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Evaluating the barrier of typical production factor flow in the Chengdu-Chongqing Urban Agglomeration based on multi-source big data

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Promoting the free flow of production factors and improving the efficiency of resource allocation is a necessary requirement for China to achieve high-quality development. Therefore, it is significant to evaluate the barrier of production factors flow and analyze its influencing factors. This study, based on the flow space theory, takes the Chengdu-Chongqing urban agglomeration as an example, constructs the factor flow barrier index (FFBI) with multi-source big data (Baidu Migration data, investment data of listed companies and patent transfer data) and statistical data to evaluate the barriers of three typical product factors flow (labor flow, technology flow and capital flow). Moreover, quadratic assignment procedure regression model is used to analyze how system, economic, society, culture, policy and facility factors affect the barrier of the three typical production factors flow. The results demonstrate that: 1) The intensity of the three typical production factors flow of Chengdu-Chongqing are the highest, and the intensity of three typical production factors flow between the two cities and other cities are higher than that between other 14 cities. 2) In 120 city pairs, 87, 100 and 106 city pairs have positive FFBI of labor flow, capital flow and technology flow, respectively. The FFBI of Chongqing between other cities are mostly positive, indicating the three typical production factors flow are hindered to some extent. Labor flow is less hindered than capital flow and technology flow. 3) Administrative division relationships and administrative level differences have important impact on the barriers of the three typical production factors flow. City pairs belonging to different provincial administrative regions or within the same administrative level have larger FFBI. The barrier of labor and capital are positively affected by the transportation cost and the similarity of the industrial structure, respectively. The framework and findings are of great significance for revealing the formation mechanism of the barrier of production factors flow and provide some guidance for promoting the free flow of production factors and forming a new pattern of high-quality development in the Chengdu-Chongqing Urban Agglomeration.

KEYWORDS

production factor flow, flow space theory, improved gravity model, quadratic assignment procedure, chengdu-chongqing urban agglomeration

1 Introduction

Benefiting from economic globalization and China's reform and opening-up policy, China has experienced rapid economic growth in the past 4 decades. In 2021, China's GDP reaches US$17.7 trillion, accounting for over 18% of the global economy. However, the trend of anti-globalization has appeared since the 2008 financial crisis, influencing the way and efficiency of global resource allocation and changing the world economic pattern (Andreas et al., 2020; Duan and Jiang, 2021). To this end, the Chinese government proposes to build a new development pattern with the domestic cycle as the main body and the domestic and international dual cycles promoting each other ("dual circulation" development pattern), and takes high-quality development as the goal of economic development. It is foreseeable that China's economic development will put more emphasis on efficiency, coordination and comprehensiveness in the future. Improving resource allocation efficiency can directly improve total factor productivity, which is considered to be the most important driving force for high-quality development (Xu et al., 2022).

Production factors are the source and basis of social production, which generally consist of six important components: natural resources, capital, labor, technology, management and information (Feldstein and Horioka, 1979; Li and Miao, 2017; Wu et al., 2017). Generally speaking, the stronger the ability of the region to gather production factors, the greater the development potential. Production factors are scarce and profit-oriented, which will produce cross-regional flow under the guidance of the market (Guo and Zhang, 2017). When production factors cannot flow freely, economic cooperation between regions is reduced and more duplicative industries are built, thereby reducing overall economic efficiency (Wang and Yang, 2021). Promoting the free flow of production factors is an important way to improve resource allocation and realize the integrated development of the regional economy (Walz, 1997; Chu et al., 2018; Chen, 2020; Yang et al., 2022). Therefore, promoting the free flow of production factors is an important starting point to achieve high-quality development for China. According to the Outline of the 14th Five-Year Plan (2021–2025) for National Economic and Social Development and Vision 2035 of the People's Republic of China, promoting the smooth flow of resources is one of the key tasks to build the "dual circulation" development pattern. To deepen the reform of market-based allocation and promote the independent and orderly flow of production factors, the "Opinions on building a more perfect institutional mechanism for the market-oriented allocation of factors" was proposed by China government. However, due to institutional mechanisms and other reasons, there are still some obstacles that affect the flow of production factors, especially in the western regions where the level of social and economic development is relatively backward (Fan, 2022).

The Chengdu-Chongqing urban agglomeration is the region with the highest development level and greatest development potential in western China. It stretches across the two provincial administrative regions of Sichuan and Chongqing and has a population of more than 95 million. In 2021, the GDP of the Chengdu-Chongqing urban agglomeration has exceeded US$1 trillion, accounting for 30.8% of the western regions. However, compared with the eastern coastal regions, the Chengdu-Chongqing urban agglomeration is still characterized with low flow intensity of production factors and insufficient coordination of regional development (Shi and Pan, 2021). Taking the Chengdu-Chongqing urban agglomeration as the study area, this study evaluates and analyzes the barriers to the three typical and representative production factors, labor, capital and technology.

The contributions of this study are as follows. First, unlike most current studies focusing on the intensity of production factors flow, this study focuses on the barriers of production factors flow. Second, this paper constructs the factor flow barrier index (FFBI), which can quantitatively evaluate the factor flow barrier. Finally, the quadratic assignment procedure (QAP) regression model is used to analyze the causes of the barriers of labor, capital and technology flow. This article endeavors to provide a better understanding of the barrier of production factors flow, which is of great significance to the high-quality development of economy in China.

The remainder of this paper is organized as follows. The literature on production factors flow is reviewed in Section 2. The research methods, including the study area, data and analytical methods are explained in Section 3. Section 4 elaborates the analysis of the strength and barrier of typical production factors flow. Section 5 concludes the research findings and suggests avenues of future research.

2 Literature review

With the improvement of transportation and communication facilities and the deepening of social, economic and cultural exchanges, the flow of people, materials, information and other elements between regions is accelerated, which attracts the attention of researchers (Mitchelson and Wheeler, 1994; Karemera et al., 2000; Dash and Rae, 2016). (Castells 1996) proposed the concept of flow space and considered flows to be real relational data that can

reflect interactions between cities. The spatial agglomeration and diffusion of factors caused by the flow of various factors profoundly shape the regional spatial structure (Moll et al., 2017). Among these factors, the flow of production factors such as labor, capital, technology and information is positively correlated with resource allocation efficiency and is considered to be an important factor affecting economic growth and regional coordinated development, drawing widespread attention under the background of high-quality development (Yin et al., 2021; Zhou et al., 2022).

Since the spatial immobility of natural resource factors and the difficulty in quantifying flow intensity of management and information factors, existing studies mainly focus on the three production factors of labor, capital, and technology and explore the flow intensity of these production factors (Ben David, 2010; Zhou et al., 2019; Ding and Sui, 2021). At present, there are two kinds of methods to measure the flow intensity of production factors. The first method is to use gravity model, breaking point model and potential model to simulate the flow intensity of production factors based on the relevant statistics (Wang et al., 2017; Zheng et al., 2020). For example, Lottum and Marks (2011) applied gravity model to estimate the interprovincial migration in Indonesia. Niu et al. (2018) used improved breaking point model to estimate the flow intensity of people and applied to the urban hinterland range division. This method only considers the size of relevant statistical indicators and the geographic distance between cities when simulating the intensity of factors flow, often deviates with the data of the actual survey (Jung, et al., 2008), which can be considered as an effective measure under natural conditions. Another method is to use multi-source big data to measure the flow intensity of factors or substitute them with parameters (Wang et al., 2017). For example, (Li et al., 2022), measured the intensity of people flow in Northeast China based on Tencent location big data. (Jin et al., 2018). fetched transaction records from Jingdong Mall website to reflect the intensity of provincial capital flow. (He et al., 2022). used patent transfer data and venture capital data between cities to analyze the intensity of production factors flow in Beijing-Tianjin-Hebei region. With the development of information technology, this method has become the main method to measure the intensity of factors flow. Relatively speaking, evaluating the barrier of production factor flow is of greater significance in promoting the free flow of production factors. However, few studies addressing the evaluation methods for the barrier production factor flow.

Many studies have focused on the influence factors that affect the production factors flow (Young, 2000; Xie and Lin, 2016). Geographical distance, economic development, innovation environment and administrative level are considered to be the main factors affecting the intensity of production factors flow (Torre, 2008; Gao et al., 2021; Gui et al., 2021). QAP regression model, Geodetector and Tobit model are commonly used to identify influence factors affecting the intensity of production factors flow. For example, using Tobit regression model, (Wang et al., 2022), concluded that factors such as city administrative level and inter-city innovation cooperation have significant effects on patent transfer in Northeast China. In the existing research on the reasons for the formation of production factors flow obstacles, it is generally believed that the institutional differences between cities and local protectionism brought about by administrative division are the fundamental reasons for restricting the free flow of production factors (Zhang et al., 2018; Dong and Chi, 2020). However, the above conclusions lack the support of quantitative models, and few studies have paid attention to the influence of cultural differences, planning guidance and other factors on the barriers of production factors flow.

To sum up, although the existing research has carried out many fruitful explorations on production factors flow, there are still some shortcomings. First, the existing studies mostly focus on the measurement of the intensity of a single production factor flow, so it is difficult to reflect the intensity of production factors flow between cities as a whole. Second, it ignores the quantitative measurement of barriers to production factors flow, which is very important for evaluating the efficiency of resource allocation. Finally, few studies have used quantitative models to analyze the multifaceted factors that cause the barriers of production factors flow and their mechanisms. Therefore, for the three production factors of labor, capital, and technology, this paper attempts to establish a quantitative method to measure the barrier of production factor flow and use quantitative models to identify influence factors that affect the barriers of different production factors flow.

3 Data and methodology

3.1 Study area

The Chengdu-Chongqing urban agglomeration is seated in Sichuan Province and Chongqing City in Southwest China. Surrounded by mountains, it is a relatively independent economic zone (Figure 1). The Chengdu-Chongqing urban agglomeration covers an area of 185,000 square kilometers and consists of two central cities, Chengdu and Chongqing, and other 14 cities (Zigong, Luzhou, Deyang, Mianyang, Suining, Neijiang, Leshan, Nanchong, Meishan, Yibin, Guangan, Dazhou, Yaan, Ziyang), among which, Chongqing is one of the four municipalities directly under the Central Government in China, Chengdu is the capital of Sichuan Province, and other 14 cities are all prefecture-level cities under the jurisdiction of Sichuan Province. Since ancient times, this area has fertile land and abundant products, which gave birth to the Bashu culture with the Ba culture and Shu culture as the main body. In 2021, the per capita GDP has exceeded US$10,000, which is quite close to the average level in China.

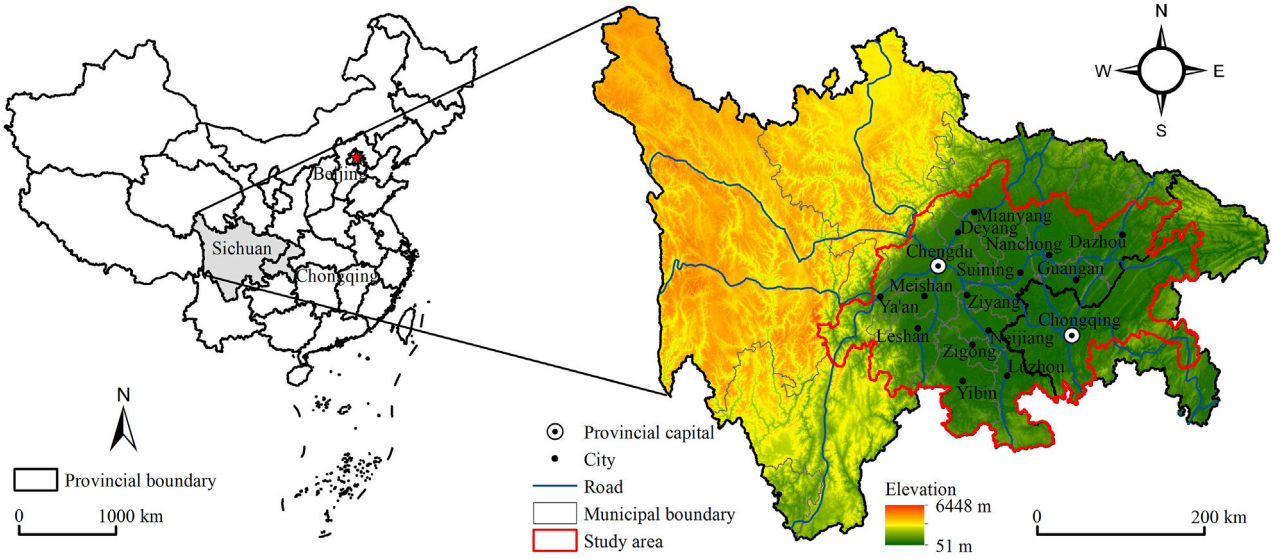

FIGURE 1
Study area.

In 2021, the Central Committee of the Communist Party of China and the State Council officially issued the "Outline of the Construction Plan for the Chengdu-Chongqing Economic Circle", focusing on promoting the Chengdu-Chongqing urban agglomeration to become a growth pole for China's high-quality development in the future. In recent years, cooperation between cities in the Chengdu-Chongqing urban agglomeration has become more intensive, and the intensity of production factors flow has tended to increase. In order to give full play to the leading role of Chengdu and Chongqing in the development of surrounding areas, the Sichuan Provincial People's Government and the Chongqing Municipal People's Government have issued the "Chengdu Metropolitan Circle Development Plan" and "Chongqing Metropolitan Circle Development Plan".

3.2 Data sources

Three types of big data, including Baidu Migration data, enterprise investment capital data and patent transfer data are used in this study. Among them, Baidu Migration is a mobile app based on big data system recording movements of mobile phone users and is commonly used for population and labor mobility research (Zhan et al., 2020). This paper screens out the population flow data between cities in the Chengdu-Chongqing urban agglomeration from January 1 to 14, 2020, fully considering working days, rest days and holidays population inflows and outflows. Enterprise investment capital data comes from the Qixinbao website (https://www.qixin.com/). By screening the location of investing companies and invested companies, we build a 16 × 16 matrix of mutual investment between cities in 2020. Similarly, patent transfer data is obtained in a similar manner, and its source website is inCopat (https://www.incopat.com/).

In addition, this paper also cites a number of statistical indicators, such as GDP, per capita GDP, urbanization rate, gross deposits of financial institutions, and the number of patent authorizations, mainly from the "Sichuan Statistical Yearbook 2021" and "Chongqing Statistical Yearbook 2021".

3.3 Empirical model

A research framework is developed in this study to achieve the research objectives. Firstly, based on multi-source big data and statistical data, the intensity of three kinds of production factors flow is respectively measured by parametric substitution and improved gravity model. Secondly, the factor flow barrier index (FFBI) is established to evaluate the barriers of production factors flow. Finally, the QAP regression model is used to analyze the factors affecting FFBI.

3.3.1 Measuring the intensity of production factor flow

This paper utilizes population migration data to reflect the intensity of labor mobility due to the difficulty in obtaining the amount of labor transfer. Patent transfer and enterprise investment are the main forms of capital and technology flow, so the data of patent transfer and enterprise investment amount can be used to represent the intensity of capital and technology

TABLE 1 Formulas for calculating the intensity of production factors flow.

Variables	Formula	Description
The intensity of labor flow	$L_{ij} = L_{i,j} + L_{j,i}$	L_{ij} is the calculated intensity of labor flow. $L_{i,j}$ and $L_{j,i}$ are the number of population flowing from city i to city j and from city j to city i, respectively
The intensity of capital flow	$C_{ij} = C_{i,j} + C_{j,i}$	C_{ij} is the calculated intensity of capital flow. $C_{i,j}$ and $C_{j,i}$ are the total investment flowing from city i to city j and from city j to city i, respectively
The intensity of technology flow	$T_{ij} = T_{i,j} + T_{j,i}$	T_{ij} is the calculated intensity of technology flow. $T_{i,j}$ and $T_{j,i}$ are the number of patents transferred from city i to city j and from city j to city i, respectively

TABLE 2 Formulas for estimating the intensity of production factors flow.

Variables	Formula	Description
The intensity of labor flow	$L'_{ij} = \frac{L_i \times L_j}{D_{ij}}$	L'_{ij} is the estimated intensity of labor flow, L_i and L_j are the total population of city i and city j, respectively. D_{ij} is the geographical distance between cities i and j
The intensity of capital flow	$C'_{ij} = \frac{C_i \times C_j}{D_{ij}}$	C'_{ij} is the estimated intensity of labor flow, C_i and C_j are the total deposits of financial institutions of city i and city j, respectively. D_{ij} is the geographical distance between cities i and j
The intensity of technology flow	$T'_{ij} = \frac{T_i \times T_j}{D_{ij}}$	T'_{ij} is the estimated intensity of labor flow, T_i and L_j are the total amount of patent authorization of city i and city j, respectively. D_{ij} is the geographical distance between cities i and j

flow between cities. Table 1 shows the formulas for calculating the flow intensity of three kinds of production factors.

In addition, the improved gravity model is applied to estimate the intensity of production factors flow under natural conditions. Gravity model is a theoretical model proposed based on the law of universal gravitation to measure the strength of the connection between regions (Tinbergen, 1966; Daniel, 2006). Scholars usually use some aggregate indicators instead of mass to improve the traditional gravitational model and apply it to the study of distance decay effects and spatial interactions (Atif et al., 2016; Saleh et al., 2019). This study takes the total population, the total deposits of financial institutions, and the total amount of patent authorization as the total scale of labor, capital, and technology in gravity model, respectively. Table 2 shows the formulas for estimating the intensity of three kinds of production factors flow.

3.3.2 Evaluating the barrier of production factor flow

The intensity of production factor flow calculated using multi-source big data is often different from that estimated based on improved gravity models. These intensity difference can reflect the degree of deviation between the intensity of the real factor flow and that under natural conditions, which can be evaluated by FFBI. The calculation formula of FFBI is as follows:

$$\boldsymbol{FFBI_{ij}} = \mathbf{1} - \frac{\boldsymbol{I_{ij}}}{\sum_{i=1,j=1}^{16} \boldsymbol{I_{ij}}} \div \frac{\boldsymbol{I'_{ij}}}{\sum_{i=1,j=1}^{16} \boldsymbol{I'_{ij}}}$$

Where $\boldsymbol{FFBI_{ij}}$ is the FFBI between city i and city j. $\boldsymbol{I_{ij}}$ is the calculated intensity of a production factor flow. $\boldsymbol{J_{ij}}$ is the estimated intensity of a production factor flow. Using this formula, the FFBI of labor, capital, and technology flows between the 16 cities in the Chengdu-Chongqing urban agglomeration can be calculated. If $\boldsymbol{FFBI_{ij}}$ is a positive value, it means that there is an obstacle to the flow of factor between cities i and j. The larger the value of $\boldsymbol{FFBI_{ij}}$, the stronger the obstacle. If $\boldsymbol{FFBI_{ij}}$ is a negative value, it means that there is a promotion effect on the flow of factor between cities i and j. The larger the value of $\boldsymbol{FFBI_{ij}}$, the stronger the promotion effect. If $\boldsymbol{FFBI_{ij}}$ is equal to 0, it means that the flow of elements between cities i and j is close to the natural state.

3.3.3 QAP regression model

QAP is a resampling-based method that has been widely used in measuring "relationships" in relational data, which can avoid the collinearity problem caused by relational data regression (Liu, 2007; Ju and Sohn, 2015; Lee et al., 2016). QAP analysis can be divided into QAP correlation analysis and QAP regression model. QAP correlation analysis compares the lattice values corresponding to two or more square matrices to give the correlation coefficients between the matrices, and conducts non-parametric tests on the coefficients (Zhang et al., 2020; Li et al., 2021). Based on the permutation of matrix data, QAP regression model studies the regression relationship between multiple matrices and one matrix, and at the same time evaluates the significance of R-squared (Cranmer et al., 2017; Chong et al., 2018). In recent years, the model has been introduced by some scholars into the study of production factors flow (Wang et al., 2021).

TABLE 3 Definition of explanatory variables.

Aspect	Variables name	Abbreviation	Definition
System	Administrative division relationship	ADR	If two cities belong to the same provincial-level administrative region, then ADR = 0; Otherwise, ADR = 1
	Administrative level differences	ALD	If two cities have the same administrative level, ALD = 0; Otherwise, ALD = 1
Economic	Difference in per capita GDP	D_GDP	Difference between GDP per capita of two cities
Society	Difference in urbanization rate	D_UA	Difference between urbanization rates of two cities
Culture	Whether belong to the same cultural division	CD	If two cities belong to the same cultural zone, then CD = 0; Otherwise, CD = 1
Policy	Whether belong to the same metropolitan area	MA	If two cities belong to the same metropolitan area, then CD = 0; Otherwise, CD = 1
Facility	Minimum driving time	MDT	The minimum travel time by car between two cities

Based on the QAP model, this paper reveals the determinants of the barrier of three kinds of production factors flow from the perspectives of system, economy, society, culture, policy and facility, to better explain the mechanism of FFBI. Among these perspectives, the system mainly considers administrative divisions and administrative levels. In the economic aspect, the difference of per capita GDP is selected as a representative variable. Since the urban-rural dual structure is an important feature of Chinese society, the model selects the difference in the urbanization rate as a social variable. In terms of culture, the main consideration is that the Chengdu-Chongqing urban agglomeration can be divided into the Ba cultural area (Chongqing, Nanchong, Guangan and Dazhou) and the Shu cultural area (Chengdu, Zigong, Luzhou, Deyang, Mianyang, Suining, Neijiang, Leshan, Meishan, Yibin, Yaan, Ziyang) in space. Planning can reflect policies that guide the development of space, and cities in the same metropolitan area tend to be more closely linked. The planning scope of Chengdu Metropolitan Circle includes Chengdu, Deyang, Meishan and Ziyang. And the planning scope of Chongqing Metropolitan Circle includes Chongqing and Guangan. In terms of facility, the shortest car travel time is mainly used as a variable to measure the convenience of transportation facilities. The definition of variables is as Table 3. Based on the above process, the study establishes seven 16 × 16 independent variable matrices.

4 Results and analysis

4.1 The intensity of production factors flow

4.1.1 The intensity of production factors flow calculated by multi-sources big data

Using natural breaks in ArcGIS, we divided the intensity of three typical production factors flow calculated by multi-sources big data into five grades (the lowest, lower, medium, higher and the highest). The colors from blue to red indicate the intensity from low to high (Figure 2). In terms of labor flow, the factors flow intensity of Chongqing-Chengdu, Chengdu-Deyang and Chengdu-Meishan are at the highest level; the factors flow intensity of Chongqing-Guangan, Chengdu-Ziyang and Chengdu-Nanchong are at higher level. Chengdu-Suining has the highest capital flow intensity. Chongqing-Chengdu, Chengdu-Leshan, Chengdu-Deyang and Chengdu-Mianyang are at the second level. Chongqing-Chengdu and Chengdu-Deyang are at the highest level of technology flow intensity. after these are Chengdu-Meishan and Chengdu-Suining. It shows that Chongqing and Chengdu are the two core cities in the Chengdu-Chongqing urban agglomeration, playing important dominant roles in the three typical production factors flow network, and Chengdu plays an even bigger role than Chongqing. The intensity of labor, capital and technology flow between other 14 cities are all medium or below.

4.1.2 The intensity of production factors flow estimated by improved gravity model

We also divided the intensity of three typical production factors flow estimated by improved gravity model into five levels at natural breaks (Figure 3). Whether it is labor mobility, capital mobility or technological mobility, Chongqing-Chengdu has the highest intensity of factors flow. Chongqing and Chengdu are at the centre of the production factors flow network with the most intensive flows with other cities. For example, the intensity of labor flow and capital flow of Chengdu-Deyang, Chengdu-Mianyang, Chengdu-Meishan are at the highest level. The intensity of technology flow of Chengdu-Deyang and Chengdu-Mianyang are at higher level. The intensity of labor flow of Chongqing-Luzhou, Chongqing-Nanchong, Chongqing-Guangan, Chongqing-Dazhou are also at higher level. Except for Deyang-Mianyang, the intensity of labor, capital and technology flow between other 14 cities are all medium or below.

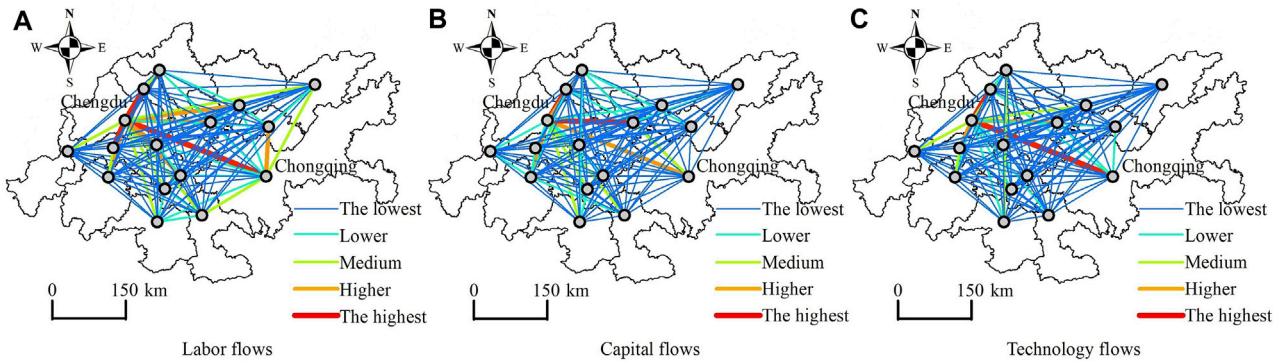

FIGURE 2
The intensity of labor, capital and technology flow calculated by multi-sources big data.

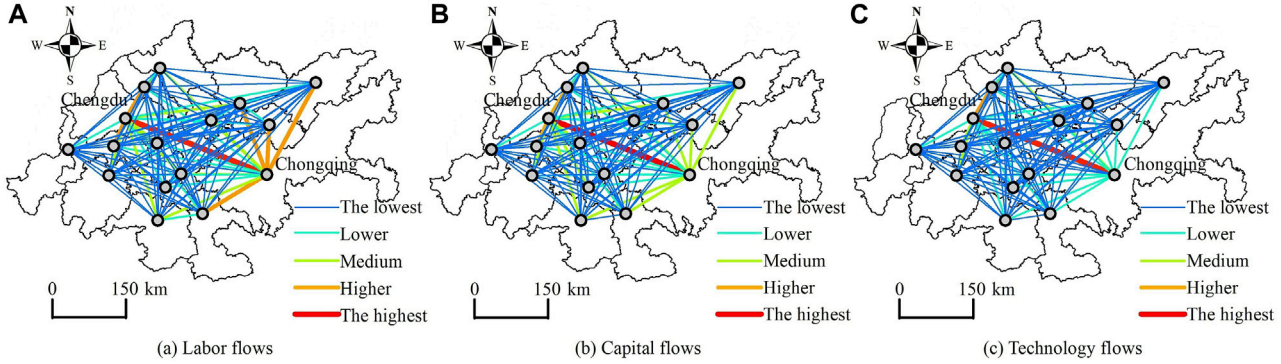

FIGURE 3
The intensity of labor, capital and technology flow estimated by improved gravity model.

4.2 The barrier of production factors flow

Figure 4 illustrates the FFBI of labor, capital and technology flow between 16 cities in the Chengdu-Chongqing urban agglomeration. The colors of line and grid from green to red indicate the FFBI from negative to positive, reflecting the production factors flow from being promoted to being hindered.

4.2.1 The barrier of labor flow

As shown in Figure 4A, the FFBI of labor flow between Chongqing and other cities are all positive, showing that the labor flow between Chongqing and other cities are hindered. Except for Chongqing, the FFBI of labor flow of the city pairs composed by Chengdu and other 14 cities are negative, indicating that labor flow between Chengdu and other 14 cities are promoted to a certain extent. Another observable spatial pattern is that the FFBI of labor flow is smaller between closed cities. For example, the FFBI of Chongqing-Guangan, Chongqing-Dazhou, Choingqing-Ziyang and Chongqing-Luzhou are smaller, indicating the impediment of labor flow between Chongqing and these neighboring cities are relatively small.

4.2.2 The barrier of capital flow

Unlike labor flow, the FFBI of capital flow of Chongqing-Suining is negative. That is to say, the capital flow of the city pairs composed by Chongqing and other cities are not all hindered. The positive and negative FFBI values of the city pairs composed by Chengdu and other cities are almost equal. Among the city pairs consist of Leshan, there are over five ones where capital flow is facilitated. Notably, the FFBI of capital flow between Ziyang and other cities are all positive, showing that the capital flow between Ziyang and other cities are all hindered, which is similar with the capital flow between Nanchong and other cities. Overall, the laws of capital flow are more complex than labor flow, and not much related to spatial proximity (Figure 4B).

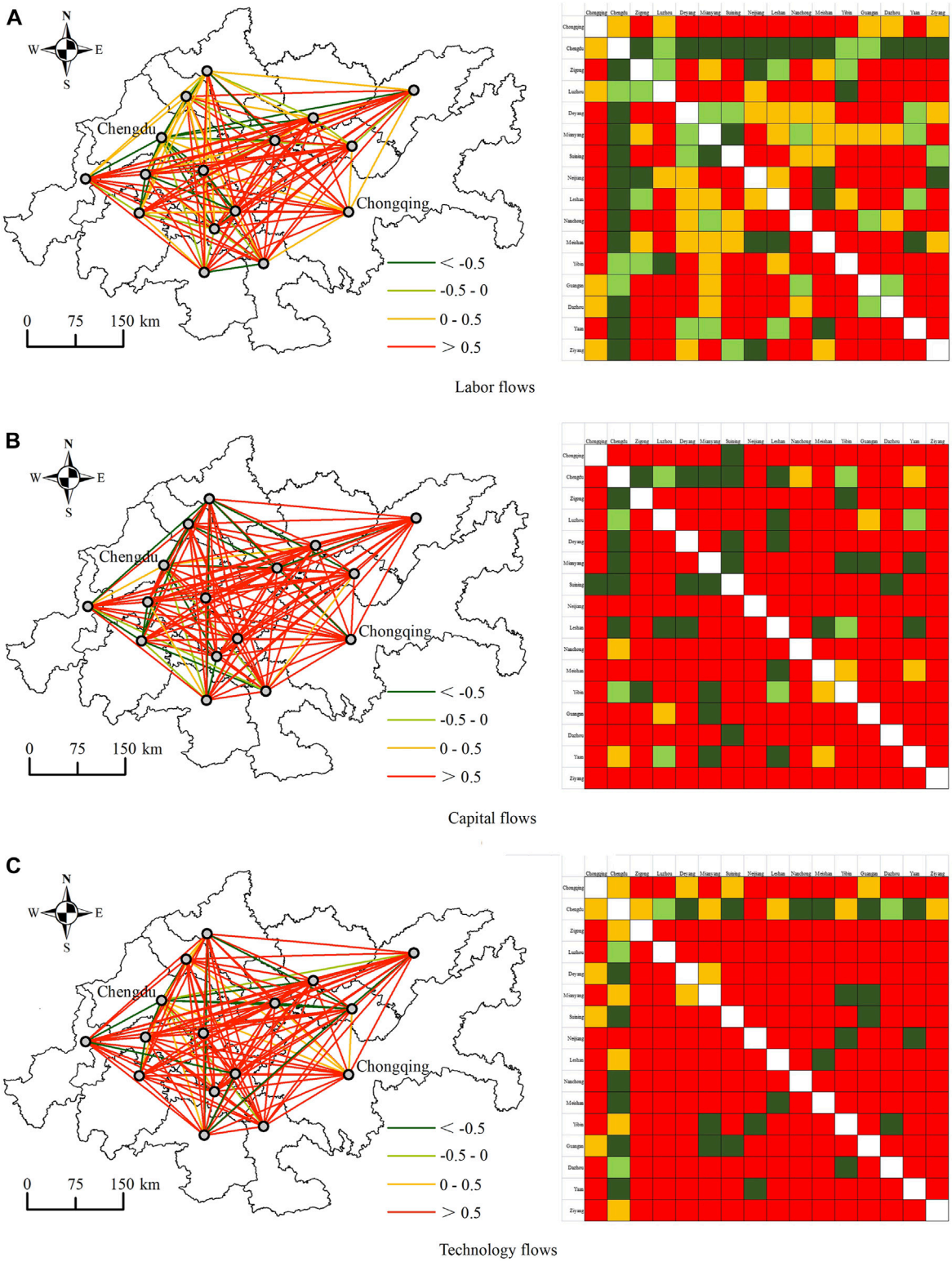

FIGURE 4
The FFBI of labor, capital and technology flow.

TABLE 4 QAP regression Model on the FFBI of three typical production factors flow.

Aspect	Variable	Labor flow		Capital flow		Technology flow	
		Standardized coefficient	*p*-Value	Standardized coefficient	*p*-Value	Standardized coefficient	*p*-Value
System	ADR	0.576**	0.000	0.281**	0.044	0.157*	0.071
	ALD	-0.820**	0.000	-0.520**	0.023	-0.294*	0.092
Economy	D_GDP	-0.098	0.142	-0.077	0.291	-0.005	0.494
Society	D_UA	0.182	0.132	0.366*	0.087	0.212	0.189
Culture	CD	0.083	0.145	0.015	0.464	0.110	0.156
Policy	MA	0.080	0.106	0.081	0.202	0.006	0.597
Facility	MDT	0.408**	0.000	0.125	0.173	-0.083	0.237
R^2		0.595	0.071	0.028			

*, ** represent a significance level of 10% and 5%, respectively.

4.2.3 The barrier of technology flow

As shown in Figure 4C, the FFBI of technology flow of the city pairs involving Chongqing, Zigong, Ziyang are all positive, showing that the technology flows of these city pairs are hindered. The positive and negative FFBI values of the city pairs composed by Chengdu and other cities are almost equal. Among the city pairs involving Yibin and Guangan, the technology flow of three city pairs are facilitated. The FFBI of technology flow of Chengdu-Deyang and Chengdu-Luzhou is the only negative values in the city pairs involving Luzhou and Deyang, respectively.

4.3 Determinants of the barrier of typical production factors flow

By importing the multidimensional independent variable matrices into the QAP regression model, and then having performed 2000 times of matrix random permutations to estimate the standard errors, the regression results are obtained. Table 4 reports the results of the QAP regression model. The model fitting result varies from 0.028 to 0.595, and the variables can better explain the difference of the FFBI of labor flow between cities than that of capital and technology flow.

In terms of labor flow, there are three variables that have an impact on the FFBI between cities at a significance level of 5%, they are ADR, ALD of system and MDT of facility, among which ADR has a positive impact on the barrier of labor flow. In other words, since Chongqing and other cities belong to different provincial administrative regions, the intensity of labor flow between Chongqing and other cities are hindered to a certain extent. However, ALD has a negative impact on the barrier of labor flow, indicating that cities at same administrative levels have larger FFBI of labor flow. MDT exerts positive impact on the barrier of labor flow. That is to say, the higher the cost of travel time between two cities, the greater the impediment to labor flow.

As for the FFBI of capital flow, factors related to system and society do exert influence. City pairs belonging to different provincial administrative regions or within the same administrative level have larger FFBI of capital flow, capital flows are more hindered. D_UA of society has a positive impact on the barrier of capital at a significance level of 10%, indicating capital flow between cities with large urbanization level gaps is more hindered.

The regression results also show that ADR and ALD of system are the two factors affecting the barrier of technology flow at a significance level of 10%. Similar to labor and capital flow, city pairs belonging to different provincial administrative regions but within the same administrative level have larger FFBI of technology flow.

5 Discussion

5.1 Comparison among the barriers of the three typical production factors flow

In 120 city pairs of the Chengdu-Chongqing urban agglomeration, 87, 100 and 106 city pairs have positive FFBI of labor flow, capital flow and technology flow, respectively. The results show that the three typical production factors flow between most cities are hindered to a certain extent and only a small number of production factors flow between cities are facilitated. For these city pairs, the FFBI of capital flow and technology flow are also greater than that of labor mobility. Thus, labor flow is less hindered than capital and technology flow. Another notable phenomenon is that the FFBI of labor flow are relatively lower in city pairs consisting of neighboring cities, but the barriers of capital flow and technology between two cities are not related to their spatial proximity obviously.

ADR, ALD of system have similar effects on the FFBI of the three typical production factors flow, indicating that

administrative division hinders the three typical production factors flow in the Chengdu-Chongqing urban agglomeration, and the Chengdu-Chongqing urban agglomeration is still in the stage of production factors agglomerated to high-level administrative cities (Chongqing and Chengdu). The difference is that time and space compression brought by informatization makes the capital and technology flow no longer subject to spatial distance, which is the reason why the low significance of the MDT factor. The difference in urbanization rate reflects the proportion of non-agricultural production population between cities is similar, and the industrial structure is more similar, which is an important factor affecting capital flow. In addition, D_GDP of economic and CD of culture have no significant impact on the FFBI of the three typical production factors flow, indicating that differences in economic development levels and cultural are not obstacles to the three typical production factors flow in the Chengdu-Chongqing urban agglomeration. Although "Chengdu Metropolitan Circle Development Plan" and "Chongqing Metropolitan Circle Development Plan" have been formulated in the past 2 years, the effect of MA on the barrier of the three typical production factors flow is not obvious, indicating these two plans have not guided the free flow of production factors due to their short implementation time.

5.2 Research and policy implications

The concept of high-quality put forward by Chinese government emphasizes the high efficiency and coordination of development. Promoting the free flow of production factors helps to improve the efficiency and fairness of resource allocation, which is the key to high-quality development. Compared with most existing studies focusing on the flow intensity of production factors, this study further explores the barriers of three typical production factors flow and their influencing factors, which is a more direct support for the research on high-quality development paths. Calculating and estimating the intensity of production factors flow by multi-source big data and improved gravity model, based on which the FFBI is established to evaluated the barrier of labor flow, capital flow and technology flow. Moreover, three QAP regression models are established to identify the factors that determine the barriers of three typical production factors flow. This study provides a methodological reference for factors flow related research.

In addition, the analysis of determinants of labor flow, capital flow and technology flow in the Chengdu-Chongqing urban agglomeration highlights some implications that could assist governments in evidence-based policymaking and policy outputs. Institutional reforms such as exploring the mode of moderate separation of administrative regions and economic regions and cultivating sub-central cities are very necessary, which will effectively break the barriers of the three typical production factors. In order to promote the free flow of labor, expressway network should be further optimized and strengthened, especially the traffic lines between major cities of Sichuan province and Chongqing. In addition, in order to form the situation of coordinated industrial development and efficient capital flow, unified industrial planning of the Chengdu-Chongqing urban agglomeration should be compiled.

5.3 Limitations and uncertainty

This research also has several limitations, which also suggests avenues for further research. One limitation relates to the accuracy of using FFBI to evaluate the barrier of production factors flow. The improved gravity model used in this study mainly draws on previous studies (Wu et al., 2017), and its estimation of the intensity of the three production factors flow under natural conditions has not been fully verified, which may affect the evaluation results of factors flow barriers to some extent. The second concern is related to the representativeness of the multi-source big data used to calculate the intensity of three typical production factors flow. For instance, Baidu Migration data mainly reflects population flow (Zhang et al., 2021), including not only labor flow data, but also population flow for other purposes such as tourism flow. Thirdly, our research evaluates the barrier of labor, capital and technology flow by FFBI, insufficient attention goes to other production factors such as natural resources, management and data for some reason. These shortcomings will be addressed through model optimization and data source supplement, which we may explore in future research to establish a more comprehensive understanding of production factors flow.

6 Conclusion

In the analysis of the Chengdu-Chongqing urban agglomeration, three meta-findings about the barriers of three typical production factors flow stand out. First, although there are differences in the intensity of three typical production flow measured by different methods, Chongqing and Chengdu are at the centre of the three typical production factors flow network with the most intensive flows with other cities, but the intensity of labor, capital and technology flow between other 14 cities are all relatively weak. Second, the three typical production factors flow between most cities are hindered to a certain extent and only a small number of production factors flow between cities are facilitated. Labor flow is less hindered than capital and technology flow. The barriers of three typical production

factors flow between Chongqing and other cities are nearly all hindered. And third, administrative division hinders the three typical production factors flow in the Chengdu-Chongqing urban agglomeration. Chengdu and Chongqing, as two cities with high administrative level, their production factors flow with other cities are facilitated. In addition, the barrier of labor and capital flow are positively affected by the transportation cost and the similarity of the industrial structure, respectively.

This study aims to describe the barriers of three typical product factors flow (labor flow, technology flow and capital flow) by FFBI and identify the influence factors by QAP regression model, which help to expand the current research dimension of production factor flow. Understanding the differences in influence factors of the barriers of the three typical production factors flow is greatly beneficial for regional and urban planners to make breakthroughs in the development path of the integration mechanism of urban agglomeration. Administrative division is the key to the barriers of the three typical production factors flow in the Chengdu-Chongqing urban agglomeration, and we should be aware of the difference of other influence factors between the three typical production flow and aim at the target in promoting the free and orderly flow of production factors (Li et al., 2021).

Data availability statement

The original contributions presented in the study are included in the article/supplementary material further inquiries can be directed to the corresponding author.

Author contributions

YZ: conceptualization, methodology, writing. XW: review and editing. ML: data curation, methodology. YC: writing—review and editing. FY: data curation.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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