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Study on Spatial Spillover Effect of County-level TFP in Sichuan Province

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Abstract. Based on the county panel data of 181 districts and counties in Sichuan province from 2008 to 2018, the spatial spillover effect of county-level total factor productivity was studied by using Spatial Dubin Model, and the heterogeneity of Chengdu-Chongqing urban agglomeration and non-urban agglomeration was analyzed. Finally, the robustness test was carried out by using economic distance spatial weight matrix. The study has demonstrated that TFP at the county level in Sichuan province has spatial autocorrelation, and the level of economic development, the industrial structure, the industrial agglomeration, the human capital and the government intervention have different impacts and spatial spillover effects on TFP at the county level in Sichuan province, but there are differences within and outside the urban agglomeration.

Keywords: Total factor productivity; Spatial Dobbin Model; Spatial spillover effect

1. Introduction

Since the beginning of reform and opening up, the pattern of economic development has been constantly transformed and upgraded. The "demographic dividend" brought by cheap labor is disappearing [1], and the "structural acceleration" caused by the adjustment of industrial structure in China's economy with the development of urbanization is also turning into "structural deceleration" [2]. At present, the transformation and development process of "three-phase superposition" and "triple impact" is facing a bottleneck, and economic growth is no longer optimistic. However, the model of economic development driven by the improvement of scale efficiency, the improvement of resource allocation and knowledge innovation to promote total factor productivity gradually shows the advantages of intensive economy in the long run. In March 2015, total factor productivity (TFP) was included in the government work report for the first time. It has become the need of policy to "improve total factor productivity, strengthen quality and standards building, and accelerate the cultivation of new growth points and poles". In the report to the 19th National Congress of the Communist Party of China in October 2017, General Secretary Xi Jinping also put forward a new development concept of "putting quality first and giving priority to efficiency, promoting quality reform, efficiency reform and driving force reform in economic development, and improving total factor productivity".

As a large province of economy and resources in southwest China, Sichuan not only takes a leading position in the construction of "Fourth pole of economic growth" in southwest, but also plays an important role in the implementation of the western development strategy and the construction of common prosperity. In order to clarify the specific development of TFP in Sichuan province, this paper used 11-year panel data of 181 districts and counties in Sichuan province to analyze the influencing factors of TFP at county-level and its spatial spillover effect by using spatial panel model, and summarized research conclusions and put forward policy suggestions.

2. Literature review

With the deepening of quantitative research on factors of production based on Cobb-Douglas function, the research on TFP has become an upsurge. Solow (1956), the representative of endogenous economic growth theory, believed that except for the traditional capital and labor production factors, TFP also contributed to the economy through production function accounting [3]. Scholar Yu Binbin (2015) believed that cities in the industrialization stage increasingly relied

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on TFP. However, cities in the urbanization stage still partly depended on the improvement of industrial structure [4]. Rubina Verma (2012) calculated the economic growth of India and showed that the growth of TFP was the main driving force for the value-added of service industry [4]. Gao Yuning et al. (2021) believed that Urbanization in China is the result of industrialization and economic growth, but has a negative impact on provincial productivity [6].

The influencing factors of TFP are also the focus of academic circles. In terms of industrial agglomeration, Wang Lili (2012) believed that the relationship between China's manufacturing industrial agglomeration and total factor productivity had a threshold effect, and the improvement effect of industrial agglomeration on TFP became more and more significant as the level of openness increases [7]. Liu Jianguo et al. (2014) believed that TFP of each province was spatially dependent, and the higher the economic agglomeration level was, the total factor productivity would be improved [8]. In terms of industrial structure, Zhu Xuqiang et al. (2016) took Jiangsu, Guangdong and Fujian as research samples and believed that there was no significant relationship between industrial structure and the growth of total factor productivity [9]. However, Wang Yumei et al. (2021) empirically concluded that the positive effect of the industrial structure supererogation on the production rate of TFP in Anhui province is relatively more significant than that of the rationalization, and that the optimization of industrial structure had a positive spillover effect [10]. In terms of capital input, Shen Zhaozhang et al. (2020) took Guangdong province as the research object and showed that the impact of fiscal science and technology input on total factor productivity differed significantly in different regions [11]. Voutsinas and Tsamadias (2014) took Greece as the research object and found that economic productivity could be improved by increasing R&D expenditure [12].

The spatial related problems of regional economy cannot be ignored. Not only does it have an impact on regional elements, but because of the transportability of inter-city resource elements, resource exchange between regions will also be closely related to form an organic whole [13]. In addition to the transfer and exchange of goods and labor resources between regions through convection, total factor productivity, as one of the economic contributions, also has spatial spillover [8,14]. At the same time, the distance will have resistance to regional interaction, that is, the farther the distance between the two places, the smaller the impact of the interaction will be. Scholars Liu Yu et al. (2014) believed that such distance attenuation comes from the cost of spatial movement and the existence of mediation opportunities [15]. In addition, urban development of different sizes is often heterogeneous. "Center" technological progress faster, its in good position also much easier to master better resources, and can drive the peripheral city to form an integrated economic development, beyond the "spillover effect", but the central city of peripheral city also has a "siphon effect" [16], the research conclusion of Enrico (2011) showed that in larger cities, the number of laborers is greater, and a reasonable match between enterprises and labors is easier [17]. If the complementarity between cities is not strong and the spillover driving ability of central cities is insufficient, the development imbalance between cities will be aggravated and it is difficult to achieve the shared prosperity.

3. Characteristic analysis of Sichuan county-level TFP

3.1 Space model setting

In this paper, the Spatial Durbin Model is used to conduct an empirical analysis of spillover effect, and the Spatial Lag Model and Spatial Error Model are used to test the results. The general spatial econometric model is shown in Formula (1) :

$$\begin{cases} \mathrm{lnTFP_{it}} = \rho w_i' \ \mathrm{lnTFP_t} + \mathrm{lnX_{it}}' \beta + w_i' \ \mathrm{lnX_t}\, \delta + u_i + \gamma_t + \varepsilon_{it} \\ \varepsilon_{it} = \lambda m_i' \ \varepsilon_t + v_{it} \end{cases} \quad (1)$$

Where, lnTFPit is the explained variable, is the TFP of region i in year t, lnXit is the set of control variables. ρ is the spatial autocorrelation (spatial lag) coefficient, which indicates the

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influence of the explained variable of the neighboring region on the explained variable of the local region. β is the influence of the local explanatory variable on the explained variable, while δ indicates the influence of the adjacent explanatory variable on the explained variable of the local region, that is, the influence of the spatial lag of the explanatory variable. μi is the regional effect. γt is the time effect. εit is the random disturbance term. λ is the spatial error coefficient, which indicates that the error term is affected by the spatial lag, and wi represents the i-th row of the spatial weight matrix Wkj.

When λ=0, the explained variable will not be affected by the spatial lag of random disturbance term, and the model is Spatial Dobbin Model (SDM); when λ=0 且 δ=0, it is not affected by the explanatory variables of adjacent areas, which is Spatial Autoegressive Model (SAR or SLM); when ρ=0 且 δ=0, it is considered that the explained variable will be affected by the random disturbance term and its spatial lag, and the Spatial Error Model (SEM) is selected as the model. As for the setting of the corresponding spatial weight matrix Wkj, this paper constructed the geographical inverse distance spatial matrix and standardized it in line, as shown in equation (2), where dij is the geographical distance between region i and region j.

$$W_{kj\,(181x181)} = \begin{cases} 1/d_{ij}\,,\ i \neq j \\ 0,\ i = j \end{cases} \qquad (2)$$

3.2 Specification of variables

3.2.1 Explained variable

Total factor productivity (TFPit). Olley and Pakes (1996) used investment as a proxy variable of productivity to solve the endogenous problem of Solow Residual based on the two-step consistent estimation of an accounting framework for economic growth[18]. However, the assumption of this method is strict, and the calculated factor elasticity will be biased. Ackerberg et al. (2006) corrected this problem [19]. Based on the CD production function in logarithmic form and the method of scholar Xu Yonghong (2020), this paper used the ACF method to modify the OP two-step estimation method to obtain the logarithms of urban total factor productivity [19]. The specific logarithmic function form is as follows:

$$\begin{cases} y_{it} = \rho_0 + \alpha_{it}k_{it} + \beta_{it}l_{it} + a_{it} + \varepsilon_{it} \quad (a) \\ a_{it} = h\,(k_{it},\ l_{it},\ m_{it}) \quad (b) \end{cases} \qquad (3)$$

Where α and β represent the output elasticity of capital and labor respectively, and it is assumed that the decision of foreign investment mit in the region is influenced by capital kit, labor input lit and TFP αit, which has been transformed into the inverse function of investment decision (equation b). For the actual output yit of this calculation, the actual GDP of each city in past years is used; the capital investment uses the whole society's fixed asset investment Iit in the region over the years, according to the processing method of Shan Haojie (2008), the perpetual inventory method is adopted, i.e. kit = Iit / Pit + (1-δt)×kit-1, and the depreciation rate δt is assumed to be 10.96% [20]. In the formula, Pit is the deflator of fixed assets, calculated from the provincial fixed assets investment index; labor input selected the number of employments in each region over the years; for foreign investment, the amount of foreign investment actually used in each county was converted into RMB.

3.2.1 Explanatory variables

Based on previous studies, the level of economic development (gdp), the industrial structure supererogation(ind), the industrial structure rationalization (ser), the industrial synergy agglomeration (coagg), the human capital (edu), the transport infrastructure (road) and the government intervention (gov) were selected as explanatory variables. The level of economic development selected the actual GDP data of each county with 2008 as the base period; the industrial structure supererogation was measured by the ratio of the output value of tertiary industry to the output value of secondary industry in each region [21]. The industrial structure rationalization

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was measured by the reciprocal of Taylor index calculated by the output value of the three industries and the employee number of the three industries [4]. The industrial collaborative agglomeration used the location entropy of secondary and tertiary industries to obtain the agglomeration level, and refereed to the existing research to calculate the industrial collaborative agglomeration level [22]. The human capital was a proxy for educational conditions using the ratio of teachers and students in primary and secondary schools [23]. The transportation infrastructure was measured by the miles of road per square kilometer [24]. And the level of government intervention adopted the ratio of local general public budget expenditure to income.

3.3 Descriptive statistics and temporal and spatial analysis of TFP

3.3.1 Descriptive statistics

This paper used panel data of the balance of 181 county-level cities in Sichuan province from 2008 to 2018. These data were from Sichuan statistical yearbook, China Statistical Yearbook and CSMAR database from 2009 to 2019. For very few missing values, the average value of the previous year and the following year was used to fill in. And all data were processed by logarithms to eliminate the influence of dimension. The data processing and empirical results output of this paper were provided by stata16.0. Descriptive statistics were performed for the logarithms of all variables, as shown in Table 1. The data obtained show that the standard deviation of output is the largest, indicating that the economic volatility is high, while the volatility of total factor productivity is low, indicating the limitations of its change. All variables have certain differences in size, which can realize the research on the impact of changes in economic growth.

Table 1 Descriptive statistics of variables

VarName	Obs	Sd	Min	Mean	Max
ln TFP	1991	0.42	1.40	2.88	4.25
ln gdp	1991	1.33	9.98	13.42	16.16
ln ind	1991	0.71	-3.51	-0.34	2.09
ln ser	1991	1.08	-0.42	2.33	9.15
ln coagg	1991	0.13	0.32	0.94	1.22
ln gov	1991	0.94	-2.25	1.71	5.03
ln edu	1991	0.26	-3.49	-2.75	-1.62
ln road	1991	0.93	-3.46	-0.20	2.84

3.3.2 Descriptive statistics analysis of temporal and spatial characteristics of TFP

In order to further understand the development trend of TFP, this paper selected the data of 2008, 2013 and 2018, divided the logarithms of TFP into six levels, and visually displayed it on the map of Sichuan (Fig. 1). It can be seen that there isn't a clear trend for TFP data, but it can be seen that it decreases in the western region, while the value in the eastern region basically maintains a high level.

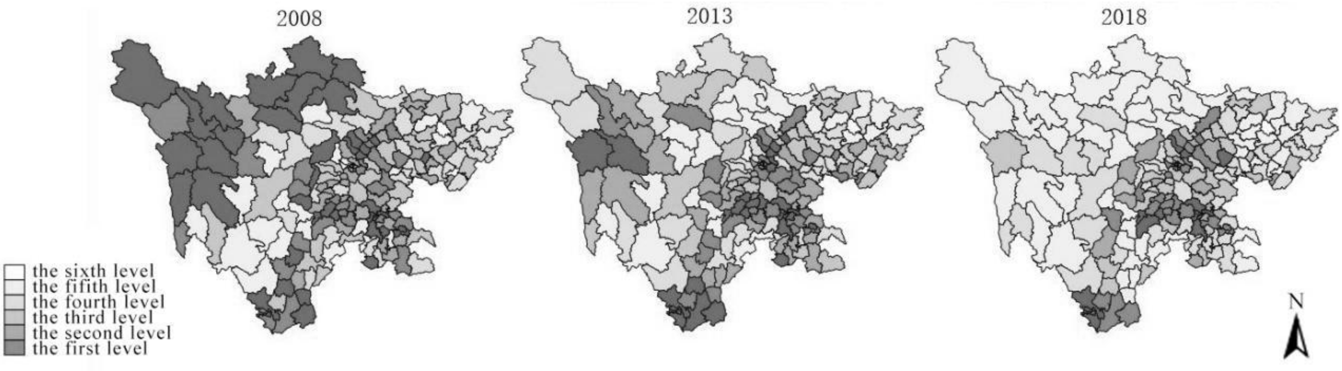

Fig. 1 Spatial distribution of lnTFP in Sichuan province

In order to clarify the change trend of TFP year by year, Sichuan province was divided into Chengdu plain economic zone, northeast Sichuan economic zone, south Sichuan economic zone,

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Panxi economic zone and northwest Sichuan ecological demonstration zone. The TFP data of counties in different regions were averaged, and shown in Fig. 2. It can be seen that TFP of southern Sichuan and Chengdu plain economic zone is maintained at a high level of more than 2.8, followed by northeast Sichuan and Panxi economic zone, and the level is similar. Northern Sichuan is at a high level in 2008, but decreases year by year in the later stage. The reason may be that, the factors of production resource in this paper involve foreign investment, which is not representative of input for the early period in northwest Sichuan. Due to the small input of this factor, the value of TFP in output is high; on the other hand, the increased factors of physical input in the later stage contribute more to the output, resulting in a small value of immature TFP.

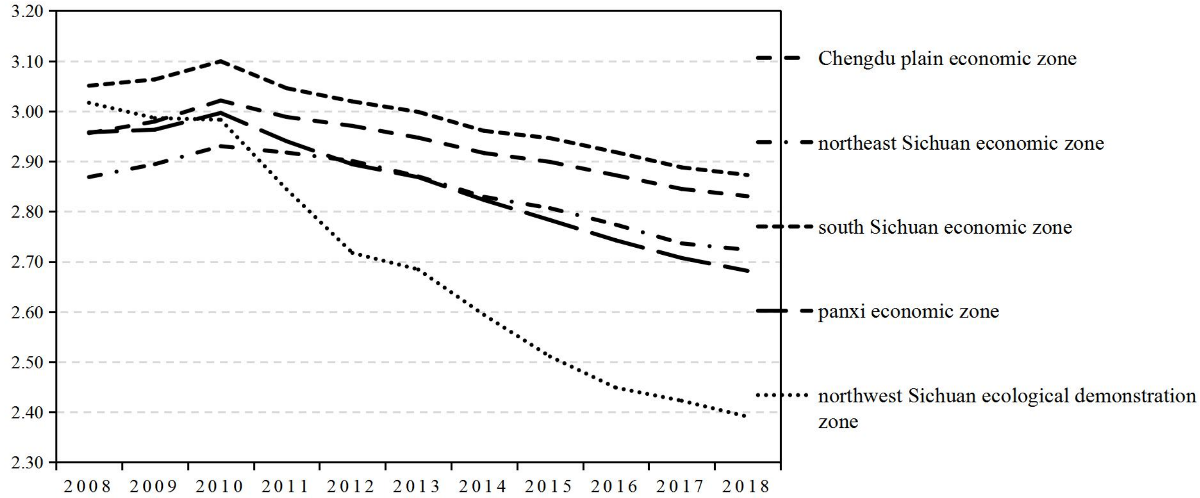

Fig. 2 Annual change trend of average TFP in five regions of Sichuan

4. Spatial spillover analysis of TFP in Sichuan county

4.1 Spatial autocorrelation test

Because spatial autocorrelation is more complex than time series correlation, it is necessary to be test. The global agglomeration of spatial series was investigated by Global Moran Index (Global Moran's I) year by year. The results show that the values are greater than 0 and pass the significance test, that is, they have significant positive spatial correlation. In order to ensure the reliability of the data, this paper used Geary Index (Geary's C) to test again, and the result is less than 1, which proves the reliability of the conclusion (Table 2).

Table 2 Global Moran's I and Geary's C of county lnTFP in Sichuan

year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Moran's I	0.062 *** (4.66)	0.061 *** (4.59)	0.071 *** (5.32)	0.098 *** (7.16)	0.116 *** (8.44)	0.125 *** (9.00)	0.129 *** (9.31)	0.144 *** (10.35)	0.156 *** (11.15)	0.138 *** (9.91)	0.151 *** (10.82)
Geary's C	0.901 *** (-4.62)	0.908 *** (-4.24)	0.902 *** (-4.48)	0.882 *** (-5.23)	0.865 *** (-5.86)	0.862 *** (-6.33)	0.855 *** (-6.88)	0.842 *** (-7.75)	0.829 *** (-8.41)	0.850 *** (-7.17)	0.835 *** (-8.06)

Note: *, ** and *** represent the significance levels of 10%, 5% and 1% respectively, and the Z-statistics are in parentheses

Local Moran's I can specifically describe the spatial agglomeration of TFP in a district or county. This paper selected the logarithmic data of TFP in each county in 2008 and 2018 for calculation, and drew the Moran index scatter plot to observe the agglomeration of each region. As shown in Fig. 3, scattered points are mainly distributed in the first and third quarters, representing the positive spatial correlation of TFP in most counties in Sichuan. Compared with 2008, the scattered

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distribution of lnTFP in 2018 is more inclined, so it has higher spatial correlation and more spatial dependence.

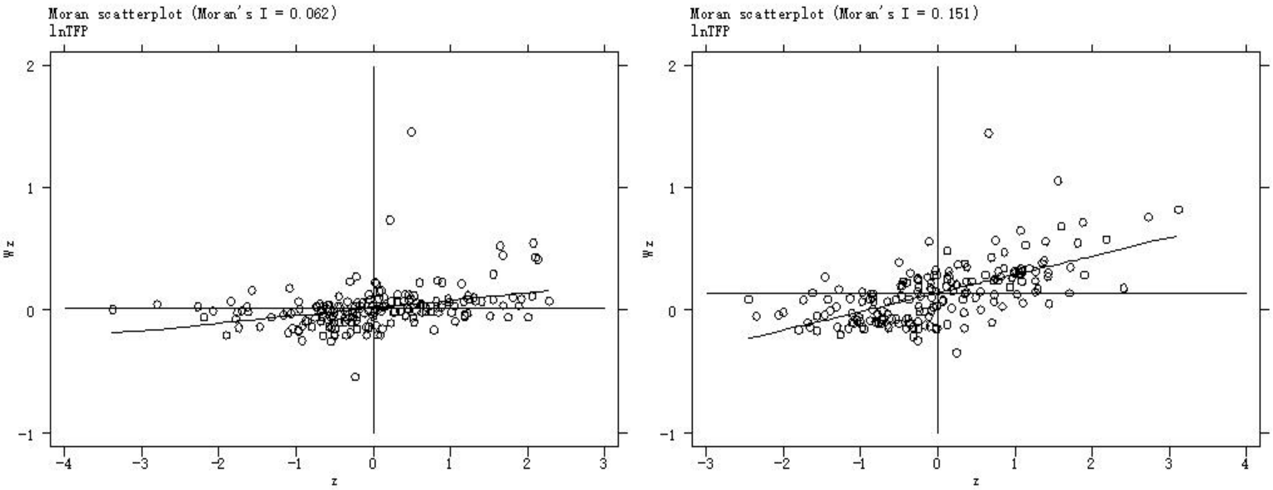

Fig. 3 Scatter diagram of Local Moran's I (left: 2008, right: 2018)

4.2 Spatial panel estimation results and analysis

4.2.1 Study on the spatial impact of county-level TFP in Sichuan province

This paper had undergone the LM test and its robustness test, and after further model estimation, the LR test and the Wald test were performed to test the imitative effect of the model. The results showed that it was more appropriate to use the SDM. And the fixed effect was selected by Hausman test for verification. The results of the three spatial panel models are shown in columns (1)-(3) of table 3. The spatial lag regression coefficient ρ of SAR and the spatial error regression coefficient λ of SEM are significant at the 1% significant level, indicating that the neighboring area plays a positive role in promoting TFP in the region, and the spatial dependence between districts and counties is obvious. In order to avoid the bias of the empirical results caused by the unbalanced economic development between the eastern and western parts of Sichuan province, this paper analyzed the counties of Sichuan province located within and outside the Chengdu-Chongqing urban agglomeration respectively, as shown in columns (4) and (5).

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Table 3 Regression results of spatial panel model

VarName	All counties			Urban agglomeration	Non-urban agglomeration
lnTFP	(1)SAR	(2)SEM	(3)SDM	(4)SDM	(5)SDM
lngdp	0.21*** (6.99)	1.12*** (5.64)	1.13*** (5.89)	0.39* (1.78)	1.44*** (5.56)
lnind	0.13*** (4.47)	0.24*** (5.85)	0.24*** (6.10)	0.06 (1.10)	0.38*** (5.27)
lnser	-0.06*** (-3.69)	-0.06*** (-3.13)	-0.06*** (-3.09)	-0.03* (-1.92)	-0.11*** (-4.27)
lncoagg	-0.50 (-2.59)***	-0.60 (-3.20)***	-0.58 (-3.32)***	-0.39 (-2.47)**	-0.25 (-0.85)
lngov	0.05** (2.39)	0.08*** (3.17)	0.07*** (3.33)	0.04 (1.61)	0.09** (2.27)
lnedu	-0.11** (-1.99)	-0.12* (-1.92)	-0.10** (-2.03)	-0.13* (-1.69)	-0.01 (-0.06)
lnroad	-0.05 (-1.57)	0.00 (0.14)	0.00 (0.13)	-0.02 (-0.57)	0.13** (2.55)
W*lngdp			-1.11*** (-5.69)	-0.41* (-1.76)	-1.34*** (-4.50)
W*lnind			-0.11 (-1.93)**	0.05 (0.75)	-0.29* (-1.76)
W*lnser			-0.14*** (-2.57)	-0.12** (-2.26)	-0.17 (-1.30)
ρ or λ	1.73*** (26.17)	0.98*** (118.45)	0.80*** (18.46)	0.65*** (9.01)	0.72*** (0.00)
$R^2_{(within)}$	0.3356	0.1180	0.4083	0.2416	0.5388
n	1991	1991	1991	1232	759

Note: Same as table 1. And the spatial lag term of SDM only selects the significant variables of the whole county.

Comparing the results of SDM, SAR and SEM, they are basically consistent, which shows that the SDM conclusion is robust. The results show that the variables gdp, ind and gov have a positive impact on the county's total factor productivity at the significant level of 1%. Economic development will pay attention to the improvement of efficiency, and will pay more attention to the development and investment of technical knowledge. It will also pay attention to the effective dissemination of knowledge, so as to improve TFP and develop into an intensive economy; the reason for the positive impact of the upgrading of industrial structure on TFP is that production factors flow to the tertiary industry with more knowledge intensive and capital intensive industries. Therefore, the resource allocation can be better developed in advanced departments and drive the exchange of key technical factors among industries; the government may actively respond to the call of the central government, provide policy assistance for industrial development and property rights protection, achieve effective intervention in technical support and advocacy, and alleviate the distortion of the matching of production factors in the market, and thus have a positive impact on total factor productivity.

The variables ser, coagg and edu have negative effects at the significant levels of 1% and 5%. It may be that the industrial structure in Sichuan province may be in an unreasonable state for a long time, during the adjustment and transformation period, the production factors of the three industries cannot be reasonably allocated in the short term, which has no positive impact on the improvement of TFP; in terms of the impact of industrial collaborative agglomeration level, previous studies have found that industrial collaborative agglomeration in the western region intensifies capital mismatch [22], therefore, it is not feasible to carry out knowledge innovation through capital investment to improve total factor productivity, and too high industrial agglomeration will lead to the replication or imitation of knowledge and technology among industries, resulting in the downturn of the overall

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innovation enthusiasm. Moreover, the development level of agglomeration economy in Sichuan province is not high, and some of them have "low-end locking", which weakens the scale effect of industrial agglomeration; for the human capital, the data selected in this paper are limited. After nine-year compulsory education has been popularized in various regions for many years, its role in TFP is difficult to improve, and the promotion of human capital by education itself is slow, so the impact may be limited.

Finally, the influence coefficient of variable road on TFP is small and insignificant. On the one hand, road traffic promotes inter-regional market exchange and trade to improve production efficiency, but it also represents a greater opportunity for the outflow of elements; on the other hand, the excessive construction of transportation infrastructure makes the marginal efficiency gradually declines, resulting in little impact on TFP. This also corresponds to the conclusion that the impact of transportation infrastructure in non urban agglomeration areas on TFP is positive and significant while the impact of urban agglomeration is negative but not significant.

From the results of urban agglomeration, the influence and significance of variables gdp, ind and gov are lower than those of non urban agglomeration. The reason for this may be that TFP in urban agglomerations is higher than that in non urban agglomerations, and the industrial structure is more mature, even if the economic development and the upgrading of industrial structure have a positive impact on TFP, the effect is relatively not obvious. Moreover, the government may have more assistance for the western region due to the Poverty Alleviation and Rural Revitalization Strategy, which has a greater impact on TFP of non-urban agglomerations. The negative impact of industrial structure rationalization on non urban agglomeration is more significant, which may be due to the low level of production factor mismatch in Chengdu-Chongqing urban agglomeration and less negative impact on TFP; the reason why the level of collaborative agglomeration has a greater negative impact on urban agglomeration is that the fierce competition in industry of urban agglomeration is easy to lead to the plagiarism of technological innovation, and the imperfect collaborative development mechanism may inhibit the development of total factor productivity; the teacher-student ratio of primary and secondary schools has more significantly negative impact in urban agglomerations than in non urban agglomerations, indicating that basic education is more difficult to play an effective role in better developed areas.

4.2.2 Spatial effect decomposition of county-level TFP in Sichuan province

According to the significant variable spatial interaction coefficient in SDM in Table 3, the economic development level and the industrial structure adjustment of the whole county have a negative effect on the TFP of its neighboring counties, but there are differences between urban agglomerations and non-urban agglomerations. Some scholars directly used this interaction term to analyze the spatial spillover effect [23], but others believed that the spatial spillover effect could be characterized by the decomposition of direct effect, indirect effect and total effect [25,26]. Therefore, this paper studied the spatial spillover effect of TFP based on these three effects.

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Table 4 Direct effects, indirect effects, and total effect decomposition of the SDM

Var	All counties			Urban agglomeration			Non-urban agglomeration		
lnTFP	(1)LR_Direct	(2)LR_Indirect	(3)LR_Total	(1)LR_Direct	(2)LR_Indirect	(3)LR_Total	(1)LR_Direct	(2)LR_Indirect	(3)LR_Total
ln gdp	1.13*** (5.78)	-1.01*** (-4.01)	0.12 (0.84)	0.40* (1.77)	-0.43 (-1.40)	-0.03 (-0.15)	1.43*** (5.48)	-1.04* (-1.74)	0.39 (0.75)
ln ind	0.24*** (6.43)	0.46 (1.43)	0.70** (2.17)	0.06 (1.23)	0.28* (1.82)	0.34** (2.46)	0.37*** (5.60)	0.01 (0.02)	0.39 (0.62)
ln ser	-0.06*** (-3.60)	-0.96** (-2.50)	-1.03*** (-2.66)	-0.03** (-2.26)	-0.41** (-2.54)	-0.44*** (-2.69)	-0.12*** (-4.84)	-0.96 (-1.48)	-1.09 (-1.64)
Lncoagg	-0.60*** (-3.39)	-2.32*** (-2.81)	-2.92*** (-3.08)	-0.42*** (-2.72)	-2.24 (-1.57)	-2.66* (-1.88)	-0.25 (-0.87)	0.25 (0.06)	-0.00 (-0.00)
ln gov	0.07*** (3.51)	0.29** (2.55)	0.36*** (2.83)	0.04* (1.78)	0.19 (1.06)	0.24 (1.29)	0.10*** (2.67)	0.47 (1.34)	0.56 (1.64)
ln edu	-0.11** (-2.02)	-0.43 (-1.60)	-0.53* (-1.70)	-0.11 (-1.63)	0.76 (1.33)	0.65 (1.18)	-0.03 (-0.31)	-1.52** (-2.39)	-1.55** (-2.37)
lnroad	0.00 (0.13)	0.00 (0.03)	0.01 (0.05)	-0.02 (-0.71)	-0.27 (-0.67)	-0.29 (-0.72)	0.13** (2.38)	-0.23 (-0.58)	-0.11 (-0.25)

Note: Same as table 1.

The decomposition of the long-term effects of SDM on all explanatory variables is shown in Table 4. Column (1) is a direct effect, indicating the impact of the explanatory variables in this region on the explained variables in this region, which also includes the impact of local explanatory variables on the explained variables in adjacent areas, so as to have an impact on the explained variables in this region, that is, the impact of feedback effect. From the results, it is basically consistent with the main regression of SDM. Column (3) is the sum of direct effect and indirect effect, that is, the total effect, which can measure the average impact of explanatory variables in all regions on the explained variables in this region. From these data, it can be seen that most indirect effects account for a higher proportion of the total effect than direct effects, which further confirms that the influencing factors of TFP have a spatial spillover effect that can not be ignored.

Column (2) is the indirect effect, also known as spatial spillover effect, which measures the impact of explanatory variables in adjacent areas on explanatory variables in this area. From the results of the whole county, the variables gdp, ser and coagg have significant negative spillovers, indicating that the development of adjacent areas inhibits the local TFP. For urban agglomeration areas, due to the high level of economic development, the siphon effect of adjacent areas is weaker than that of non urban agglomeration areas, and has less negative impact; as for the rationalization of industrial structure and the industrial synergy agglomeration, as high-level sector industries generally gather in urban agglomeration areas, there is stronger competitive pressure, the siphon effect is more obvious, and the adjacent areas of urban agglomeration have a greater negative impact on the development of local TFP; the industrial upgrading variable ind has a significant positive spatial spillover in urban agglomerations, indicating that in better developed areas, industrial adjustment and upgrading is more effective for improving the efficiency of adjacent areas; although gov variables have a significant spillover effect on TFP in counties across the province, they are not significant in urban agglomeration and non urban agglomeration samples. It may be that the public expenditure of district and county governments is internally digested, which is difficult to reflect the significance when the area is small and the data are few; variables edu has negative spatial spillovers in non urban agglomerations, which may be due to the improvement of basic education has instead made its human resources flow to the urban agglomeration areas, so that the adjacent areas have no effective effect on the local TFP.

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4.3 Robustness test

In order to test the reliability of the empirical results, the economic distance spatial weight matrix (equation 4) was used to test the results [27], which is multiplied by the geospatial distance matrix and the diagonal matrix of the annual average value of the actual GDP of each region. In the diagonal matrix data, $\overline{y_n}$ is the annual average of the actual GDP of the regions n, and $\bar{y}$ is the annual average of the actual GDP of all regions. Except the diagonal, other data are 0.

$$\begin{cases} W_{jj\ (181x181)} = W_{kj} * E_y \\ E_y = \begin{bmatrix} \frac{\overline{y_1}}{\bar{y}} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \frac{\overline{y_n}}{\bar{y}} \end{bmatrix} \end{cases} \tag{4}$$

The regression results are shown in Table 5, which are basically consistent with those based on geospatial weight matrix. The significant positive coefficient ρ also indicates that TFP has spatial autocorrelation. After the effect decomposition of SDM model, it is consistent except that the negative sign of the indirect effect of industrial structure upgrading and human capital is opposite, but the two items are not significant. Therefore, it can be determined that the relevant conclusions obtained in this paper are robust and reliable.

Table 5 Results of spatial panel models based on the spatial weight matrix of economic distances

Var	The SDM regression results		Effect decomposition		
lnTFP	Main	W*X	LR_Direct	LR_Indirect	LR_Total
ln gdp	1.17*** (6.38)	-1.26*** (-6.71)	1.16*** (6.23)	-1.37*** (-6.29)	-0.20 (-1.49)
ln ind	0.26*** (6.76)	-0.20*** (-3.70)	0.26*** (7.01)	-0.13 (-1.32)	0.13 (1.48)
ln ser	-0.06*** (-3.01)	-0.11** (-2.49)	-0.06*** (-3.14)	-0.30*** (-3.29)	-0.36*** (-3.72)
ln coagg	-0.54*** (-2.82)	-0.44 (-1.06)	-0.56*** (-2.96)	-1.66* (-1.87)	-2.22*** (-2.60)
ln gov	0.08*** (3.43)	0.01 (0.09)	0.08*** (3.65)	0.11 (0.93)	0.19 (1.62)
ln edu	-0.13** (-2.13)	0.26 (1.18)	-0.12** (-2.14)	0.39 (0.93)	0.26 (0.67)
ln road	0.01 (0.32)	0.03 (0.21)	0.011 (0.33)	0.078 (0.29)	0.089 (0.33)
ρ	0.541*** (8.99)				
$R^2_{(within)}$	0.4283				
n	1991				

Note: Same as table 1.

5. Main conclusions and policy recommendations

Based on the the CD production function in logarithmic form, this paper used the ACF correction method to calculate the TFP, took the geographical distance as the spatial weight matrix, and used the SDM to study and analyze the spatial spillover effect of TFP in 181 districts and counties of Sichuan province. The results show that the TFP of counties in Sichuan has spatial autocorrelation, and the influence variables have heterogeneous influence and spatial spillover effect between urban agglomeration areas and non urban agglomeration areas. Economic development, the upgrading of industrial structure and the government intervention can promote

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TFP, and the upgrading of industrial structure and the government intervention can also have a positive spatial spillover effect. According to the development status of Sichuan province and the empirical research results of this paper, the following policy suggestions are put forward:

Blindly deepening capital cannot replace the effect of TFP on labor productivity, and may even lead to accelerating the decline of capital return, resulting in the decline of capital return [28]. Sichuan urgently needs to change the driving mode of economic growth from the input of material factors to the intensive development of improving TFP, so as to avoid falling into the dilemma of development stagnation. In the face of today's new normal form of economic development, the high-quality growth mode of "from factor-driven and investment-driven to innovation-driven" can make long-term progress.

At present, China's industrial structure is precocious, and the proportion of manufacturing structure declines too fast, resulting in economic weakness [29]. The industrial structure supererogation must be based on the industrial structure rationalization. Sichuan province should avoid the hollowing of industry caused by excessive development of service economy in the process of promoting the advanced industry. More time should be reserved for the upgrading and development of technology-intensive industries and service industries. In the process of advanced development, we should pay attention to the rational development of the industry, otherwise it can only be "virtual height", which is detrimental to the development of TFP.

Within the industrial cluster, we also need to strengthen the incentive for innovation and the protection of intellectual property rights. While inducing enterprises to strengthen scientific and technological innovation, we should also avoid technology replication and imitation among industries, get rid of homogeneous competition by cracking down on knock-off products, and build a good enterprise cooperation and competition relationship within the industrial cluster. Supervision over industries with low technology content or causing serious damage to the environment should be strengthened, meanwhile, it is necessary to pave the way for the development of knowledge intensive industries and high-tech industries, and reduce the negative impact of "low-end locking".

Pay attention to the education of scientific and technological knowledge and the cultivation of high-quality talents, increase investment in scientific research and education, and retain high-tech and high-quality talents. At the same time, we should reasonably allocate the labor resources in the eastern and western regions, pay attention to the balanced development and construction of the central and western regions, and narrow their differences of development. The government's investment should be appropriately coordinated with the market, while making reasonable intervention, the government should also strengthen the sensitivity of resource allocation of factor market itself.

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