**R&D Factor Flow, Regional Innovation Efficiency and High Quality Economic Development**

**Abstract:** Based on the panel data of 30 provinces in China from 2010 to 2022, the gravity model is used to measure the flow of R & D factors, the stochastic frontier function is used to measure the regional innovation efficiency, and the SBM model considering undesirable output super efficiency is used to measure the green total factor productivity.The spatial Durbin model is used to empirically test the impact of R&D factor flow on high-quality economic development and its spatial spillover effect, and further test the mediating effect of regional innovation efficiency in the process of R&D factor flow promoting high-quality economic development. On this basis, we deeply explore its heterogeneous effects in the eastern, central and western regions. The results show that the flow of R&D factors in China effectively promotes the high-quality development of the economy, and the flow of R&D capital plays a more obvious role in promoting the high-quality development of the economy. R&D personnel flow plays a significant direct and indirect role in high-quality economic development, while R&D capital flow has a significant spatial spillover effect in the process of promoting high-quality economic development. R&D factor flow promotes high-quality economic development by improving regional innovation efficiency; the flow of R&D capital in the east and the flow of R&D personnel in the west have significant advantages.The impact of R & D capital in the eastern region is more significant, while the western region is mainly concentrated in R & D personnel. Based on this, it is proposed to effectively promote the flow of R&D factors, improve the efficiency of regional innovation, improve the policy system, guide the cross-regional flow of R&D factors, adopt regional differentiation policies,. Exploring this issue will help provide empirical evidence for the high-quality development of developing countries.

**Keywords:** R&D factor flow; regional innovation efficiency; high-quality economic development; spatial Durbin model

# 1.Introduction

Under the background of sustainable economic and social development, our focus of development has shifted from "quantity" to "quality". Realizing high-quality economic development has become the key to achieving the trinity goal and the fundamental requirement of Chinese modernization. As an important resource to promote the implementation of China' s innovation-driven strategy, R&D factors (R&D personnel and R&D capital) play an important role in the high-quality development of the economy. As an interactive way, the flow of R&D elements helps to strengthen the links between different regions, which is in line with the "promotion of regional coordinated development" proposed in the report of the 20th National Congress of the Communist Party of China. The inter-regional flow of R&D elements will improve the efficiency of regional innovation through the technology diffusion effect, and there will be unreasonable flow of R&D elements under the profit-seeking effect, which will not be conducive to the improvement of regional innovation efficiency and hinder the high-quality development of the economy. In the context of the new era, it is an urgent problem to be solved in the current Chinese-style modern economic development to explore the mechanism of the flow of R&D factors on the high-quality economic development, so as to guide the rational flow of R&D factors, so as to effectively promote the high-quality economic development.

In the new era, scientific and technological innovation has become an important focus and breakthrough for high-quality economic development, supporting China' s economic growth to achieve high quality and high quantity development. The implementation of innovation-driven development strategy is inseparable from the support of R&D elements. R&D personnel are the most dynamic subject of R&D innovation activities, and R&D elements provide strong support for R&D activities. The research on the relationship between R&D factor flow, regional innovation efficiency and high-quality development in the new era has important practical and theoretical significance, which is conducive to exploring the important role of R&D factor flow and regional innovation ability under the goal of high-quality development. In addition, it is an urgent practical problem to explore the mechanism path of R&D factor flow affecting high-quality development, guide the rational flow of R&D factors, and effectively promote high-quality economic development.

In order to promote the implementation of innovation-driven strategy, scholars in the past have carried out a lot of research on the flow of R&D factors, regional innovation efficiency and high-quality development. The existing research has fully confirmed two points: first, R&D personnel and R&D capital actually represent regional innovation factors, and their flow between regions will change regional innovation efficiency. Second, the level of regional innovation efficiency will have an impact on the high-quality development of the economy. Although scholars have produced many achievements on the relationship between R&D factor flow, regional innovation efficiency and high-quality development, the specific impact mechanism between the three is still unknown. This paper focuses on the mechanism black box between R&D factor flow, regional innovation efficiency and high-quality development. From the perspective of mediating effect, it profoundly reveals the mechanism of R&D factor flow promoting high-quality development, and tests the mediating role of regional innovation efficiency in R&D factor flow promoting high-quality development. This paper explores the internal mechanism and decomposition effect of R&D factor flow on promoting high-quality economic development in space, and examines the regional heterogeneity of R&D factor flow for high-quality economic development.

# 2.Literature review

At present, domestic and foreign scholars' research on R&D factor flow, regional innovation efficiency and high-quality development is mainly carried out from the following three aspects.

First, R&D factor flow and regional innovation efficiency. At present, the research on the impact of R&D factor flow on regional innovation efficiency at home and abroad can be basically divided into two levels: one is based on the global perspective of R&D factors; second, from the perspective of the classification of R&D elements, the R&D elements are specifically divided into the flow of R&D personnel and R&D capital, which is also the concern of most scholars. When Zou Huang et al.(2019) studied “the relationship between R&D factor flow and regional innovation efficiency, he found that R&D factor agglomeration significantly improved regional innovation efficiency, and the greater the R&D investment, the greater the impact of R&D factor agglomeration on innovation efficiency”. Secondly, the research of Yang et al.(2024) shows that “R&D capital flow can improve innovation efficiency, but the cross-regional flow of R&D personnel does not have a significant impact on innovation efficiency”. However, Li&Li (2018) proposed that “the flow of R&D factors has strong knowledge and technology spillover effects, and the flow of R&D factors can significantly promote regional innovation efficiency”. Based on this, Zhou et al.(2020) conducted an empirical study on the relationship between the flow of R&D factors and regional innovation development from the dimensions of 'quantity' and 'quality', and found that the cross-regional flow of R&D personnel can significantly improve the quality of regional innovation, thus making up for the defect that most scholars only pay attention to 'quantity' and ignore 'quality'(Audretsch& Feldman,2004).

Second, the impact of regional innovation efficiency on high-quality economic development. Rodríguez-Pose&Crescenzi (2008) conducted an empirical study on the mechanism effect of R&D factor flow on China' s high-quality economic development, and found that scientific and technological innovation ability significantly promoted high-quality economic development. Based on the grey correlation analysis, Chun-Chien et al.(2008) found that “China' s regional scientific and technological innovation and high-quality development are in a basic equilibrium state, but there is still a gap in the level of high-quality coordinated development. In addition”, Saleem et al.(2019) shows that “China' s scientific and technological innovation has an effective role in promoting, but the problem of unbalanced development in different regions is prominent”.

Third, R&D factor flow and high-quality economic development. Englander et al. (1988) pointed out in the article that there is a clear spatial spillover in the cross-regional flow of R&D factors, and this spillover effect has a positive impact on China' s economic growth. Based on the perspective of economic growth, Saleem et al.(2019) found that the flow of R&D factors has obvious spatial spillover effects(Pan et al.,2022).Hua et al.(2021), taking the Yangtze River Delta and Northeast China as examples, through empirical research on the impact and transmission mechanism of the spatial flow of factors in the regional and regional adjacent areas on the economic growth of the region, found that the economic growth of the region has a strong dependence on the economic activities of the adjacent regions(Crescenzi& Rodríguez-Pose,2011). In addition, Chen&Huo (2022) found that there are obvious path dependence and spatial accumulation characteristics in China' s high-quality economic development.

“In summary, the research on R&D factor flow, regional innovation efficiency and high-quality development has been relatively mature, and relevant theoretical research is also constantly developing and improving”(Furman et al.,2002). At the same time, through combing the existing literature, we find that the existing research mainly focuses on these two aspects, but pays little attention to the integration of these three aspects, and lacks the intermediary role of regional innovation efficiency on high-quality economic development based on the flow of R&D factors.Therefore, compared with previous studies, the contribution of this paper is mainly reflected in the following three aspects. First, from the perspective of mediating effect, this paper integrates R&D factor flow, regional innovation efficiency and high-quality economic development into a unified research system, profoundly reveals the mechanism of R&D factor flow promoting high-quality development, and tests the mediating role of regional innovation efficiency in R&D factor flow promoting high-quality development. Secondly, considering the spatial correlation generated by the flow of R&D factors, this paper explores the internal mechanism and decomposition effect of the flow of R&D factors on stimulating high-quality economic development in space. Thirdly, it examines the regional heterogeneity of R&D factor flow for high-quality economic development, and deeply studies the role of R&D factor flow in the process of high-quality economic development through decomposition effect from the three major regions of the eastern, central and western regions.

# 3.Theoretical analysis

The mechanism framework of R&D factor flow driving high-quality development can be divided into two parts: first, R&D factor flow improves regional innovation efficiency (regional innovation capability), including the increase in the number of regional scientific research achievements and the increase in the conversion rate of scientific research achievements; second, regional innovation efficiency drives high-quality economic development, mainly through the transformation of scientific and technological achievements, injecting innovation and vitality into economic development.

**(1)Direct effect**

“According to the theory of factor endowments, the uneven distribution of regional R&D factor endowments has led to the flow of R&D factors between regions. R&D personnel and R&D capital are two essential subjects of R&D elements. The price of R&D personnel's available means of consumption will affect the choice of R&D personnel for R&D regional institutions. If somewhere provides better wages and reasonable lower house prices for R&D personnel, this will greatly attract the inflow of R&D personnel. For R&D capital, due to the existence of the 'profit-seeking effect', R&D capital always flows to areas where greater profits can be obtained. If the region has a high degree of financial development and a high level of economic growth, this will continue to attract R&D capital inflows under the 'profit-seeking effect'”(Tang et al.,2023).

The above is a theoretical explanation for the uneven distribution of regional R&D factor endowments that constitutes the flow of R&D factors. How can the flow of R&D factors further improve the efficiency of regional innovation?

The flow of R&D elements between regions helps to improve the efficiency of resource allocation, change the structure of original R&D elements, and release the innovation vitality of R&D elements(Audretsch&Feldman,1996). According to the production knowledge function, R&D factors (R&D personnel, capital) can only improve innovation efficiency and increase R&D effective output under a reasonable input ratio. Through the flow of R&D elements, it helps to optimize the rational allocation of R&D elements in various regions and effectively promote regional R&D innovation output. Secondly, the flow of R&D elements to a certain area forms an aggregation, and continues to expand the scale of technology, forming a certain accumulation of knowledge and technology, and enterprises are more likely to obtain scientific and technological innovation achievements and transform scientific and technological achievements. With the continuous accumulation of R&D elements and the expansion of technology scale, regional R&D innovation ability has been continuously improved, and regional innovation efficiency has been significantly improved. Finally, the spillover effect of R&D factors makes the technical cooperation and innovation information exchange in different regions, which will promote the improvement of scientific and technological innovation ability in adjacent cooperative regions to varying degrees. In the process of the flow of R&D elements, each subject in the innovation network obtains the technology spillover benefits brought by technology interaction, and constantly enhances its own innovation strength.

Based on the above analysis, the following hypotheses are proposed:

Hypothesis 1: R&D factor flow can significantly improve regional innovation efficiency.

**(2) Indirect effect**

“The improvement of regional innovation capability (regional innovation efficiency) will first bring about a significant increase in innovation results, which will have a certain impact on traditional industries, promote the adjustment and upgrading of traditional industries, and also give birth to emerging industries. The application and transformation of R&D achievements promote the high-quality development of the industry, and then the high-quality development of the industry enables the high-quality development of the economy”(Jaff et al.,1993).

For traditional industries, with the wide application of scientific and technological achievements, traditional industries have changed their production methods under the stimulation, and the products of traditional industries have been upgraded to achieve diversified, high-quality and high-value-added development. Secondly, the improvement of technical level and the change of production mode are conducive to the formation of technical advantages, better expansion of market share, more economic benefits, while realizing the structural optimization of traditional industries and guiding the upgrading of industrial structure. In addition, the improvement of production technology can greatly improve the efficiency of single factor and multi-factor use, reduce the cost of factors, improve the utilization rate of factors, and help the improvement of factor income(Döring&Schnellenbach,2006).

For emerging industries, the emergence of emerging technologies has spawned a number of emerging industries. The application and transformation of emerging achievements have brought new production technologies and novel product design to enterprises, thus deriving a generation of emerging industries(Crescenzi& Rodríguez-Pose,2022). The development of emerging technologies adapts to the current reality of product production on the consumer side, and can effectively adjust production methods and production goals based on changes in consumer preferences, so as to better meet market demand, expand market space and increase market size. Emerging industries promote the continuous extension of the industrial chain and lead the development trend of the industry through leading technology and progressive innovation(OECD,2023). The commercial application of emerging industries has impacted traditional industries, realized the intelligence and digitization of production, sales and circulation processes, promoted the production and marketing docking and supply and demand matching, and greatly released the dividends of R&D elements. Technological innovation has brought about changes in business models and the upgrading of industrial structure to continuously expand the activity boundaries of enterprises and enhance the position of the industry in the value chain. Or is it that scientific and technological innovation is conducive to carrying out technical exchanges and assistance with relevant regions by helping regions get rid of technical constraints, and promoting balanced and high-quality regional development through coordinated development.

Based on the above analysis, the following hypotheses are proposed:

Hypothesis 2: Regional innovation efficiency can significantly drive high-quality economic development.

# 4.Research Design

**(1) Model construction**

①Spatial weight matrix

The spatial weight matrix can represent the relationship and degree of association between two spatial units. The ordinary 0-1 adjacency matrix represents the mutual influence between provinces based on geographical adjacency. In this geographic matrix, there is no economic activity exchange between non-adjacent provinces, so it cannot fully represent the relationship between spatial units. According to experience, the exchange of economic activities between provinces with close distance is obviously more frequent than that between provinces with far distance. Therefore, this paper uses the geographical distance space matrix, which is defined as follows , whererepresents the spatial distance between  provinces and .

②Spatial econometric model

Because the flow of R&D factors makes innovation activities and high-quality development have spatial effects, this paper establishes a spatial econometric model to empirically study the spatial impact of R&D factor flow on high-quality economic development on the basis of considering spatial factors. The common spatial econometric models are spatial error model (SEM) and spatial lag model (SLM). The spatial Durbin model (SDM) includes the research characteristics and transmission mechanism of the above two models, and also considers the interaction between them, which can be transformed into the form of two models.

Therefore, this paper constructs a spatial Durbin model to analyze the impact of R&D factor flow on high-quality economic development. The model form is:, represents the explained variable, represents the explanatory variable, represents the spatial weight matrix, and represents the random disturbance term.

**(2) Variable selection and description**

①Explained variables

The explained variable of this paper is the level of high-quality economic development (GTFP). At present, the existing research on the selection of indicators for high-quality economic development is mainly divided into the following three categories. First, by constructing the index system of high-quality economic development, the combination weighting method is used to measure the high-quality economic development index; second, a single indicator is used to characterize the high-quality economic development system, such as per capita GDP; third, the total factor productivity including input and output indicators is used to characterize the degree of high-quality economic development. Because a single data indicator is difficult to measure the quality of economic development, there is a link that omits undesired output. Therefore, this paper uses green total factor productivity including expected output and unexpected output as a characterization index of high-quality economic development level.

This paper selects the number of employees in the whole society, the stock of social capital and the use of social energy as input factors. The expected output index is the regional GDP, and the undesired output index is the three waste emissions. At the same time, the SBM model considering the undesired output super efficiency is used to measure the green total factor productivity.

Table 1 Index system of high-quality economic development

|  |  |  |  |
| --- | --- | --- | --- |
| Index type | First-level index | Second-level index | Unit |
| Input  indicators | labor factor | number of employed people in the whole society | ten thousand |
| capital factor | fixed capital stock of the whole society | billion yuan |
| energy factor | total electricity consumption of the whole society | billions of kilowatt hours |
| Output indicators | expected output | region GDP | 100 million yuan |
| unexpected output | industrial solid waste emissions | ten thousand tons |
| industrial waste gas emissions | thousand tons |
| industrial wastewater discharge | ten thousand tons |

This paper draws on Tone (2004) to establish a super-efficient SBM model to measure green total factor productivity. Among them, the model takes the province as the decision-making unit, assuming that in the period, there are provinces**, using**input, producing expected output**, and releasing undesired output**(representing green total factor productivity, ):

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②Core explanatory variables

The core explanatory variable of this paper is the flow of R&D factors. The flow of R&D factors can be divided into R&D personnel flow and R&D capital flow.

R&D personnel flow

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| --- | --- |
|  |  |

Among them,  is the number of R&D personnel in  province, is the average salary of urban unit employees in province, andrepresents the geographical distance between.  represents the flow of R&D personnel from province to  province, andrepresents the flow of R&D personnel in province in a certain year.

R&D capital flow

|  |  |
| --- | --- |
|  |  |

andrepresent the R&D capital stock of Provinceand Province, respectively. This paper adopts the perpetual inventory method to calculate the capital stock, following Wu Yanbing's approach. The formula is:. denotes the R&D capital flow from Province to Province, whilerepresents the R&D capital flow of Province  in a specific year.

③intermediary variables

The mediating variable of this paper is regional innovation efficiency (RIE).

There are two methods to evaluate the technical efficiency of decision making units: parametric and non-parametric. The parameter method mainly uses the data envelopment method (DEA) when calculating the efficiency, while the non-parametric method uses the SFA stochastic frontier function to measure the efficiency level. Considering the measurement error and the interference of statistical processing, this paper uses the SFA stochastic frontier method to measure the regional innovation efficiency.

For the selection of innovation efficiency input indicators, this paper mainly considers from two aspects: talent input and capital input. Human input is measured by the number of R&D personnel and the full-time equivalent of R&D personnel. Capital investment is characterized by the expenditure of scientific and technological activities and the internal expenditure of R&D research funds.

Table 2 Innovation efficiency input index

|  |  |
| --- | --- |
| Human capital | Investment |
| Number of R&D personnel | Expenditure on scientific and technological activities |
| Full-time equivalent of R&D personnel | Internal expenditure of R&D research funds |

As for the output of science and technology, the output of scientific and technological innovation is mainly studied from three aspects: the number of scientific and technological papers published, the number of patent applications and the income of patent transfer. Among these three indicators, the number of patent applications can better reflect the innovation achievements and innovation ability of a region. Therefore, this paper selects the number of patent applications to characterize the output of science and technology.

This paper selects four input variables, using stochastic frontier model (SFA) and translog production function model:

|  |  |
| --- | --- |
|  |  |

④Control variables

This paper selects control variables from government support, openness, human capital level, economic development level and regional investment level. Among them, the government support is expressed by fiscal expenditure on science and technology, the degree of opening to the outside world is expressed by the proportion of foreign trade to GDP, the level of human capital is expressed by the average years of education of the labor force, the level of economic development is expressed by the per capita GDP, and the level of regional investment is expressed by the investment in fixed assets of the whole society.

Table 3 Index selection

|  |  |  |
| --- | --- | --- |
| Index attribute | Index name | Index explanation |
| Control variables | Government support ( gov ) | Fiscal expenditure on science and technology |
| Openness ( open ) | The proportion of foreign trade in GDP |
| Human capital level ( edu ) | The proportion of junior college degree labor force |
| Economic development level ( pgdp ) | Per capita GDP |
| Regional investment level ( invest ) | Investment in fixed assets of the whole society |

This paper primarily uses panel data from 30 provinces and cities in China (Tibet not included due to significant data gaps) from 2010 to 2022. The data sources include the China Statistical Yearbook, China Labor Statistical Yearbook, China Energy Statistical Yearbook, China Science and Technology Statistical Yearbook, and China Fixed Asset Statistical Yearbook. Missing values were filled using interpolation methods.

**(3) Index measurement and analysis**

①Green Total Factor Productivity (GTFP)-Green Total Factor Productivity Measurement

Due to the limited space, this paper chooses to analyze the green total factor productivity of 2012,2014,2016,2018 and 2020 to study the high-quality economic development level of various provinces and cities in China since 2012. It can be seen from Table 4 that the average value of China' s overall green total factor productivity is 0.5052, and the overall high-quality development level of China' s economy is at a medium level. The mean value of green total factor productivity in each province in 5 years is quite different, with the minimum value of 0.1827 and the maximum value of 1.2091, which shows the unbalanced state of high-quality economic development level in each province. Comparing the green total factor productivity of 30 provinces and cities, it can be found that the efficiency of Beijing, Shanghai, Jiangsu and Guangdong is the best and the efficiency value is much higher than the average level. Compared with the green total factor productivity at the provincial level, the efficiency value of Hainan Province in 2012 is 1.2581, which is the maximum value in the whole research scope, and the efficiency value of Qinghai Province in 2020 is 0.1517, which is the minimum value in the whole research scope.

Obviously, China' s provincial green total factor productivity is significantly different. Through the above analysis, China' s high-quality development level is at a medium efficiency level, and the green total factor productivity is significantly different between years and provinces.

Table 4 Green total factor productivity and its mean value of provinces and cities in China since 2012

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| City | 2012年 | 2014年 | 2016年 | 2018年 | 2020年 | 均值 |
| Beijing | | 1.2201 | 1.1987 | 1.2336 | 1.2268 | 1.1533 | 1.2091 |
| Tianjin | | 0.5739 | 1.0962 | 1.1247 | 0.5004 | 1.0465 | 0.8205 |
| Hebei | | 0.4122 | 0.3603 | 0.2849 | 0.2549 | 0.2378 | 0.3172 |
| Shanxi | | 0.3687 | 0.3340 | 0.2899 | 0.2833 | 0.2567 | 0.3102 |
| Inner Mongolia | | 0.4280 | 0.3122 | 0.2444 | 0.2422 | 0.2308 | 0.3069 |
| Liaoning | | 0.6378 | 0.3809 | 0.3020 | 0.2937 | 0.2602 | 0.4303 |
| Jilin | | 0.4570 | 0.3684 | 0.2738 | 0.3141 | 0.3201 | 0.3554 |
| Heilongjiang | | 0.8101 | 1.0313 | 1.0132 | 0.3429 | 0.3150 | 0.6669 |
| Shanghai | | 1.1695 | 1.1226 | 1.0633 | 1.1237 | 1.1524 | 1.1241 |
| Jiangsu | | 1.0267 | 1.2449 | 0.4768 | 1.1908 | 1.1652 | 1.0137 |
| Zhejiang | | 0.5362 | 0.4613 | 0.4062 | 0.3918 | 0.4288 | 0.4552 |
| Anhui | | 1.0391 | 1.0210 | 1.0415 | 0.3706 | 0.3665 | 0.7195 |
| Fujian | | 1.0093 | 1.0020 | 0.2680 | 0.3671 | 0.4032 | 0.6430 |
| Jiangxi | | 0.5405 | 0.4195 | 0.3468 | 0.3074 | 0.3148 | 0.4054 |
| Shandong | | 0.8122 | 0.5990 | 0.6805 | 0.4812 | 0.3545 | 0.5587 |
| Henan | | 0.6386 | 0.4470 | 0.3308 | 0.2819 | 0.3066 | 0.4157 |
| Hubei | | 0.4822 | 0.4285 | 0.3602 | 0.3440 | 0.3708 | 0.4022 |
| Hunan | | 0.5118 | 0.4717 | 0.3829 | 0.3442 | 0.3583 | 0.4223 |
| Guangdong | | 1.0381 | 1.0424 | 1.0485 | 1.0212 | 0.5485 | 0.9858 |
| Guangxi | | 0.4389 | 0.3876 | 0.3002 | 0.2523 | 0.2402 | 0.3331 |
| Hainan | | 1.2581 | 1.0434 | 0.4354 | 0.4459 | 1.0178 | 0.6744 |
| Chongqing | | 0.4610 | 0.3928 | 0.3231 | 0.2977 | 0.3250 | 0.3655 |
| Sichuan | | 0.3936 | 0.3572 | 0.3066 | 0.2964 | 0.3011 | 0.3348 |
| Guizhou | | 0.2477 | 0.2405 | 0.2278 | 0.2128 | 0.2012 | 0.2291 |
| Yunnan | | 0.4280 | 0.3607 | 0.2580 | 0.2439 | 0.2477 | 0.3181 |
| Shaanxi | | 0.3804 | 0.3400 | 0.3211 | 0.2930 | 0.3368 | 0.3359 |
| Gansu | | 0.2949 | 0.2844 | 0.2658 | 0.2123 | 0.1978 | 0.2574 |
| Qinghai | | 0.2273 | 0.2085 | 0.1871 | 0.1913 | 0.1517 | 0.1994 |
| Ningxia | | 0.2192 | 0.1784 | 0.1709 | 0.1776 | 0.1585 | 0.1827 |
| Xinjiang | | 0.4091 | 0.3811 | 0.3565 | 0.3212 | 0.3111 | 0.3625 |
| Mean value | | 0.6156 | 0.5838 | 0.4774 | 0.4208 | 0.4359 | 0.5052 |
| Maximum value | | 1.2581 | 1.2449 | 1.2336 | 1.2268 | 1.1652 | 1.2091 |
| Minimum value | | 0.2192 | 0.1784 | 0.1709 | 0.1776 | 0.1517 | 0.1827 |

②Regional innovation efficiency ( RIE ) measurement

Using Stata14.0 software to calculate the estimated value of each parameter and the p value, it can be seen from Table 5 that the gamma value is not 0, and the model is significant. Among them, the p value of 0.000 passed the 1% significance level, the corresponding p value of 0.027 passed the 5% significance level, and the corresponding p value of 0.046 passed the 5 % significance level.

Table 5 SFA regression coefficient and p value

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| parameter | | Coefficient | | Std.error. | | P>|z| | | [95% conf. | | interval] | |
|  | | 0.839591 | | 0.104305 | | 0.000 | | 0.635157 | | 1.044024 | |
|  | | 0.083849 | | 0.085489 | | 0.027 | | -0.08371 | | 0.251405 | |
|  | | 0.023688 | | 0.011849 | | 0.046 | | 0.000465 | | 0.046912 | |
| \_cons | | -0.92678 | | 0.569341 | | - | | -2.04267 | | 0.189107 | |
| mu | | 0.868774 | | 0.20658 | 0.104 | 0.463885 | | 1.273663 | |
| eta | | 0.084803 | | 0.012353 | 0 | 0.060592 | | 0.109014 | |
| lnsigma2 | | -2.26671 | | 0.155487 | 0 | -2.57146 | | -1.96196 | |
| lgtgamma | | -0.17639 | | 0.342967 | 0 | -0.84859 | | 0.495809 | |
| sigma2 | | 0.103653 | | 0.016117 | 0.607 | 0.076424 | | 0.140582 | |
| gamma | | 0.456016 | | 0.085078 | - | 0.299728 | | 0.621474 | |
| sigma\_u2 | | 0.047267 | | 0.015606 | - | 0.016681 | | 0.077854 | |

Using the stochastic frontier model to measure the regional innovation efficiency of 30 provinces and cities in China since 2010, the results are shown in table 6. This paper chooses the regional innovation efficiency of the next year after 2010 to analyze, and shows the mean, maximum and minimum values between each year and each province to analyze the regional innovation efficiency of China' s provinces since 2010 more comprehensively.

Table 6 Regional innovation efficiency of 30 provinces and cities in China since 2010

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Provinces | 2010 | 2012 | 2014 | 2016 | 2018 | 2020 | Mean |
| Beijing | 0.1949 | 0.2513 | 0.3116 | 0.3736 | 0.4356 | 0.4958 | 0.3438 |
| Tianjin | 0.1698 | 0.2237 | 0.2825 | 0.3439 | 0.4061 | 0.4673 | 0.3156 |
| Hebei | 0.0915 | 0.1327 | 0.1818 | 0.2371 | 0.2967 | 0.3586 | 0.2164 |
| Shanxi | 0.1541 | 0.2062 | 0.2637 | 0.3245 | 0.3867 | 0.4484 | 0.2973 |
| Inner Mongolia | 0.0411 | 0.0676 | 0.1028 | 0.1466 | 0.1977 | 0.2546 | 0.1351 |
| Liaoning | 0.2372 | 0.2967 | 0.3585 | 0.4205 | 0.4813 | 0.5393 | 0.3889 |
| Jilin | 0.1873 | 0.2431 | 0.3029 | 0.3649 | 0.4269 | 0.4874 | 0.3354 |
| Heilongjiang | 0.1049 | 0.1491 | 0.2005 | 0.2576 | 0.3182 | 0.3803 | 0.2351 |
| Shanghai | 0.1982 | 0.2550 | 0.3154 | 0.3775 | 0.4393 | 0.4994 | 0.3475 |
| Jiangsu | 0.1659 | 0.2194 | 0.2779 | 0.3392 | 0.4014 | 0.4628 | 0.3111 |
| Zhejiang | 0.2610 | 0.3217 | 0.3838 | 0.4455 | 0.5052 | 0.5619 | 0.4132 |
| Anhui | 0.1928 | 0.2491 | 0.3093 | 0.3713 | 0.4333 | 0.4936 | 0.3416 |
| Fujian | 0.2264 | 0.2852 | 0.3467 | 0.4089 | 0.4700 | 0.5286 | 0.3776 |
| Jiangxi | 0.0514 | 0.0816 | 0.1206 | 0.1676 | 0.2215 | 0.2801 | 0.1538 |
| Shandong | 0.2022 | 0.2592 | 0.3199 | 0.3820 | 0.4438 | 0.5036 | 0.3518 |
| Henan | 0.0995 | 0.1425 | 0.1930 | 0.2494 | 0.3096 | 0.3717 | 0.2276 |
| Hubei | 0.1515 | 0.2033 | 0.2605 | 0.3212 | 0.3834 | 0.4452 | 0.2942 |
| Hunan | 0.0768 | 0.1145 | 0.1605 | 0.2134 | 0.2715 | 0.3327 | 0.1949 |
| Guangdong | 0.2433 | 0.3031 | 0.3649 | 0.4269 | 0.4875 | 0.5452 | 0.3951 |
| Guangxi | 0.0812 | 0.1200 | 0.1670 | 0.2207 | 0.2793 | 0.3407 | 0.2015 |
| Hainan | 0.2646 | 0.3254 | 0.3875 | 0.4491 | 0.5087 | 0.5652 | 0.4168 |
| Chongqing | 0.0982 | 0.1409 | 0.1912 | 0.2475 | 0.3076 | 0.3697 | 0.2259 |
| Sichuan | 0.0731 | 0.1099 | 0.1550 | 0.2073 | 0.2649 | 0.3258 | 0.1893 |
| Guizhou | 0.0811 | 0.1199 | 0.1669 | 0.2206 | 0.2792 | 0.3406 | 0.2014 |
| Yunnan | 0.0713 | 0.1075 | 0.1522 | 0.2041 | 0.2614 | 0.3222 | 0.1865 |
| Shaanxi | 0.1124 | 0.1579 | 0.2105 | 0.2683 | 0.3294 | 0.3916 | 0.2450 |
| Gansu | 0.1539 | 0.2059 | 0.2634 | 0.3242 | 0.3864 | 0.4481 | 0.2970 |
| Qinghai | 0.1960 | 0.2526 | 0.3129 | 0.3750 | 0.4369 | 0.4971 | 0.3451 |
| Ningxia | 0.0864 | 0.1266 | 0.1746 | 0.2292 | 0.2883 | 0.3500 | 0.2092 |
| Xinjiang | 0.1683 | 0.2221 | 0.2807 | 0.3421 | 0.4043 | 0.4656 | 0.3139 |
| Mean value | 0.1479 | 0.1965 | 0.2506 | 0.3087 | 0.3687 | 0.4291 | 0.2836 |
| Maximum value | 0.2646 | 0.3254 | 0.3875 | 0.4491 | 0.5087 | 0.5652 | 0.4168 |
| Minimum value | 0.0411 | 0.0676 | 0.1028 | 0.1466 | 0.1977 | 0.2546 | 0.1351 |

Specific analysis is as follows: First, according to table 5, the output elasticity of R&D personnel and R&D external expenditure  is 0.8396, = 0.0237, indicating that the high-knowledge labor factor plays a major role in scientific and technological innovation, and China' s overall scientific and technological innovation activities are dominated by high-tech talents. The output elasticity of capital (R&D external expenditure) is 0.0237, indicating that patent output activities do not give full play to the role of capital, that is, there is capital redundancy.

Second, from the calculation results of regional innovation efficiency, the average level of overall regional innovation efficiency is low, only 0.2836, and the proportion of inefficiency factors is 0.7164. Considering the imbalance of innovation efficiency within each region, the gap of innovation ability within the region is large, and the regional innovation efficiency of each region is an indicator reflecting the overall internal space, so the overall regional efficiency level is low. On the whole, the efficiency level of regional innovation activities in various regions has gradually increased over time, and the maximum, minimum and mean values of regional innovation efficiency in each year have been increasing over time. The regional innovation efficiency of each region is quite different, among which Zhejiang Province has the highest regional innovation efficiency in 2020, up to 0.5652.The lowest level of innovation efficiency in Inner Mongolia is 0.0411 in 2010. From the horizontal point of view, the regional innovation efficiency of Zhejiang Province and Hainan Province is among the best, which is 0.4132 and 0.4168 respectively, while the regional innovation efficiency of Guizhou, Yunnan and Inner Mongolia in the western region is only about 0.20, which is at a very low level.

# 5.Empirical results analysis

**(1) Spatial autocorrelation test**

The Moran's index can represent the intrinsic spatial correlation attributes of the data, with a range of-1 to 1, greater than 0 indicates positive spatial autocorrelation, and less than 0 indicates negative spatial autocorrelation. The Moran 's index of China' s high-quality economic development level from 2011 to 2020 is shown in the following table.

From Table 7, it can be seen that the Moran's index of China's high-quality economic development in 2011-2020 is significantly positive, and all passed the significance test at the 1% level, indicating that China's high-quality economic development presents a significant spatial positive correlation in space, and the spatial econometric model is applied for analysis.

Table 7 Moran 's index of high-quality economic development in China from 2011 to 2020

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| year | I | E(I) | Sd(I) | Z | P-value |
| 2011 | 0.118 | -0.0345 | 0.0351 | 4.3434 | 0.0000 |
| 2012 | 0.1155 | -0.0345 | 0.0356 | 4.2189 | 0.0000 |
| 2013 | 0.0883 | -0.0345 | 0.0355 | 3.4612 | 0.0005 |
| 2014 | 0.1099 | -0.0345 | 0.0357 | 4.0418 | 0.0001 |
| 2015 | 0.101 | -0.0345 | 0.0352 | 3.8526 | 0.0001 |
| 2016 | 0.0661 | -0.0345 | 0.0354 | 2.8441 | 0.0045 |
| 2017 | 0.0668 | -0.0345 | 0.0343 | 2.9512 | 0.0032 |
| 2018 | 0.0748 | -0.0345 | 0.0345 | 3.1722 | 0.0015 |
| 2019 | 0.0771 | -0.0345 | 0.0344 | 3.2445 | 0.0012 |
| 2020 | 0.0927 | -0.0345 | 0.0350 | 3.6329 | 0.0003 |

**(2) Selection of spatial econometric model**

①LM and Hausman test

It can be seen from Table 8 that LM-Error, Robust LM-Error, LM-Lag, and Robust LM-Lag passed the significance test at the 1% and 5% levels. Therefore, this paper selects the spatial Durbin model for empirical analysis. Secondly, through the Hausman test, this paper finds that chi2 (5) = 28.71, Prob > = chi2 = 0.000, and the original hypothesis can be rejected at the 1% level. The Hausman test is significant, so this paper chooses the fixed effect model to continue the research.

Table 8 LM test and Hausman test

|  |  |  |
| --- | --- | --- |
| LM test | statistic | P value |
| LM-Error | 795.35 | 0.000 |
| Robust LM-Error | 583.54 | 0.000 |
| LM-Lag | 227.4 | 0.000 |
| Robust LM-Lag | 4.11 | 0.043 |
| Hausman test | 28.71 | 0.000 |

②LR and Wald test

Table 9 shows that the LR and Wald tests are significant at the 1% level, and the null hypothesis is rejected, that is, the SDM model cannot be converted to the SAR model, and the SDM model cannot be converted to the SEM model. Therefore, this paper will continue to use the SDM model for analysis and research.

Table 9 LR and Wald test

|  |  |  |
| --- | --- | --- |
| Null hypothesis | LR statistical value | Waldstatistical value |
| SDM model converted to SAR model | 26.87\*\*\*(0.0000) | 7.71\*\*\*(0.0055) |
| SDM model converted to SEM model | 28.11\*\*\*(0.0001) | 25.57\*\*\*(0.0000) |

**(3) Spatial SDM model analysis of R&D factor flow on high-quality economic development**

Based on the conclusion of the Hausman test, we use a fixed effect model based on the spatial Durbin model. Table 10 is the result of the spatial SDM model that studies the relationship between factor flow and high-quality economic development. In this study, (1) is a model without control variables and fixed effects; in (2), the control variable is added without considering the fixed effect; in Model (3), in addition to the introduction of control variables, the impact of time factors and urban personal factors on economic growth is also considered.

It can be seen from the estimation results that the spatial term coefficients have passed the significance test at the 1% level and are significantly positive, which indicates that other provinces can effectively promote the high-quality development of the province's economy. The first column shows that the regression coefficients of Inpf and Incf are both positive at a significant level of 5%, indicating that the flow of R&D personnel and the flow of R&D funds can effectively promote the high-quality development of the economy. In the second column, Inpf value and Incf value are positive significance and positive significance respectively.

Among the control variables, Ingov, Inopen, Inedu, Inpgdp and Ininvest all passed the significance test, and the coefficient was positive, indicating that government support, opening up, human capital, economic development level and regional investment level have a significant role in promoting high-quality economic development. In the third column, the fixed effects of time and city are added. From the regression results, it can be seen that the spatial interaction term W \* Inpf and W \* Incf coefficients are significant at the levels of 5% and 10%, respectively. This shows that the flow of R&D talents in other provinces has a certain impact on the high-quality economic development of the province, but it does not have a significant overall promotion effect. However, the study found that the significance of research capital flows has always been maintained at about 5%, which indicates that research capital flows have a significant role in promoting the high-quality development of China' s economy. The results show that the study of capital flow is more conducive to the high-quality development of regional economy than the flow of research and development personnel.

Table 10 Regression results of spatial SDM model of R&D factor flow on high-quality economic development

|  |  |  |  |
| --- | --- | --- | --- |
| model | (1) | (2) | (3) |
| Ingtfp | Ingtfp | Ingtfp |
| Inpf | 0.147\*\* | 0.00917\*\*\* | 1.717\*\* |
|  | (0.074) | (0.00338) | (0.819) |
| Incf | 1.449\*\* | 0.336\*\* | 2.760\*\*\* |
|  | (0.439) | (0.158) | (0.995) |
| Ingov |  | 0.0921\*\* | 0.0589\*\*\* |
|  |  | (0.0617) | (0.0218) |
| Inopen |  | 0.132\*\* | 0.0791\*\* |
|  |  | (0.0577) | (0.158) |
| Inedu |  | 0.422\*\*\* | 0.0525\*\* |
|  |  | (0.135) | (0.246) |
| Inpgdp |  | 0.00831\*\* | 0.0872\*\*\* |
|  |  | (0.0041) | (0.0321) |
| Ininvest |  | 0.0757\* | 0.0567\*\* |
|  |  | (0.0468) | (0.0288) |
| W\*Inpf | -0.356\*\*\* | -0.534\*\*\* | 1.269\* |
|  | (0.132) | (0.199) | (0.743) |
| W\*Incf | 0.419\*\* | 0.114\*\* | 0.167\*\* |
|  | (0.209) | (0.053) | (0.080) |
| Spatial rho | 0.486\*\* | 0.251\*\*\* | -0.623\*\*\* |
|  | (0.100) | (0.135) | (0.0974) |
| *R*2 | 0.419 | 0.576 | 0.502 |

Note: \* \* \* , \* \* and \* represent the significance level of 1%, 5% and 10% respectively, and the standard error is in parentheses, the same below.

**(4) Spatial spillover effect of R&D factor flow on high-quality economic development**

Table 11 shows that the spatial interaction coefficients of R&D flow and R&D flow are significant, but the estimated coefficients of SDM model cannot well reflect the impact of R&D factor flow on high-quality economic development. Therefore, it is necessary to analyze its direct effect, indirect effect and overall effect through spatial effect decomposition.

It can be seen from Table 8 that the direct and indirect effects of R&D personnel mobility are positive and pass the significance test at the 10% level, which indicates that R&D personnel mobility has a significant role in promoting the high-quality economic development of the province and other provinces. The flow of R&D personnel has promoted the technical exchanges between the region and its neighboring regions. The two sides actively carry out innovative cooperation projects and jointly improve the level of regional innovation. However, the direct and indirect effects of R&D capital have passed the significance test at the level of 10% and 1%, respectively. The significance of the direct effect is smaller than that of the indirect effect, indicating that the promotion effect of R&D capital flow on the high-quality economic development of the province is not obvious, but the promotion effect on the high-quality economic development of other surrounding provinces is better.R&D capital is profit-driven. The loss of R&D capital is irreversible for the province, which will reduce the regional innovation capital stock to a considerable extent and indirectly form resistance to high-quality economic development. In general, the flow of R&D personnel and the flow of R&D capital have a significant role in promoting the high-quality development of the economy in and outside the province, but the effect of R&D capital flow is greater than that of R&D personnel flow.

For the control variables, the direct effect of government support and human capital level is positive and significant, and the indirect effect is significantly negative, indicating that government support and human capital level can significantly promote the high-quality development of the province's economy, while for other provinces, it has a certain hindrance.

Table 11 Spatial effect decomposition

|  |  |  |  |
| --- | --- | --- | --- |
| Variables | direct effect | indirect effect | gross effect |
| Inpf | 0.188\* | 1.558\* | 1.916\*\* |
|  | (0.118) | (0.916) | (0.917) |
| Incf | 0.543\* | 1.960\*\*\* | 2.188\*\*\* |
|  | (0.302) | (0.728) | (0.831) |
| Ingov | 0.132\*\*\* | -0.453\* | 0.321\*\* |
|  | (0.0423) | (0.259) | (0.270) |
| Inopen | 0.0316\*\* | 0.0414\* | 0.0730\*\* |
|  | (0.0155) | (0.0259) | (0.0348) |
| Inedu | 0.294\*\* | -0.878\*\* | 0.584\*\* |
|  | (0.136) | (0.409) | (0.419) |
| Inpgdp | 0.207\*\* | 0.982\*\* | 1.190\*\*\* |
|  | (0.131) | (0.493) | (0.537) |
| Ininvest | 0.297\*\*\* | 0.702\*\* | 0.999\*\* |
|  | (0.0923) | (0.398) | (0.408) |

**(5) Mechanism test**

①Spatial regression analysis of mechanism black box

Through the above analysis, this paper argues that the inflow of R&D has a significant role in promoting the economic growth of the province and its neighboring areas. So, how does the flow of R&D factors promote the high-quality development of China's economy ? How does the mechanism black box work? Then, this paper will use SDM model and stepwise regression method to study the mechanism of R&D factor flow promoting high-quality economic development.

Table 12 R&D factor flow, regional innovation efficiency and high-quality development

|  |  |  |  |
| --- | --- | --- | --- |
| model | (1) | (2) | (3) |
|  | Inrie | Indtfp | Indtfp |
| Inpf | 0.0357\*\*\* |  | 0.275\*\* |
|  | (0.014) |  | (0.138) |
| Incf | 0.383\*\* |  | 0.240\*\* |
|  | (0.192) |  | (0.122) |
| Ingov | 0.0833\*\*\* | 0.0864\*\* | 0.104\*\*\* |
|  | (0.042) | (0.045) | (0.039) |
| Inopen | 0.0680\*\* | 0.0966\*\*\* | 0.0940\*\*\* |
|  | (0.034) | (0.048) | (0.0486) |
| Inedu | 0.621\*\*\* | 0.0407\*\* | 0.0677\* |
|  | (0.23) | (0.021) | (0.053) |
| Inpgdp | 0.0389 | 0.195\*\* | 0.214\* |
|  | (0.36) | (0.072) | (0.175) |
| Ininvest | 0.402\*\*\* | 0.676\*\*\* | 0.651\*\*\* |
|  | (0.152) | (0.26) | (0.252) |
| InRIE |  | 0.00517\*\* |  |
|  |  | (0.003) |  |
| *R*2 | 0.525 | 0.584 | 0.586 |

Table 12 Model (1) is a regression model about the flow of R&D factors to promote regional innovation efficiency. The coefficients of R&D personnel flow and R&D capital flow are 0.0357 and 0.383 respectively, reaching the significance of 1% and 5% respectively. The results show that the inflow of R&D elements has a significant effect on the improvement of regional innovation efficiency. The second column is the high-quality economic growth model with innovation efficiency as the main driving force in various regions of China. The analysis results show that the technological innovation efficiency of each region in China has reached a significant level. Therefore, improving regional innovation efficiency is of great significance to high-quality economic development. Model ( 3 ) is a regression model of R&D factor flow for high-quality economic development. From the regression results, it can be seen that both R&D personnel and R&D capital flow are significant at the 5% level and the coefficient is positive, indicating that R&D factor flow can significantly promote high-quality economic development.

②Mediation effect test

This paper continues to verify whether regional innovation efficiency plays an intermediary role between R&D factor flow and high-quality economic development. The intermediary effect test procedures are as follows:

|  |  |  |
| --- | --- | --- |
|  | | （1） |
|  | （2） | |
|  | （3） | |

The mediating variable is the regional innovation efficiency (RIE), while the other variables are consistent with those mentioned earlier. Since R&D factors are divided into R&D personnel and R&D capital, this study will examine these two aspects separately.

Model (1) reflects the overall effect of high-quality R&D economic development, where coefficient  represents the total effect. In model (2), coefficient  indicates the impact of R&D factor mobility on regional innovation efficiency. In model (3), coefficient  reflects the direct effect of R&D factor mobility on high-quality economic development, and the product of coefficients  and  in model (2), denoted as, represents the mediating effect of regional innovation efficiency. The regression results show that R&D factor mobility can promote high-quality economic development by continuously enhancing regional innovation efficiency. The absolute value of the expected regression coefficient  is less than that of , indicating that regional innovation efficiency plays a mediating role in the promotion of high-quality economic development through R&D factor mobility.

Table 13 R&D personnel flow, regional innovation efficiency and high-quality development

|  |  |  |  |
| --- | --- | --- | --- |
| model | (1) | (2) | (3) |
|  | Indtfp | Inrif | Indtfp |
| Inpf\* | 2.550\*\*\* | 2.422\*\* | 1.730\* |
|  | (0.91) | (0.91) | (0.31) |
| Inrif | - | - | 0.326\*\*\* |
|  | - | - | (0.126) |
| Ingov | 0.0349\*\* | 0.143\*\*\* | 0.00590\* |
|  | (0.016) | (0.057) | (0.004) |
| Inopen | 0.0929\* | 0.122\*\* | 0.0644 |
|  | (0.073) | (0.053) | (0.36) |
| Inedu | 0.310\*\* | 0.0675\* | 0.183\* |
|  | (0.147) | (0.051) | (0.121) |
| Inpgdp | 0.00647\* | 0.0653\*\* | 0.0120\*\* |
|  | (0.005) | (0.033) | (0.064) |
| *R*2 | 0.844 | 0.976 | 0.847 |

According to the procedure of intermediary test, the results of this paper are as shown in the table. The test results in the first column of Table 13 show that the flow of R&D personnel can significantly promote the high-quality development of the economy at the 5% significance level. In the second column, the intermediary variable regional innovation efficiency is added to the regression of model (2). The results show that the flow of R&D personnel can significantly improve the efficiency of regional innovation. In the table, it is significant at the level of 5% and 1%, respectively, indicating that regional innovation efficiency is significant as a mediating variable. At the same time, the coefficient of R&D personnel flow is still significant at the level of 10%, indicating that regional innovation efficiency plays a partial intermediary role. Regional innovation efficiency is the way mechanism for R&D personnel mobility to promote high-quality economic development, and the mediating effect accounts for 31.42% of the total effect.

Next is the intermediary test of R&D capital for high-quality economic development, which is consistent with the above. The first column test results of table 14 show that at a significant level of 5%, R&D capital flows can significantly promote the high-quality development of the economy. In the table, both are significant at the level of 5%, indicating that regional innovation efficiency is significant as an intermediary variable between the two. The coefficient of R&D personnel flow is significant at the level of 10%, indicating that regional innovation efficiency plays a partial mediating role. Regional innovation efficiency is a channel for R&D capital flows to promote high-quality economic development, and the mediating effect accounts for 19.36% of the total effect.

Table 14 R&D capital flow, regional innovation efficiency and high-quality development

|  |  |  |  |
| --- | --- | --- | --- |
| model | (1) | (2) | (3) |
|  | Indtfp | Inrif | Indtfp |
| Inpf\* | 2.107\*\* | 1.338\*\* | 2.086\*\* |
|  | (0.98) | (0.78) | (0.99) |
| Inrif | - | - | 0.305\*\* |
|  | - | - | (0.14) |
| Ingov | -0.0383\*\* | 0.137\*\*\* | -0.00540\*\*\* |
|  | (0.0197) | (0.06) | (0.0014) |
| Inopen | -0.0963\*\* | 0.111\* | -0.0794\*\* |
|  | (0.049) | (0.95) | (0.045) |
| Inedu | 0.155\* | 0.110\* | 0.0126\* |
|  | (0.11) | (0.068) | (0.009) |
| Inpgdp | -0.164\*\* | 0.101\*\*\* | -0.156\*\* |
|  | (0.84) | (0.38) | (0.76) |
| *R*2 | 0.847 | 0.976 | 0.850 |

**(6) Regional heterogeneity analysis**

Considering the differences in economic development and innovation ability in different regions, this paper will analyze the impact of R&D factor flow on high-quality economic development in China's three major regions from the perspective of decomposition effect.

Table 15 Decomposition results of SDM effect under different regions

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Region | R&D personnel flow | | | R&D capital flow | | |
| Eastern region | Mid region | Western region | Eastern region | Mid region | Western region |
| direct effect | 0.614 | 0.0305 | 0.110\*\* | 1.786\*\*\* | -0.0274 | 0.227\*\*\* |
| (0.982) | (0.123) | (0.057) | (0.692) | (0.115) | (0.089) |
| indirect effect | 0.315\* | 0.289 | 0.748 | 2.500\*\* | 0.468\*\*\* | 1.558\*\* |
| (0.199) | (0.223) | (1.550) | (0.989) | (0.189) | (0.552) |
| gross effect | 0.699\*\* | 0.320 | 0.538\* | 0.914\*\*\* | 0.496\*\*\* | 1.786\*\*\* |
| (0.358) | (0.200) | (0.325) | (0.371) | (0.196) | (0.566) |

It can be seen from Table 15 that the effect of R&D personnel flow on high-quality economic development shows an unbalanced trend, that is, the total effect of the eastern, central and western regions is quite different, and the total effect of the eastern region is the largest. The direct effect of the western region is significantly positive. The flow of R&D personnel in the western region plays an important positive contribution to the high-quality development of the economy, which reflects the western development strategy advocated by the state and the policy of encouraging the flow of talents to the western region.

Secondly, from the perspective of indirect effects, only the indirect effects of the eastern region are significant and positive, indicating that the current eastern region has a strong talent attraction and is consistent with the strategy of 'giving priority to the development of the eastern region'. At the same time, the eastern region also shows a strong talent spillover effect, thus driving the development of the central and western regions. Horizontally, the direct effect, indirect effect and total effect of the central region are not significant, which indicates that the flow of R&D personnel in the central region contributes less to the high-quality economic development of the region, while for the eastern and western regions, the inflow of talents in the central region will significantly promote the high-quality economic development of the eastern and western regions.At the same time, for the central region, it is necessary to strengthen the attraction of talents and adopt policies to attract talents to guide the inflow of R&D talents, so as to realize the high-quality development of its own economy and the high-quality development of the economy as a whole.

In the total effect of R&D capital flow, the three regions showed a strong significant level. Specifically, the total effect of R&D capital flow in the western region ranks first. On the whole, the three major effects of the eastern, central and western regions are significant at different levels, and the coefficient is positive, which indicates that the R&D capital flows in the eastern, central and western regions have a significant role in promoting high-quality economic development. R&D capital flows promote regional technological innovation, and also promote the exchange of knowledge and information through the radiation effect. Objectively, it also improves the technological innovation capability of the surrounding areas, and also greatly promotes technological cooperation and innovation activities among enterprises, thus promoting the high-quality development of the economy as a whole. However, the direct effect of the central region is significantly negative. Considering the profitability of capital, we speculate that the R&D capital in the central region flows to the eastern and western regions in a large scale. Therefore, the R&D capital flow in the central region shows a negative hindering effect, hindering the high-quality development of the regional economy.

# 6.Conclusions and recommendations

**(1) Research conclusion**

Based on the panel data of 30 provinces ( except Tibet ) in China from 2010 to 2020, this paper uses the SDM model to empirically study the impact of R&D factor flow on high-quality economic development, and on this basis, carries out expansion analysis and draws the following conclusions.

The flow of R&D factors has a significant role in promoting high-quality economic development. Opening up, human capital, economic development level and regional investment level have a significant role in promoting high-quality economic development. R&D personnel flow has a significant positive impact on the high-quality economic development of the region and its neighboring regions. R&D capital flow has no obvious effect on the high-quality economic development of the region, but has a significant effect on the high-quality economic development of neighboring provinces. R&D factor flow can effectively improve regional innovation efficiency, and regional innovation efficiency can effectively promote high-quality economic development, among which regional innovation efficiency is significant as a mediating variable. There is regional heterogeneity in the impact of R&D factor flow on high-quality economic development.. There is a certain gap between the three effects of R&D factor flow on high-quality economic development. At the total effect level, the effect of R&D personnel flow in the eastern region is the largest, while the effect of R&D capital flow in the western region is the largest.

**(2) Policy recommendations**

①Releasing the vitality of R&D elements and promoting the efficiency of regional innovation

For other developing countries, we must first strengthen inter-regional transportation, communications and other infrastructure construction. This is like building a ' bridge ' for the flow of factors. For example, in some countries in Southeast Asia, investment in ports, railways and transnational communication networks can be increased to make it easier for talents, technology and capital to flow between countries in the region. For example, Thailand and Malaysia can promote the exchange of scientific research personnel and share resources such as scientific research equipment by improving the traffic connection in the border areas.

In terms of talent policy, other developing countries can learn to develop flexible immigration and visa policies. Taking India as an example, for foreign talents with expertise in key areas such as information technology, it can provide long-term visas and convenient residence permit processing procedures to attract global talent gathering. At the same time, it can also create conditions for the flow of domestic talents to neighboring developing countries and achieve the optimal allocation of regional talents.

Developing countries should increase financial investment and policy support for science and technology research and development. For example, Brazil can set up a special science and technology innovation fund to finance cutting-edge technology research carried out by domestic enterprises and research institutions. At the same time, through tax incentives and other ways, enterprises are encouraged to transform R & D results into actual products. For example, for Brazilian enterprises that have successfully developed and industrialized new energy vehicle battery technology, preferential policies such as corporate income tax reductions and exemptions are given to improve the innovation enthusiasm of enterprises.

In terms of intellectual property protection, other developing countries should strengthen the construction of laws and regulations. Taking South Africa as an example, improve the registration and protection system of intellectual property rights such as patents and trademarks, and provide legal protection for innovation activities. At the same time, we should actively participate in international intellectual property cooperation, so that our scientific and technological achievements can be effectively protected and rationally utilized in the international market, and promote the transnational transformation of scientific and technological achievements.

②Improve the policy system and guide the cross-regional flow of R&D factors.

In areas where developing countries are concentrated, such as Africa, a regional scientific research talent exchange platform can be established. For example, in the East African Community countries ( Kenya, Uganda, Tanzania, etc. ), national scientific research institutions can share scientific research personnel information on the platform, and realize the co-construction and sharing of talents through joint research projects, academic exchange activities, etc. This can give full play to the advantages of scientific research talents in various countries and avoid the waste of human resources.

Developing countries can also jointly establish talent training bases. For example, Argentina, Chile and other countries in South America can jointly establish training centers in the field of agricultural science to train agricultural science and technology talents for countries. These talents can flow freely between countries in the region and provide intellectual support for agricultural science and technology innovation in various countries. Developing countries should improve the financial market system and attract international R & D capital. For example, Vietnam can attract foreign venture capital institutions by establishing international financial cooperation parks. At the same time, the establishment of financial regulatory agencies to monitor and regulate capital flows. Such as the establishment of a special financial monitoring group, to track the flow of capital into the field of research and development, to prevent the unreasonable flow of capital, to ensure that funds for real scientific and technological innovation projects.

③Adopt regional differentiation policies to achieve high-quality economic development as a whole.

For resource-based developing countries, such as Nigeria ( rich in oil resources ), they should use their own resource advantages to increase investment in R & D of resource deep processing technology. At the same time, through policy guidance, the R & D elements of resource industries are transferred to non-resource industries to promote the diversification of economic structure. For example, using the funds accumulated by the petroleum industry to support local research and development of new chemical materials, attract relevant talents and capital, and gradually transform into a high value-added chemical product manufacturing industry.

In Central Asia, Kazakhstan and other countries can strengthen R & D cooperation with neighboring countries such as China and Russia. Kazakhstan can use its advantages in the field of mineral resources and energy to carry out joint R & D projects with China and Russia in the development of new energy and the efficient use of mineral resources. At the same time, in regional cooperation, through the establishment of a reasonable benefit distribution mechanism, the rational flow of R & D elements between different countries and regions is promoted, and the high-quality development of regional economy is realized.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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