Technological Progress, Higher Education Quality and China's Industrial Upgrading: An Empirical Study Based on the Spatial Dubin Model

Jiasheng Cheng(✉)

School of Public Administration, Sichuan University, Chengdu, China
cjs19990624@163.com

Abstract. This article concentrates on the efficiency of technological progress and higher education quality on China's industrial upgrading. On the ground of the 30 Chinese provinces' spatial panel data from 2011 to 2020, using the spatial Dubin model, this article empirically studies the effect of technological progress and higher education quality on China's industrial upgrading at the spatial level. The results show that: (1) technological progress and higher education quality can promote China's industrial upgrading, but the impact is different in different provinces; (2) The development of higher education not only promotes local industrial upgrading but also promotes neighboring provinces' industrial upgrading through spatial spillover effect; (3) On the spatial level, technological progress has different effects on China's industrial upgrading in different regions. Specifically, it plays a substantial direct function in promoting local provinces' industrial upgrading. In contrast, it has no significant negative spillover effect on upgrading the industry in neighboring provinces.

Keywords: Technology and Innovation · Data Analysis · Educational Technology · Industrial Economics

1 Introduction

Since China's reform and opening, the dividend of industrial upgrading and transformation on the ground of the redistribution of production factors among industries has gradually decreased with the loss of low-cost advantages, and the mode of economic development driven by the expansion of material resources and low labor costs has not met the needs of the development of the new era [1]. In order to comply with the requirements of the current new stage of economic development in China, it has become a widespread consensus to bring higher education and technological progress into full play represented by information technology and computer technology capabilities to promote further China's industrial upgrading and high-quality economic development. However, as Yu Binbin (2015) [2], Xu Xiaozhou (2017) [3] and other scholars have said there are noticeable regional differences in technological progress, higher education quality, and China's industrial upgrading. The impact of technological progress

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and higher education quality on Chinese industrial structure in different provinces at the spatial level based on geographical distance is meritorious of in-depth study. Given this, this article recapitulates the current research results and approaches, systematically expounds the theories relevant to technological progress, higher education quality, and China's industrial upgrading, and discusses the internal logic of the technological progress, higher education quality and China's industrial upgrading at the spatial level based on geographical distance with the help of the spatial Dubin model. Compared with previous analyses, this article focuses on progress from the following two philosophies: first, progress in research content. This study systematically deduces empirical evidence of the effect of technological progress and higher education quality on upgrading the Chinese industrial structure from a practical perspective using a spatial econometric model, enriching the research perspective of relevant fields; Second, the invention in research methods. The spatial Dubin model empirically tests the effect of technological progress and higher education quality on upgrading the Chinese industrial structure. Moran's I index analyzes China's spatial aggregation effect of industrial upgrading. By the way, the spatial Dubin model is further divided to examine whether there is a spatial spillover effect of higher education quality and technological progress on industrial upgrading. Providing decision support for the formulation and undertaking of relevant policies.

2 Theoretical Analysis and Hypothesis

2.1 Mechanism Analysis of Higher Education Quality on China's Industrial Upgrading

In conformity with the theory of human capital [4], the blossoming of higher education can improve the knowledge level and professional skills of the educated, cultivate high-level general-purpose and professional talents, and improve the quality of human social capital. And then act on China's industry from both labor supply and labor demand, promoting industrial upgrading. From the perspective of labor supply, the high-level labor force trained by higher education has accelerated the elimination of labor-intensive industries. Then making room for capital-intensive and technology-intensive industries, thus accelerating the speed and quality improvement of China's industrial upgrading. In terms of labor demand, higher education quality has brought about the high-end consumption demand of labor groups. The elimination of labor-intensive industries accelerates the speed and quality improvement of industrial structure optimization and upgrading.

To sum up, this article considers that the relationship between China's industrial upgrading with higher education quality is reflected in the optimistic direct effect within the province and the positive spillover effect outside the province. That is, higher education can promote China's industrial upgrading in this region. Due to labor mobility and other factors, higher education quality can also promote the upgrading of neighboring regions' industrial structures. Based on this, this section proposes the following assumptions:

Hypothesis 1: Higher education quality can further local regional industrial upgrading.
Hypothesis 2: Higher education quality can further neighbor regional industrial upgrading.

2.2 Mechanism Analysis of Technological Progress on China's Industrial Upgrading

Technological progress is the power source to promote industrial structure upgrading [5]. On the one hand, technological progress brings technological progress, which drives the overall technical level of the industry to improve. It then uses new technologies to transform traditional industries and promote upgrading the Chinese industrial structure. For example, the Internet of Things, artificial intelligence, industrial Internet, and other new-generation information technologies transform traditional industries into digital, networked, and intelligent directions. On the other hand, technological progress enhances the production efficiency of enterprises and promotes the optimization and upgrading of industrial structures from labor-intensive to technology-intensive industries. According to the empirical research of scholars from the spatial level, the new technological innovation brought by technological progress not only influences contributing to China's industrial upgrading in the region but also can transmit new technologies to adjacent regions, which facilitates on spillover effect on the industrial upgrading of adjacent regions. As a result of this, this study further proposes the following assumptions:

Hypothesis 3: Technological progress can promote local regional industrial upgrading.
Hypothesis 4: Technological progress can promote neighboring regional industrial upgrading.

3 Research Design

3.1 Selection Criteria of Spatial Panel Model

It is crucial to determine the spatial correlation between variables when utilizing the spatial Dubin model for econometric analysis. The spatial effect should be additionally confirmed if there is a spatial correlation. Here, global Moran's *I* is in the habit of confirming the spatial correlation of variables. It can be expressed by:

$$\text{Moran's I} = \sum\nolimits_{j=1}^{n} \frac{\sum_{i=1}^{n} W_{ij}\left(X_i - \overline{X}\right)\left(X_j - \overline{X}\right)}{\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2 \sum_{j=1}^{n}\sum_{i=1}^{n} W_{ij}} \tag{1}$$

Where I represents the globe Moran index, X represents the arithmetic mean, n describes regions' number, and W_{ij} represents the spatial weight matrix. The value range of Moran's *I* is [-1, 1]. The smaller the spatial correlation of variables, the closer Moran's *I* is to 0, and vice versa; If Moran's *I* is positive, the variable has a positive correlation. Otherwise, it is a negative correlation. If $I = 0$, space does not matter. Secondly, this study also distinguish between fixed and random effects by using the Hausman test. Finally, this study uses the LM-err and LM-lag Test to determine whether a spatial model is needed and what spatial model is used.

3.2 Spatial Dubin Model (SDM)

If the spatial autocorrelation test consequences are noteworthy, the spatial panel model can be additionally assembled. For this study, the development of higher education as an essential guarantee of high-quality human capital and technological progress as a source of vitality for sustainable economic development promotes not only upgrading the region's industrial structure, but also its spatial spillover effect will have an influence on China's industrial upgrading in adjacent provinces. Therefore, here we use the SDM, which combines the godsends of the spatial lag model and the spatial error model. Its feature is to integrate the spatial error model into the spatial lag model, that is, to examine the effect of the neighborhood independent variables on the dependent variables. It can be utilized to analyze the spatial correlation among explained variables, explanatory variables, and accidental error. The SDM can be expressed as:

$$LnSu_{it} = \rho WD_{it} + \alpha In + \beta X_{it} + WX_t\theta + \mu_i + \gamma_t + \varepsilon_{it} \tag{2}$$

Where SU refers to the industrial structure upgrading; X is a matrix composed of explanatory variables and control variables, including the development level of higher education (DHE), technological progress (TI), urbanization (U), FDI, basic facilities development (BFD) and Industrial development (InD); W represents the spatial weight matrix, and In represents the unit matrix; The space utility is μ_i; The time utility is γ_t; The random disturbance term is ε_{it}.

And this paper uses the partial differential method proposed by LeSage et al. (2009) [6] to estimate the direct impact and spillover effect of technological progress, higher education quality and Chinese industrial upgrading. Rewrite the SDM (model (3)) into the following matrix expression:

$$Y = (I - \delta\omega)^{-1}\alpha + (I - \delta\omega)^{-1}\left(X^{'} + \omega X^{'}\theta\right) + (I - \delta\omega)^{-1}\varepsilon \tag{3}$$

Where Y represents the endogenous variable of the 1st to Nth regions. The partial differential matrix of the k-th variable in X' is as follows:

$$\left[\frac{dy}{dx_{1k}} \cdots \frac{dy}{dx_{Nk}}\right] = (I - \delta\omega)^{-1}\begin{bmatrix} \beta_k & \cdots \omega_{1N}\theta_k \\ \vdots & \ddots & \vdots \\ \omega_{N1}\theta_k & \cdots & \beta_k \end{bmatrix} \tag{4}$$

LeSage et al. (2009) defined the mean value of diagonal elements of the rightmost matrix of the above formula as a direct effect, and the mean value of the sum of off-diagonal elements in each row or column as an indirect effect, that is, spatial spillover effect.

3.3 Variable Selection

This article uses the advanced index of industrial structure proposed by Fu Linghui (2010) [7] to express the explained variable "China's industrial upgrading". See model (6) and model (7) for the specific measurement method. Proportion of teachers and students in higher education in each province is used to express the explanatory variable "higher education quality" [8]; meanwhile, the number of patent applications in each province is used to express the explanatory variable "technological progress". The control variables set in this article are the social development level (U) index; the level of opening (FDI); basic facilities development (BFD) and industrial development (InD).

$$W = \sum_{k=1}^{3} \sum_{j=1}^{3} \theta_j \tag{5}$$

$$\theta_j = \arccos\left(\frac{\sum_{i=1}^{3} \left(x_{i,j} \times x_{i,0}\right)}{\sum_{i=1}^{3} \left(x_{i,j}^2\right)^{1/2} \times \left(x_{i,0}^2\right)^{1/2}} \right) \tag{6}$$

4 Empirical Analysis

4.1 Spatial Metrological Inspection Criteria

This section first measures the global Moran's *I* of industrial upgrading (SU) according to model (1) to determine whether there is spatial correlation. As shown in Table 1.

On the ground of the results in Table 1, the global Moran's *I* test of industrial upgrading in 30 Chinese provinces (cities) during 2011–2020 depicts that the global Moran's *I* of China's industrial upgrading indicators in each province from 2011–2020 is between 0.40 and 0.45 ($P < 0.05$), meaning that there is an optimistic spatial autocorrelation in China's industrial upgrading at the provincial level from 2011 to 2020. Industrial upgrading has a spatial spillover effect. That is, provinces with significant industrial upgrading hold an optimistic role in forcing neighboring provinces. Therefore, it is suitable to adopt the spatial panel model in the following empirical research.

In order to additionally demonstrate the existence of random effects of spatial econometric models and select the types of spatial econometric models, the Hausman test and LM test are used for screening in this analysis. The screening consequences are exhibited in Table 2.

Table 1. Global Moran's *I* Test

Year	Moran's I	P-value
2011	0.444	0.011
2012	0.433	0.032
2013	0.422	0.032
2014	0.427	0.001
2015	0.438	0.042
2016	0.439	0.005
2017	0.439	0.023
2018	0.449	0.038
2019	0.430	0.029
2020	0.435	0.002

Table 2. Spatial econometric model test

Econometric Test	Result of Tests
HausmanTest	53.468***
LMLAG	55.024*
R-LMLAG	47.236*
LMERR	17.344**
R-LMERR	4.256**

Robust standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

4.2 Analysis of the Results of the Spatial Dubin Model

This study utilizes Stata17 to examine the model (2) layer by layer under the fixed effect of SDM. The order is no space effect, space fixed effect, time fixed effect, and double fixed effect. The outcomes are shown in Table 3.

Table 3 reflects the empirical results of the SDM under the fixed effect level by level, including the impact of independent variables and their spatial weights on upgrading the Chinese industrial structure. In this regard, there is the following interpretation: First, the blossoming of higher education has an optimistic correlation with upgrading the Chinese industrial structure; that is, higher education quality changes by 1%, and upgrading the Chinese industrial structure changes by 0.362% in the same direction.

Table 3. Spatial Dubin Model Analysis

Variable	*No fixed effects*	*Spatial fixed effects*	*Time fixed effects*	*Double fixed effects*
lnDHE	0.237***	0.251*	0.212**	0.362***
lnTI	0.167***	0.099*	0.103*	0.213**
lnU	0.063*	0.164***	0.109***	0.107***
lnBFD	0.157	0.221*	0.263*	0.271**
lnInD	0.149**	0.232**	0.143***	0.123***
lnFDI	0.068**	0.122*	0.201*	0.061*
*W*lnDHE*		0.208***	0.223***	0.215**
*W*lnTI*		-0.099	-0.212***	-0.047***
*W*lnU*		-0.106**	-0.211***	-0.001
*W*lnBFD*		0.132*	0.142*	0.272*
*W*lnInD*		0.062**	0.109**	0.310***
*W*lnFDI*		0.720*	0.034***	0.079***
R^2	0.473	0.686	0.785	0.894
Observations	300	300	300	300

Robust standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

From the perspective of the spatial weight coefficient W × lnDHE, higher education has a vital spatial effect; and higher education quality not only affects China's industrial upgrading within the province but also has spillover effects on the upgrading of neighboring provinces. Secondly, technological progress has a substantial optimistic correlation with China's industrial upgrading at 5%, meaning for every 1% of technological progress that is developed, Chinese industrial upgrading increases by 0.213%. From the perspective of the spatial weight coefficient W × lnTI, the elasticity coefficient of spatial effect is negative at the level of 1%; technological progress may harm upgrading the Chinese industrial structure within and adjacent provinces. However, the direct impact and spillover effect of technical progress and development of higher education on the province and neighboring provinces must further decompose the SDM under the fixed effect.

4.3 Decomposition Analysis of the Spatial Dubin Model

After analyzing the impact of the SDM under fixed effects, the SDM is decomposed to determine further the direct influence and spillover result of the corresponding variables of the independent variables. The results are indicated in Table 4.

The empirical analysis results in Table 4 are as follows: (1) The direct influence of higher education quality on China's industrial upgrading and the spillover effect are positively correlated at 10% and 1% levels, respectively. The elasticity index is 0.097 and 0.236, respectively, to verify the establishment of hypothesis 1 and hypothesis 2, and the spillover effect of higher education quality is greater than the direct impact, with greater significance. The technological progress' direct impact on industrial upgrading is positive at the level of 1%, and the elasticity index is 0.215. However, the spillover effect of technological progress on neighboring provinces shows no significant inhibition, thus verifying the establishment of hypothesis 3 while denying hypothesis 4. In this regard, this study further analyzes and makes the following explanations: technological progress eliminates labor-intensive industries through industrial technological progress, encourages the development of capital-intensive and technology-intensive industries, and promotes local industrial structure. However, due to institutional factors and economic considerations, the transmission of new technologies and patents has

Table 4. Decomposition analysis of spatial effects of SDM

Variable	*Direct Influence*	*Overflow Effect*	*Total effect*
lnDHE	0.097*	0.236***	0.333***
lnTI	0.215***	-0.028	0.187*
lnU	-0.853*	-0.096*	-0.949*
lnBFD	0.627**	0.427**	1.054**
lnInD	0.043***	0.236***	0.279***
lnFDI	0.197*	0.103*	0.300**

Robust standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

a specific time lag, and technological progress can ensure that local enterprises have long-term market advantages, thus hindering the development of the same industry in neighboring provinces. From this perspective, technological progress harms the neighboring provinces' industrial structure upgrading, which has specific logic support; this conclusion is consistent with the research results of He Yiqing et al. (2019) [9].

5 Conclusion

The main conclusion of this study is that higher education quality plays a meaningful function in promoting China' industry at the spatial level on the ground of geographical distance, which is reflected in the direct promotion of China's industrial upgrading within the provincial region and the positive spillover effect industrial upgrading outside the provincial region, Higher education quality plays a more significant role in promoting industrial upgrading outside the provincial area. Technological progress faces different regions at the spatial level based on geographical distance, the impact of industrial upgrading is different, which shows that it plays a meaningful direct role in promoting China' industrial upgrading within the provincial region. In contrast, it has an insignificant negative spillover effect on industrial structure upgrading outside the provincial region.

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