realized.

Table 4. Test Results of Threshold Variables

Threshold	F	P	Thresholds	BS times	Threshold		
					10%	5%	1%
Single Threshold	28.99	0.085	0.7984	1000	27.075	32.838	45.544

Double Threshold	9.79	0.562	1000	23.108	28.554	41.937

Table 5. Regression Results of Threshold of Influence of Indt on Aie

Explained variable	(1) *Aie*
Indt (Hum≤γ)	0.526
	(0.845)
Indt(Hum>γ)	2.176***
	(0.495)
pgdp	1.240***
	(0.370)
str	0541***
	(0.159)
put	0.060
	(0.135)
city	8.138***
	(1.697)
N	330
R^2	0.946

4.3 Robustness Test

This research employs three techniques to verify the aforementioned conclusions' robustness to confirm the findings once more: lagged explanatory variables, adding control variables, and removing "singular values". First, considering that there may be a lag effect in promoting the Aie in Indt, this paper draws on Ding et al. (2023) and Table 6 model (1) displays the Indt lagging phase findings, which pass the robustness test and are essentially consistent with the results of the benchmark regression; Secondly, considering that the improvement of the level of informatization may have an impact on the Aie, this paper adds informatization as a control variable, and the robustness of the findings in this research is demonstrated by the model in Table 6 (2), which demonstrates that the influencing factor will not alter the direction or significance of the benchmark regression results; Thirdly, the level of technological advancement in the municipalities directly under the central government, policy support is frequently superior to that of provincial-level regions, so the data of municipalities directly under the central government are excluded and the results are regressed, as shown in Table 6 model (3), and the benchmark regression findings do not significantly differ from one another, demonstrating the robustness of the benchmark regression results (Cheng et al., 2024).

Table 6. Robustness Test Results

Variables	(1)	(2)	(3)
	Aie	Add control variables	Culling data
L.Indt	1.877***		
	(0.409)		
Indt		1.579***	2.215***
		(0.332)	(0.362)
pgdp	1.323***	0.990***	0.866***
	(0.199)	(0.182)	(0.242)
str	0.510***	0.382***	0.488***
	(0.068)	(0.066)	(0.085)
put	0.029	0.171***	0.070
	(0.062)	(0.059)	(0.063)
city	7.639***	4.223***	9.660***
	(0.913)	(0.899)	(1.335)
xin		0.888***	
		(0.118)	
Constant	-11.415***	-9.047***	-7.491***
	(1.636)	(1.469)	(1.908)
N	300	330	286
R^2	0.938	0.951	0.944

5. Conclusions and Recommendations

In summary, this paper finds that Indt plays a significant positive role in innovation and entrepreneurship activity and presents the characteristics of "Midwest > East", which is still valid after a series of robustness tests of lagged explanatory variables, adding control variables and removing "singular values". In addition, there is a significant threshold effect on the impact of Indt on Aie. When the region has a strong concentration of talents, Indt has a greater effect on the promotion of innovation and entrepreneurship activity.

Drawing from the aforementioned conclusions, this article proposes the subsequent policy recommendations:

(1) Strengthen support for Indt and promote innovation and entrepreneurship. The previous research found that Indt has a significant role in promoting the Aie. As a big manufacturing country, China has great potential for the development of Indt, thus it is essential to actively seize the chance of a fresh industrial revolution, encourage the change of Indt, strengthen policy support, and create a good policy environment for the development of Indt.

(2) Accurately formulate development plans for each region. The previous research found that Indt has different effects on Aie in different regions, and it presents the characteristics of "Midwest > Eastern". The eastern region will give full play to innovation and leadership, improve its independent research and development capabilities, and promote intelligent upgrading to maintain and enhance its competitiveness; In the central and western regions, it will implement talent introduction and training plans and formulate industrial support policies to accelerate the process of Indt.

(3) Improve the level of talent agglomeration. The previous study found that the higher the level of talent agglomeration, the more significant the promotion effect of Indt on Aie. Thus, the government should enhance the system, increase the avenues through which talent is introduced, and implement measures to keep talent, such as tax incentives, housing subsidies, etc., to promote the full release of talent agglomeration dividends. At the same time, local enterprises should also actively cooperate with the government to promote regional advantages to attract talent, promote information flow and knowledge sharing, reduce the cost of innovation and entrepreneurship, and promote the increase of innovation and entrepreneurship activity.

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