The Nonlinear Characteristics and Spatial Differentiation of the Impact of Bidirectional FDI Collaboration on Digital Divide Bridging

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Abstract

It is of great significance to evaluate and study the spatial dynamic evolution characteristics of the impact of bidirectional FDI collaboration on the bridging of the digital divide under the pattern of high-quality trade openness, which is of great significance for the construction of Chinese-style modern institutional opening-up. Based on the inter-provincial data in China from 2008 to 2020, this paper constructs a threshold panel model, empirically testing the nonlinear relationship between the bidirectional FDI collaboration and the digital divide bridging and discussing multiple heterogeneity and spatial spillover characteristics of the effect at the level of different economic factors according to the nature of the digital divide, and further intuitively describes the dynamic evolution characteristics of bidirectional FDI collaboration and digital divide bridging under the spatial pattern from a comprehensive perspective by the TSA, map classification and SDE analysis. The results show as follows: (1) there is a direct positive effect of the bidirectional FDI collaboration on the digital divide bridging, and this effect has triple heterogeneity at the level of three different economic factors: economic structure, urbanization level and human capital; (2) the effect is a single threshold effect, showing the nonlinear evolution characteristics of increasing marginal efficiency;(3) the effect shows “high-high” agglomeration in the eastern China and “low-low” in the western China. This conclusion should be helpful to further stimulate the endogenous potential of domestic factor allocation, promote the effective bridging of the digital divide between regions, broaden the breadth and depth of the development of the digital economy with bidirectional FDI, and seek the digital empowerment demonstration effect of the new development pattern under the condition of high-quality trade opening.

Keywords: bidirectional FDI collaboration; digital divide bridging; panel threshold model; spatial lag model.

1.0 Introduction

As an important channel for international knowledge spillover and technology spillover, the coordinated development of bidirectional FDI is conducive to the acquisition of technical resources and the optimal allocation of funds in the global market, which is the core of China's implementation of the two-wheel drive strategy of “bringing in” and “going out”, and an important foundation for China's “secondary transformation” process of building an all-round opening pattern. It is an important means for China to adjust the internal and external imbalances in the economy and better adapt to the new economic development pattern, and accumulate momentum for development in promoting high-level opening up, leading institutional opening up and promoting unimpeded double cycles.

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The inherent advantages and essential characteristics of digital economy, such as cross-time information dissemination, data creation and sharing, and significantly reducing transaction costs, provide important support for the upgrading of China's industrial structure and the enhancement of innovation activity. However, the unbalanced development of digital economy and digital infrastructure construction has derived the existence of digital divide, which is more obvious in areas such as region, urban and rural areas, age and gender. The development of digital economy will bring about changes in investment methods or investment content, while the existence of digital divide will hinder this benign change and the digital dividend it brings, excluding some social groups with information disadvantage (such as low education or the elderly). Therefore, it is necessary to actively guide the orderly and reasonable flow of bidirectional FDI to broaden financing channels. We will assist in the implementation of projects to improve and upgrade basic networks in backward or underdeveloped areas, narrow the digital divide between regions, urban and rural areas, age and gender, and make the fruits of development more equitably benefit all people and achieve common prosperity in the process of Chinese-style modernization. Therefore, the study of the nonlinear characteristics and spatiotemporal dynamic evolution path of the influence of bidirectional FDI cooperation on the bridging of the digital divide has important strategic significance for promoting the balanced development of digital intelligence between regions in China, promoting the digital economy as a whole, accelerating the construction of domestic industrial circulation, and promoting the new development pattern of domestic and international double circulation.

2.0 Literature review

2.1 Relevant researches on bidirectional FDI

In an open environment, the IFDI (Foreign direct Investment) system and OFDI (foreign direct investment) system are often in an unbalanced state at the initial stage due to the interaction of economy, resources, finance and other factors. The coordinated development of the two systems can be regarded as the transformation process of the bidirectional FDI complex system from the unbalanced state to the balanced state. Since then, studies on the effect of bidirectional FDI have increased, mainly focusing on the measurement of bidirectional FDI, interaction effect, and influencing factors.

2.2 Relevant researches on digital divide

The concept of digital divide was first proposed in the 1990s to explain the difference between using computers and not using the Internet. Since 2002, its connotation has been further expanded, and the concept of the first digital divide [†]and the second digital divide [‡]have appeared. Later, a third digital divide emerged as a result of the beneficial consequences of Internet use and the inequalities it engenders. The digital divide can often be defined as “the gap between individuals, households, businesses and geographical areas at different socioeconomic levels in terms of access to information and communication technologies and access to and use of the Internet for various activities”. The digital divide is a complex phenomenon, which is influenced by many different factors: education, income, gender, age and infrastructure are important factors that form the digital divide. There is also evidence that geography plays an important role in the digital divide.

[†] The first digital divide refers to differences in access to ICT.
[‡] The second digital divide refers to differences in the way ICT is used and so on.

2.3 Related researches on the impact of bidirectional FDI cooperation on the bridging of digital divide

Generally, international technology spillovers can be divided into three types: trade openness, foreign direct investment (OFDI) and foreign direct investment (IFDI). At present, the research on technology spillover mechanism of trade openness and IFDI has been relatively mature. In recent years, due to poor trade, domestic market saturation and the “Belt and Road” initiative, the research enthusiasm of OFDI has been promoted, but the reverse technology spillover mechanism of OFDI has not yet reached a definite conclusion. Therefore, the technology spillover mechanism of two-way FDI cooperation also has uncertainties, thus affecting the effective bridging of the digital divide. The relevant researches can be divided into “pessimistic theory” and “optimistic theory”. The pessimistic view is that OFDI does not necessarily improve the total factor productivity of the home country and promote the bridging of the digital divide. There are two possible reasons: one is related to investment motivation. Resource-seeking OFDI and market-seeking OFDI mainly involve enterprises acquiring scarce resources or expanding the market in the host country for the home country, which has no substantial impact on the improvement of total factor productivity and the bridging of the digital divide. Only technology-seeking OFDI has a certain degree of reverse technology spillover effect on the home country. Second, it is related to the absorption capacity of the home country. The reverse technology spillover effect of OFDI depends on the absorption capacity of the home country to the reverse technology spillover of the host country. When the absorption capacity is less than a certain threshold value, the reverse technology spillover effect of OFDI is not significant. The “optimistic theory” holds that the reverse technology spillover effect of OFDI can promote the improvement of the total factor productivity of the home country and effectively bridge the digital divide. There are also two possible reasons: one is the “talent positive feedback effect”. Through OFDI, the home country sets up enterprises in the host country, participates in the local human capital market, and attracts local excellent technical talents. Thus, the higher talent and technical level of the host country inversely promotes the technological progress of the home country, which is conducive to the bridging of the digital divide in the home country. The second is “demonstration effect”. When OFDI is conducted on the host country, the home country will give full play to the learning effect and demonstration effect of enterprises, complete the learning, imitation and absorption of high-end technologies of the host country in the cooperation, acquire new technologies and new knowledge, and make enterprises closer to the high-quality resources and core technologies of the host country.

Existing studies have not reached a consensus. Two possible reasons are found after reviewing the literature: First, is it reasonable to describe the reverse technology spillover mechanism of OFDI with linear features? The technology spillover of FDI shows a nonlinear relationship and exists threshold effect. Therefore, it is necessary to further test whether bidirectional FDI cooperation also exists threshold effect. Second, the possibility of reverse technology spillover or spatial correlation effect is ignored. In fact, technological spillover and technological innovation are spatially correlated between provinces in China. Therefore, whether the technological spillover of bidirectional FDI cooperation also has spatial spillover effect needs to be discussed. To sum up, the possible marginal contribution of this paper is mainly reflected in the following two aspects:

(1) Taking bidirectional FDI collaboration as the threshold variable, the relationship between bidirectional FDI collaboration and digital divide bridging is correctly clarified, and its nonlinear characteristics as the threshold variable are described, which enriches the

technological spillover mechanism of bidirectional FDI collaboration; At the same time, according to the nature of the digital divide, the sample regions are divided by three economic factors, namely, the level of economic development, the level of urbanization and the level of human resource capital, and the heterogeneity of the effect of bidirectional FDI cooperation on the bridging of the digital divide at the above three levels is explored, which is conducive to further releasing the coordinated development dividend of bidirectional FDI and alleviating the impact of the “triple pressure”. Build a high-quality liberalized domestic and foreign trade network, and promote the effective transformation of the positive feedback effect of bidirectional FDI cooperation and digital gap bridging.

(2) Fully consider the spatial correlation of technology spillovers between provinces and regions, use the spatial lag model to verify and analyze the spatial spillover effect of bidirectional FDI cooperation on digital divide bridging, and provide a theoretical basis for implementing feasible policy paths; Further using the new economic geography to conduct standard deviation ellipse analysis to better identify the differential change trend and spatial dynamic evolution path among provinces and regions, it is helpful to break the inter-regional barriers, adapt to local conditions, rationally allocate resources, seek balanced inter-regional development, and realize the mutual promotion and resilience linkage of domestic and international double cycles in building a new development pattern. It will provide new driving forces for the development of China's modern institutional opening-up.

3.0 Research design

3.1. Model construction

3.1.1. Basic regression model

In order to test the effect of bidirectional FDI collaboration on digital divide bridging and the effect of bidirectional FDI collaboration as the threshold variable and trade openness as the regulating variable on digital divide bridging, this paper first sets the basic measurement model as follows:

$$DDI_{it} = \alpha_0 + \beta_1 IDFDI_{it} + \beta_2 GDP_{it} + \beta_3 SGDP_{it} + \beta_4 CCE_{it} + \beta_5 HC_{it} + \beta_6 FE_{it} + \varepsilon_{it} \quad (1)$$

In order to prevent the empirical results from being affected by heteroskedasticity, the variables in the model are logarithmized and model (2) is obtained:

$$lnDDI_{it} = \alpha_0 + \beta_1 lnIDFDI_{it} + \beta_2 lnGDP_{it} + \beta_3 lnSGDP_{it} + \beta_4 lnCCE_{it} + \beta_5 lnHC_{it} + \beta_6 lnFE_{it} + \varepsilon_{it} \quad (2)$$

3.1.2. Threshold model

As China's bidirectional FDI cooperation capability is constantly improving, it is speculated that there may be a threshold relationship between the impact of bidirectional FDI cooperation on digital divide bridging. In order to explore whether this threshold relationship exists, the panel threshold model proposed by Hansen is used for reference, and the following single threshold regression model is established with the bidirectional FDI cooperation of each province as the threshold variable:

$$lnDDI_{it} = \alpha_0 + \beta_1 lnIDFDI_{it} * I(lnIDFDI_{it} \le c) + \beta_2 lnIDFDI_{it} * I(lnIDFDI_{it} > c) + \beta_3 lnGDP_{it} + \beta_4 lnSGDP_{it} + \beta_5 lnCCE_{it} + \beta_6 lnHC_{it} + \beta_7 lnFE_{it} + \varepsilon \quad (3)$$

3.1.3. Spatial econometric model

In this paper, a binary adjacency space weight matrix **W** is established, following the Rook adjacency rule, that is, if two regions have a common boundary, they are regarded as adjacency. The specific weight element value W_{ij} is set as follows: the main diagonal element is 0; If provinces i and j are adjacent, $W_{ij} = 1$; If provinces i and j are not adjacent, $W_{ij} = 0$. Before the empirical test, the constructed adjacency matrix was normalized. Refer to the judgment method of static spatial panel metrology model category: The LM (Lagrange multiplier) test is carried out on the basis of the model that does not consider spatial factors when applying OLS. If only one of the two statistics of LM-LAG (Lagrange multiplier of spatial LAG model) and LM-ERR (Lagrange multiplier of spatial error model) is significant, the model corresponding to the statistical significance is selected. If both LM-LAG and LM-ERR statistics are significant, their Robust forms should be observed. If robust LM-LAG (robust Lagrange multiplier of spatial lag model) is statistically more significant than Robust-LM-ERR (robust Lagrange multiplier of spatial error model), SLM (spatial lag model) is considered to be a more suitable model, on the contrary, if Robust-LM-ERR is more significant, SEM (spatial error model) is considered to be a better model. Table 1 shows the LM test results, which show that the test results of the spatial lag model and the spatial error model are statistically significant, but the robustness test of the spatial lag model is significant, while the spatial error model is not. Therefore, this paper constructs a spatial lag model in which bidirectional FDI cooperation affects the bridging of the digital divide (see equation (4)), and studies the spatial dynamic evolution of the two.

Table 1: Results of LM test and R-LM test

	Spatial Error Model (SEM)			Spatial Lag Model (SLM)	
	Moran's I	Lagrange multiplier	Robust Lagrange multiplier	Lagrange multiplier	Robust Lagrange multiplier
statistic	2.012^{**}	60.702^{***}	2.533	119.681^{***}	61.512^{***}
P	0.044	0.000	0.111	0.000	0.000

Note: ***, **, * indicates significant at the level of 1%, 5%, 10%.

$$lnDDI_{it} = \alpha_0 + \beta_1 lnIDFDI_{it} + \beta_2 lnGDP_{it} + \beta_3 lnSGDP_{it} + \beta_4 lnCCE_{it} + \beta_5 lnHC_{it} + \beta_6 lnFE_{it} + \rho \sum_j W_{ij}\, lnDDI_{it} + \varepsilon_{it} \quad (4)$$

In model (1) - model (4), α and β are the coefficients respectively, *i* represents the province and *t* represents the year. $\ln DDI_{it}$ is the explained variable *digital divide*, indicating the bridging level of digital divide in *i* province in *t* year; $\ln IDFDI_{it}$ is the explanatory variable, indicating the level of bidirectional FDI cooperation of Province i in *t* year. $\ln GDP_{it}$, $\ln SGDP_{it}$, $\ln CCE_{it}$, $\ln HC_{it}$, $\ln FE_{it}$ are all control variables in the model, respectively representing the economic development level, tertiary industry development level, information and communication capability, human capital and financial efficiency of Province i in *t* year. $\sum_j W_{ij}\, lnDDI_{it}$ is the spatial lag variable. W_{ij} is the element value of the binary adjacency space weight matrix; ρ represents the spatial autoregressive coefficient. When $\rho>0$, the explanatory variable of the adjacent region has a significant positive spillover effect on the explained variable of the local region. When $\rho<0$, there is a significant negative spillover effect on the explanatory variables in the adjacent region. ε is the random disturbance term.

3.2. Variable selection and measurement

3.2.1. The explanatory variable

Bidirectional FDI cooperation ($\ln IDFDI_{\mathrm{it}}$). It uses the coupled system model to measure the coordinated development level of bidirectional FDI, and the coupling degree formula is calculated as follows:

$$C_{it}(IO) = \frac{IFDI_{it} * OFDI_{it}}{(\alpha IFDI_{it} * \beta OFDI_{it})^{\gamma}} \quad (5)$$

Where: Taking into account the high volatility of OFDI flows among Chinese provinces, $IFDI_{\mathrm{it}}$ is the actual utilization amount of OFDI of *i* province in *t* year, and $OFDI_{\mathrm{it}}$ is the stock of non-financial OFDI. The data are obtained from China Statistical Yearbook and China Statistical Bulletin of OFDI. In order to eliminate the impact of different dimensions, frequency conversion and unit conversion were performed on the data before calculation, and the average annual price of RMB exchange rate was used to convert the US dollar data into RMB, and all of them were converted into data in tens of thousands. α and β represent the weights of IFDI and OFDI respectively, and both α and β are set to 0.5; γ is the adjustment coefficient, set to 2; According to the coupling degree formula, the coupled coordinated development index is further introduced. The formula for calculating the coordinated development level of bidirectional FDI is as follows:

$$IDFDI_{it} = D_{it}(IO) = \left[C_{it}(IO) * \frac{IFDI_{it} + OFDI_{it}}{2}\right]^{\frac{1}{2}} = \left[\frac{IFDI_{it} * OFDI_{it}}{(IFDI_{it} + OFDI_{it})/2}\right]^{\frac{1}{2}} \quad (6)$$

3.2.2. The explained variable

Digital divide ($\ln DDI_{\mathrm{it}}$). The problem of digital divide is not only a simple problem of information wealth, but a comprehensive reflection of a series of factors. Therefore, this paper constructs a comprehensive evaluation system composed of three criterion layers and seven indicator layers (Table 2), and adopts principal component analysis (PCA) to measure quantitative indicators. All indicator data comes from China Statistical Yearbook, Ministry of Industry and Information Technology, National Bureau of Statistics and WIND Financial Database.

Table 2: Index system of digital divide measurement

Target layer	Criteria layer	Indicator layer	Unit
Digital divide	Digital life	Mobile phone penetration	Percentage(%)
		Number of mobile phone subscribers	Ten thousand households
		Telecommunication traffic	100 million yuan
	Digital facilities	Number of websites	number
		Broadband access users	Ten thousand households
	Digital capability	Absorbed technology transaction amount	100 million yuan
		Information transmission, computer services, software industry social fixed assets investment	100 million yuan

Using principal component analysis to conduct information concentration research, first it analyzes whether the research data is suitable for principal component analysis. If the KMO value is higher than 0.8, it is suitable for analysis. If the value is between 0.7 and 0.8, it is suitable for analysis. If the value is between 0.6 and 0.7, the analysis can be performed. If this value is less than 0.6, it is not suitable for analysis. After testing, the KMO value of each index in the principal component analysis of 30 provinces is greater than 0.6, and the range is [0.608, 0.828], and most of them hover between 0.7 and 0.75. In addition, all P values are 0.00, meeting the requirements of Bartlett's sphericity test ($p<0.05$) and the prerequisite requirements of principal component analysis, which means that the index data can be used for principal component analysis research and the analysis results have good reliability. The measured digital divide bridging data is relative data. The larger the value, the higher the level of digital divide bridging in the province, and the smaller the existing digital divide.

3.2.3. Control variables

Economic development level ($\ln GDP_{\mathrm{it}}$), expressed by the gross regional product (GDP) of each province. The higher the GDP of a region, the higher the level of economic development, the more sufficient market space can be provided to help foreign investors obtain more profits, the more attractive it will be to foreign enterprises, and the greater the possibility of providing financial support for foreign investment and expanding the scale of foreign direct investment.

The tertiary industry development level ($\ln SGDP_{\mathrm{it}}$), represented by the tertiary industry GDP of each province. When the demand side of China's inward-looking economy is weak and the traditional industry is in the process of transformation, the external investment demand presented by the international social and economic development has become a new driving force for China's capital export and boosting the export-oriented economy. Among them, the rapid growth of FDI in the tertiary industry has become a new bright spot in the development of export-oriented economy, and the position of FDI has become increasingly important.

Information and communication capacity ($\ln CCE_{\mathrm{it}}$), depicted by provincial communications expenditure per capita. The higher the per capita communication expenditure, the more convenient the external digital connections of the province, the closer the foreign economic exchanges, the lower the cost of traditional communication facilities, the better to promote foreign investment and attract foreign investment simultaneously.

Human capital ($\ln HC_{\mathrm{it}}$), measured by the number of students enrolled in higher education institutions in each province. College students affect the level of higher education, and the more talents with higher education, the more conducive to improving the absorption capacity and innovation ability of enterprises. Therefore, foreign-funded enterprises are more inclined to outsource business activities and enjoy the dividend radiation of “talent flow effect” and “talent accumulation effect”, so as to promote a large number of new enterprises to enter and carry out a new round of investment activities. We will raise the utilization rate and efficiency of investment.

Financial efficiency ($\ln FE_{\mathrm{it}}$), described as the ratio of deposit balances to loan balances in each province. The higher the efficiency of financial market, the higher the efficiency of social resource allocation, the greater the promotion of investment to industry, the promotion of industrial structure transformation and upgrading, and the improvement of technological progress and total factor productivity.

3.3. Data source and data processing

According to the principle of data availability and operability, it selects panel data of 30 provinces, autonomous regions and municipalities in China from 2008 to 2020 for empirical test and analysis. The data used in this paper are all from China Statistical Yearbook, National Bureau of Statistics, People's Bank of China, Ministry of Industry and Information Technology, Provincial Statistics Bureaus and WIND Financial Database. In order to eliminate the impact of different dimensions, unit conversion and frequency conversion processing are carried out for data with different dimensions and frequencies. Before logarithmic processing of each variable, in order to ensure that all logarithms after processing are meaningful, coordinate translation in unit 1 is carried out for values less than 1. For the individual missing data in the index, linear interpolation method of panel data is used for linear interpolation.

4.0 Empirical analysis

4.1. Threshold effect analysis

4.1.1. Threshold effect test and threshold value determination

The panel threshold regression model is constructed. Firstly, whether threshold effect exists is considered. If so, the number of thresholds and the corresponding threshold value need to be further clarified. Based on this, threshold regression bootleg sampling method was adopted to test the significance of the bidirectional FDI collaborative threshold effect by sampling 500 times under the assumptions of single threshold, double threshold and triple threshold. The results are shown in Table 3: For bidirectional FDI cooperation, only the single threshold effect passed the significance test at the 5% level, while the double threshold and triple threshold effect did not pass the test. Based on Hansen theory, bidirectional FDI collaboration has a single threshold effect on digital divide bridging, and its threshold value is 0.6376, and the confidence interval at the 90% level is [0.6329, 0.6419] (Table 4). See Fig.1 for LR diagram.

Table 3: Test results of threshold effect

Threshold number	F value	P value	Bootstrap number	10% critical value	5% critical value	1% critical value
single threshold	26.35	0.024	500	21.6978	24.104	28.7316
double threshold	9.49	0.442	500	16.4506	20.313	26.8344
triple threshold	4.42	0.838	500	20.5296	24.9353	32.622

Table 4: Results of threshold estimates

lnIDFDI	threshold value	confidence interval	P value
single threshold	0.6376	[0.6329,0.6419]	0.024
double threshold	0.5406	[0.4976,0.5435]	0.444
triple threshold	0.6114	[0.6109,0.6119]	0.838

Note: Stata15.0 software was used for panel data processing, and xthreg command of Qunyong Wang was used for threshold regression. The P-value was the result obtained by repeated sampling 500 times using bootstrap.

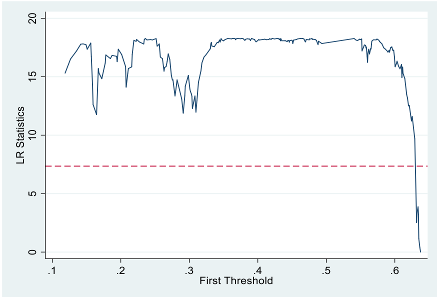

Fig. 1: LR diagram with bidirectional cooperation as a single threshold

4.1.2. Threshold effect regression analysis

With bidirectional FDI cooperation as the explanatory variable and threshold variable, and digital divide as the explained variable, the empirical analysis is conducted by using the provincial panel data of China from 2008 to 2020, and the results are shown in Table 5. Column (1) as a baseline regression result, it shows that bidirectional FDI cooperation significantly promotes the effective bridging of the digital divide at the 5% level; Column (2) as a threshold regression result, it shows that when bidirectional FDI cooperation is lower than the threshold value 0.6376, the coefficient of digital divide bridging is positive but does not pass the significance test; When bidirectional FDI cooperation crosses the threshold value 0.6376, bidirectional FDI cooperation passes the significance test at the 1% level and the direction is positive, indicating that with the improvement of bidirectional FDI cooperation level, the promoting effect on digital divide bridging gradually increases. However, only within the optimal threshold interval of bidirectional FDI cooperation greater than 0.6376. Only then can bidirectional FDI cooperation play a catalytic role in bridging the digital divide. From the perspective of control variables, there is no significant difference in the coefficient values and significance of the two columns of variables, and the level of economic development and human capital are significantly positive at the 1% level in the regression results, indicating that the proportion of provincial GDP and human capital quality have a positive promoting effect on the bridging of the digital divide. The information and communication capability is significantly positive at the level of 1% and 5% respectively, indicating that the higher the per capita communication expenditure, the higher the digital level of the city and the digital capability of the people, the more conducive to the bridging of the digital divide in the province;

The influence of financial efficiency on the bridging of digital divide is significantly negative at the level of 1%, which will play a certain hindrance to the bridging of local digital divide. The possible explanations are as follows: the high savings rate reduces the quantity and quality of factors that can be invested in the financial market, and reduces the possibility of capital misallocation, and the digital economy produces scale effects through this path, so it will cause idle and waste of financial resources, and even aggravate financial risks, which is not conducive to the development of the digital economy and the improvement of the digital level, and lead to the widening of the digital divide. Although the coefficient of tertiary industry GDP is positive, it does not pass the significance test and has no obvious impact on the bridging of digital divide. To sum up, it can be found that bidirectional FDI cooperation not only has a direct positive effect on digital gap bridging, but also has a single threshold effect, which is specifically manifested as a non-linear feature of increasing marginal efficiency. Thus hypothesis 1 is valid.

Possible explanations for the nonlinear characteristics of “bridging effect” are as follows: On the one hand, when the cooperation level of bidirectional FDI is low, the efficiency of outbound investment is not high, while the less resources (such as digital technology, digital talents and digital capabilities) are obtained through bidirectional FDI; at the same time, the utilization rate of domestic foreign investment is low, resulting in the ineffective allocation and utilization of resources. On the other hand, even if the level of bidirectional FDI cooperation still has room to rise, more or less there will be a certain technology spillover effect, through which to obtain advanced digital technology, that can be used in the input and output of the domestic market, being conducive to improving the digital economy capacity of the province and promoting the bridging of the digital divide. Under the joint action of both positive and negative aspects, the “bridging effect” has a certain degree of uncertainty, which is manifested as the non-linear feature of increasing marginal efficiency.

Table 5: Basic regression results of bidirectional FDI cooperation on digital divide bridging

Variables	$ln\,DDI$	
	（1）	（2）
lnIDFDI	0.210^{**}	
	(0.0951)	
lnGDP	0.857^{***}	0.886^{***}
	(0.0693)	(0.0673)
lnFE	-1.167^{***}	-1.027^{***}
	(0.140)	(0.139)
lnHC	0.392^{***}	0.349^{***}
	(0.133)	(0.129)
lnCCE	0.0529^{**}	0.0647^{***}
	(0.0225)	(0.0219)
lnSGDP	0.00404	0.00243
	(0.0220)	(0.0213)
lnIDFDI≤0.6376		0.0226
		(0.0995)
lnIDFDI>0.6376		0.317^{***}
		(0.0945)
Constant	-12.54^{***}	-12.31^{***}
	(1.486)	(1.440)
Observations	390	390

Note: ***, **, * indicates significant at the level of 1%, 5%, 10%.

4.1.3. Multiple heterogeneity analysis

Due to the diversity of influencing factors and existing ways of digital divide, the resource endowment of different provinces in China and the construction of digital infrastructure vary from place to place, the size of the objective digital divide varies and the ability to bridge the digital divide varies from high to low. According to the nature of the divide, the digital divide can be divided into three types: capacity divide, access divide and use divide. The economic strength of a region determines the “capacity divide bridging level” of the region, the urban-rural divide brought about by the construction of digital infrastructure affects the “access divide bridging level”, and the “use divide bridging level” depends on the education level and technical operation ability of people in a region. Taking the “accurate bridging” of digital divide as the starting point, focusing on the existing ways of capability divide, access divide and use divide as the driving point, and depending on the level of economic development, urbanization level and human capital as the revealing point, it makes multiple heterogeneity analysis on the bridging effect of bidirectional FDI cooperation on digital divide. Among them, the heterogeneity of economic development level was tested by the four economic regions classified in *the Evaluation and Comparison Report of the Comprehensive Economic and Social Development Index of 31 Provinces in 2020* released by the Scientific Research Committee of China's Comprehensive Economic and Social Development Index. The “Hu Huanyong line” was used to characterize the heterogeneity of urbanization level. Using Arcmap10.8 software, the proxy variable - the average value of high-tech talents in each province from 2008 to 2020 was visually analyzed, and the heterogeneity of talent capital in the five regions was measured by sub-sample regression.

(1) Heterogeneity analysis of different levels of economic development

Table 6: Heterogeneity regression results of different economic development levels

Variables	*lnDDI*			
	(1)Eastern region	(2)Central region	(3) Western region	(4) Northeast region
lnIDFDI	0.328^{**}	0.858^{***}	0.364^{***}	0.591
	(0.142)	(0.0997)	(0.104)	(0.217)
lnGDP	0.131	-1.116^{**}	0.392	0.260
	(0.280)	(0.466)	(0.677)	(1.053)
lnSGDP	1.097^{***}	1.374^{***}	0.668	-0.936
	(0.243)	(0.429)	(0.615)	(0.621)
lnCCE	0.00516	0.262^{**}	0.280^{*}	0.610^{**}
	(0.142)	(0.112)	(0.146)	(0.113)
lnHC	-1.094^{***}	-0.165	0.359	6.531^{**}
	(0.349)	(0.361)	(0.441)	(1.045)
lnFE	-1.018^{**}	-0.817^{*}	-1.449^{*}	-2.436
	(0.410)	(0.429)	(0.757)	(0.951)
Constant	4.306	0.586	-14.64^{**}	-85.43^{**}
	(3.448)	(2.732)	(4.710)	(17.14)
Observations	78	130	143	39
Number of pro	6	10	11	3

Note: ***, **, * indicates significant at the level of 1%, 5%, 10%.

The regression results of heterogeneity at the level of economic development are shown in columns (1) - (4) of Table 6. In the eastern, central and western regions, economic development can significantly promote the improvement of digital divide bridging level, while in the northeast region, economic development has no significant positive impact on digital divide bridging level. Specifically, the significance of economic development in the eastern region is smaller than that in the central and western regions. The digital divide bridging effect of promoting bidirectional FDI cooperation at the 5% level is positive in the central and western regions at the 1% significance level, and the significance coefficient of the central region is about 2.35 times that of the western region. Under the background of a better economic foundation, the impact of digital economy in the eastern region is similar to that in the central region. The possible reason is that the construction of domestic recycling system in the eastern region has been relatively perfect, the level of international recycling is high, and the marginal promotion effect of economic development on the bridging of the digital gap in bidirectional

FDI cooperation is small, and the “icing-on-the-cake” effect gradually tends to saturation. We need to find new economic growth points. From 2008 to 2020, the dynamic evolution trajectory of the center of gravity of bidirectional FDI cooperation is located in Henan Province in the central region, with Henan Province as the center radiating to the surrounding provinces, while most cities in the central region are within the radiation range. Economic development is steadily advancing in the construction of “three bases and one hub”, and the overall economic development is better promoted by digital economy. The dividend of bidirectional FDI coordinated development is larger, and the effect on bridging the digital divide is more obvious, indicating that the central region has made better use of the enabling and innovative effects of the digital economy on the limited economic basis. Among the 11 provinces in the western region, Inner Mongolia Autonomous Region, Guangxi Province, Yunnan Province, Shaanxi Province, Gansu Province, Qinghai Province, Ningxia Hui Autonomous Region and Xinjiang Uygur Autonomous Region are all cities along the Belt and Road Economic Belt, benefiting from the benefits of the “Belt and Road” policy. The economic development and the level of bidirectional FDI cooperation in the central region have been increased and improved, which is more conducive to promoting the bridging of the digital divide. Although the industrial chain construction in Northeast China is intact and the economic foundation is relatively strong, it has failed to make full use of the dividends of the development of the digital economy, indicating that the region's digital economy is insufficient, the degree of industrial transformation and upgrading is low, and the smart people's livelihood and innovation-driven lag behind other regions in the country. Therefore, the impact of bidirectional FDI cooperation on digital divide bridging varies with different levels of economic development, and there is heterogeneity.

(2) Heterogeneity analysis of different urbanization levels

Table 7: Heterogeneity regression results of different urbanization levels

Variables	*lnDDI* (1)Southeastern hemispheres	*lnDDI* (2)Northwestern hemispheres
lnIDFDI	0.552***	0.381*
	(0.139)	(0.216)
lnGDP	0.831***	3.562**
	(0.284)	(1.554)
lnSGDP	0.0400	0.354
	(0.0852)	(0.875)
lnCCE	0.309**	0.116
	(0.129)	(0.133)
lnHC	-0.354	-1.185
	(0.333)	(1.349)
lnFE	-1.541***	-1.785
	(0.277)	(2.756)
Constant	-4.478	-17.55
	(3.989)	(16.45)
Observations	338	52
Number of pro	26	4

Note: ***, **, * indicates significant at the level of 1%, 5%, 10%.

As shown in Table 7, the different results of the two halves of the “Hu Huanyong Line” show that different urbanization levels have heterogeneity on the digital divide bridging effect of bidirectional FDI collaboration. In the southeastern hemispheres, the urbanization level promotes the bridging of digital divide at the significance level of 1%, while in the northwestern hemispheres, the bridging effect is significantly lower than that in the southeastern hemispheres at the significance level of 10%. “Hu Huanyong Line”, as the dividing line between the main and non-main areas of China's new urbanization and the unbalanced and inadequate economic and social development of China, is characterized by the differences in natural environment, population density and ecological distribution on the east and west sides, resulting in the unbalanced economic and social development and the obvious difference in urbanization level between the two regions. The densely populated areas are almost all in the southeastern hemispheres, that are basically prefecture-level units with developed economies or provincial administrative centers, with GDP ratio and city scale higher than the northwestern hemispheres, high urbanization level, and perfect digital infrastructure construction, which is conducive to releasing the coordinated development dividends of digital economy and bidirectional FDI, and effectively promoting the bridging of the digital divide.

On the other hand, there are almost no large cities and megacities in the northwestern hemispheres, with low urbanization level, small city scale and large digital divide, so the promotion effect of digital divide bridging is lower than that of the southeastern hemispheres. (3) Heterogeneity analysis of different human capital Arcmap10.8 was used to visualize the average value of high-tech talents in 30 regions from 2008 to 2020 (as shown in Figure 2), which was divided into five regions for exploring the heterogeneous characteristics of the bridging effect at human capital level in: regions with a few average number of high-tech talents, regions with fewer average number of high-tech talents, regions with a moderate average number of high-tech talents, regions with an average number of more high-tech talents and regions with a large average number of high-tech talents.

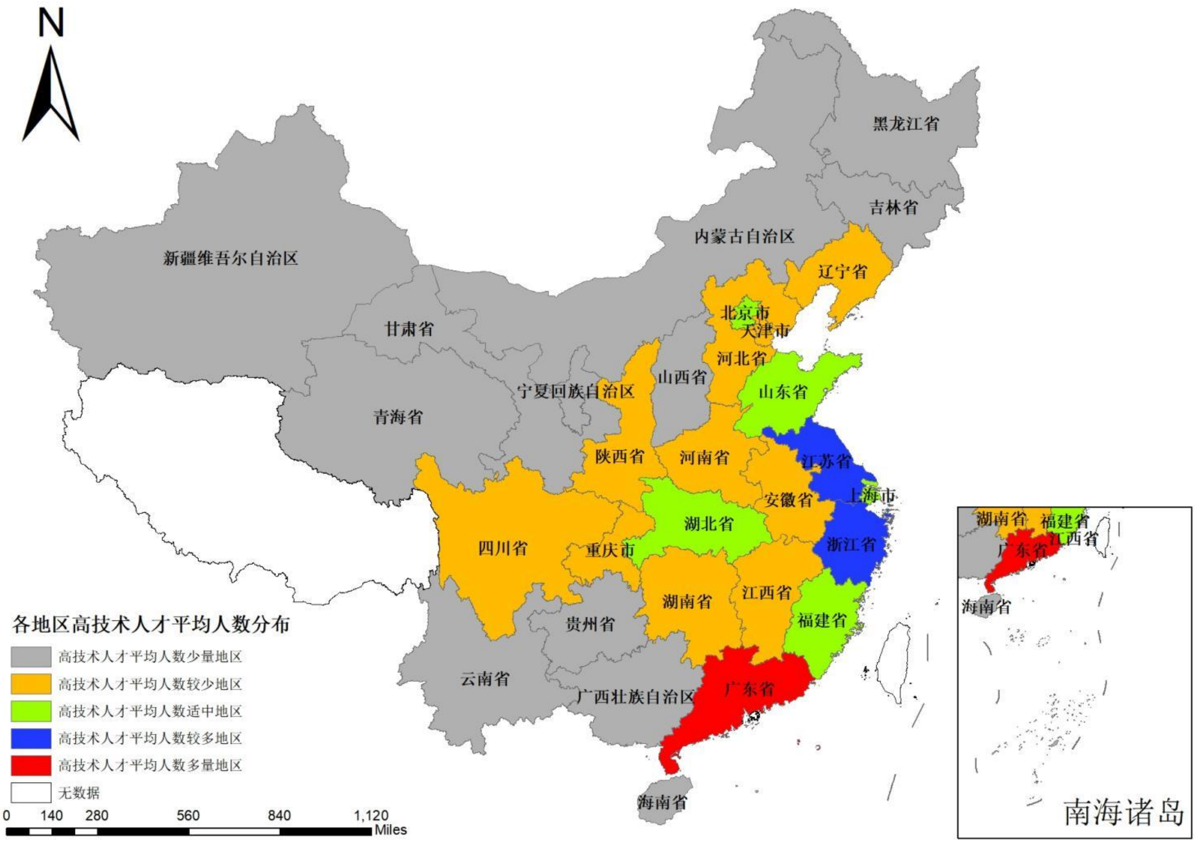

Fig. 2: Average distribution of high-tech talents in different regions from 2008 to 2020

As shown in Table 8, in addition to the significant positive effect in the regions with a few and fewer high-tech talents, the other three regions are not significant, and even the regions with more and a large number of high-tech talents show no significant negative impact. The reason is consistent with the heterogeneity of economic development level. Figure 2 shows that there are three provinces with abundant high-tech talents, namely Zhejiang, Jiangsu and Guangdong, all of which are located in the southeast coastal area. The economic foundation has developed well, the GDP growth rate is high, the development level of digital economy continues to improve, the positive promotion effect gradually tends to saturation, and the marginal promotion benefit for bridging the digital divide of bidirectional FDI cooperation is small. It is necessary to find new economic growth points, and even continuous FDI may lead to market saturation and weak competition, resulting in technology spillover and talent spillover, but it will not make substantial contribution to the improvement of the level of bridging the digital divide. However, most of the regions with relatively low high-tech talents are central cities, which are basically located in the trajectory of the dynamic evolution of bidirectional FDI cooperation, and are all exposed to the radiation of the dividends of coordinated development of bidirectional FDI. The development process of digital economy is advancing steadily, the overall economic development degree is good, and the synergistic effect on the bridging of digital divide is more obvious. On a limited economic basis, the digital economy makes good use of the enabling and innovation effect, the industrial transformation and upgrading degree is good, and the digital empowerment and innovation driving performance is relatively good, indicating that the digital divide bridging effect of bidirectional FDI cooperation is more significant in the regions with weak economic foundation, and has the nature of universal benefit. Therefore, there is also heterogeneity in the bridging effect of different talent capital on bidirectional FDI collaboration.

Table 8: Heterogeneity regression results of different human capital

Variables	*lnDDI* (1) regions with a few average number of high-tech talents	(2) regions with fewer average number of high-tech talents	(3) regions with a moderate average number of high-tech talents	(4) regions with an average number of more high-tech talents	(5) regions with a large average number of high-tech talents
lnIDFDI	0.481^{***}	0.386^{**}	0.410	-0.213	-0.0187
	(0.113)	(0.196)	(0.336)	(0.109)	(0.518)
lnGDP	-1.805^{***}	0.548	0.734^{**}	-6.418	-10.80^{***}
	(0.686)	(0.732)	(0.286)	(3.705)	(1.427)
lnSGDP	3.047^{***}	0.690^{**}	-0.0422^{***}	5.584	8.848^{***}
	(0.754)	(0.278)	(0.0160)	(4.008)	(1.282)
lnCCE	0.249^{**}	0.153	0.779^{***}	0.617	1.532^{***}
	(0.113)	(0.204)	(0.290)	(0.463)	(0.187)
lnHC	-0.982^{***}	-0.391	0.249	2.888	-0.209
	(0.303)	(0.483)	(0.345)	(2.785)	(2.106)
lnFE	-0.0396	-1.633^{***}	-0.677^{*}	-1.735	-1.391
	(0.642)	(0.446)	(0.396)	(0.752)	(0.791)
Constant	3.028	-5.887	-15.24^{***}	-31.43	20.20
	(2.444)	(3.665)	(5.287)	(42.45)	(28.89)
Observations	156	130	65	26	13
Number of pro	12	10	5	2	1

Note: ***, **, * indicates significant at the level of 1%, 5%, 10%.

4.2. Spatial spillover effect analysis

4.2.1. Spatial correlation analysis

Spatial autocorrelation test is the basic content of spatial econometric analysis. The premise of using spatial econometric model is that the research object has spatial correlation, which is generally tested by Moran's Index (Moran's I). Moran's Index usually ranges from 0 to 1. When Moran's I>0, it indicates that there is a spatial positive correlation between the horizontal values of adjacent regions. When Moran's I<0, it means that there is a spatial negative correlation between the horizontal values of adjacent regions. The greater the absolute value of Moran's Index, the higher the degree of spatial correlation. It uses adjacency matrix **W** and Stata 15.0 software to estimate Moran's I of the impact of bidirectional FDI collaboration on digital divide bridging (see Table 5).

(1) Global autocorrelation analysis
Table 9 shows the spatial autocorrelation test of the impact of bidirectional FDI collaboration on digital divide bridging. With the exception of 2020, the Moran's Index is positive, and with the exception of 2009, 2019 and 2020, the Moran's Index is significantly positive at the level of 10%. Although the Moran's Index, which is not significant in the past three years, exists objectively, it can still basically show that there is a certain spatial autocorrelation between the influence of bidirectional FDI cooperation on digital divide bridging during the sample period, that is, the digital divide bridging level of each region has a significant spatial spillover effect on the surrounding region, so it is necessary to adopt a spatial measurement model for empirical test.

The insignificance of Moran's Index in 2009, 2019 and 2020 in this paper cannot completely explain that the spatial autocorrelation of the digital divide bridging level does not exist in this period. The main reason for this phenomenon may be that the Moran's I index is obtained through a simple binary 0-1 adjacent spatial weight matrix, which already has drawbacks [31]. The spatial adjacency standard of the weight matrix holds that whether space units are connected depends on whether they are adjacent, that is, as long as space units are not adjacent to each other, they are considered to have no mutual influence. If the spatial units are adjacent, they are considered to have the same degree of influence on each other, which is obviously inconsistent with the essential characteristics of the development of the digital economy and the bridging level of the digital divide. As we all know, the development of digital economy has obvious spatial mobility due to its special communication mode, and it is obviously not valid to judge whether there is spillover effect of digital divide bridging between spatial units simply based on whether space is adjacent. Firstly, China's eastern coastal provinces have a high level of economic development and complete digital economic infrastructure. Compared with the central and western regions, they have natural resource endowment advantages in digital divide bridging ability. Secondly, according to the regional geographical location measured by the spatial adjacency standard, only Guangdong and Zhejiang provinces are adjacent to Fujian Province. However, it cannot be hastily considered that the improvement of Fujian's digital divide bridging level is only related to the above two provinces and has no connection with other provinces and regions. Nor can we blindly believe that the interaction between Fujian and Hubei Province, which is close to each other geographically, is the same as that between Fujian and other relatively distant provinces and regions (such as Gansu, Xinjiang and Qinghai) (the weight between Fujian and Hubei and between Fujian and Qinghai and Xinjiang is set to 0 in the adjacently-weighted matrix).

Table 9 Global Moran’s Index

Year	I value	Z value	P value
2008	0.290	2.898	0.004
2009	0.017	0.455	0.649
2010	0.300	2.819	0.005
2011	0.371	3.495	0.000
2012	0.303	2.822	0.005
2013	0.184	1.836	0.066
2014	0.332	3.041	0.002
2015	0.351	3.245	0.001
2016	0.381	3.453	0.001
2017	0.382	3.421	0.001
2018	0.279	2.522	0.012
2019	0.153	1.502	0.133
2020	-0.046	-0.095	0.924

(2) Local autocorrelation analysis

Moran's Index is not significant. It cannot be judged that the level of digital divide bridging in any region is unrelated to the neighboring region, because the correlation may only exist in some regions, or the positive and negative cancel each other out, which is not statistically significant. Therefore, the spatial autocorrelation of local regions can be investigated through the local Moran scatter plot. Four years, 2008, 2011, 2014 and 2017, are selected as the local Moran scatter plot of the effect of bidirectional FDI cooperation on digital divide bridging (see Figure 3 and Figure 4). As can be seen from the figure, the “bridging effect” of bidirectional FDI cooperation on the digital divide is not randomly distributed, and most provinces are concentrated in the first and third quadrants, which are “high-high-neighboring” and “low-low-neighboring” respectively, showing significant local spatial positive autocorrelation characteristics. To be specific, Beijing-Tianjin-Hebei and Jiangsu-Zhejiang-Shanghai in North China and the east belong to high-high agglomeration, while Yunguichuang, Xinjiang and Qinghai in the west belong to low-low agglomeration. Therefore, it can be concluded that the bridging effect of China's bidirectional FDI cooperation on the digital divide exists spatial agglomeration phenomenon, that is, each province generally presents high-high agglomeration (H-H) or low-low agglomeration (L-L).

Fig. 3: Moran scatter plots for 2008 (left) and 2011 (right)

Fig. 4: Moran scatter plots for 2014 (left) and 2017 (right)

4.2.2. Analysis of spatial lag model results

Traditional econometrics assumes that variables in different regions are independent. While ignoring the influence of spatial interaction, due to the objective existence of spatial dependence of economic activities between regions, for the spatial panel econometrics model, serious errors will be caused if OLS is continued to be used for parameter estimation, resulting in biased or invalid estimation results. Therefore, the maximum likelihood method was applied in this paper for parameter estimation. Through the Hausmann test, the P-values under the spatial weight matrix are all significant at the level of 10%, so this paper adopts the fixed effect for empirical analysis; Through Wald Test, the hypothesis that SDM degenerates into SLM and SEM models cannot be rejected. At the same time, the individual fixed effect model is selected as the best by testing the individual, time and mixed fixed effect models. Therefore, it conducts regression analysis through the individual fixed effect of the spatial lag model, and the results are shown in Table 10.

As shown in Table 10, the spatial autoregressive coefficient ρ is 0.544, which is significantly positive at 1% test level, indicating that the “bridging effect” of bidirectional FDI cooperation in each province has an expected spatial spillover effect, which is specifically manifested as a positive feedback effect, indicating that spatial factors should be considered when analyzing the impact of bidirectional FDI cooperation on the bridging of digital divide. At the same time, it also means that regions with relatively high digital divide bridging ability have a positive driving effect on neighboring regions, which is specifically manifested as a positive spatial spillover effect, promoting the improvement of digital divide bridging ability in neighboring regions, and verifying the validity of hypothesis 2.

The coefficient of bidirectional FDI cooperation is 0.115, which passes the 1% significance level test, indicating that the increase of bidirectional FDI cooperation by 1 percentage point will increase the digital divide bridging ability by 0.115 percentage point. It can be seen that bidirectional FDI cooperation has a significant promoting effect on bridging the digital divide, indicating that the digital technology and digital talent resources obtained through the bidirectional FDI technology spillover channel can be well utilized into the input and output of the domestic market, driving the expansion of ICT, Internet, software and other industries, and thus improving technological progress and total factor productivity, and promoting the growth of the digital economy, which is conducive to the effective bridging of the digital divide. In terms of control variables, the human capital is significantly positive at the level of 1%, indicating that the improvement of human capital has a significant role in promoting the bridging of the digital divide in the region, and the increase of per capita years of education contributes to the improvement of human capital quality and intelligence level, thus promoting regional technological progress and the development of digital economy. In the context of the gradual disappearance of demographic dividend and innovation-driven environment, the improvement of regional human capital level can mitigate the negative impact of the decline in the number of labor force to a certain extent, and then continue to promote the rapid and positive growth of the ability to bridge the digital divide. Economic development level and per capita communication capability also promote the bridging of the digital divide at the significance level of 1%, indicating that provincial GDP and per capita communication capability are positively correlated with the development of the digital economy in the province. The higher the provincial GDP and per capita communication capability, the higher the digital capability of people, and the more conducive to the improvement of digital infrastructure and the bridging of the digital divide. Neither the financial efficiency nor the development level of the tertiary industry has passed the significance test, which may be because the development of the financial industry and the tertiary industry is relatively slow and lags behind, so the effect is not significant in the short term and a certain period is required.

Table 10: Regression results of spatial spillover effect

Variables	SLM $ln\,DDI$
lnIDFDI	0.115^{***}
	(0.0423)
lnGDP	0.385^{***}
	(0.130)
lnSGDP	-0.0256
	(0.0337)
lnCCE	0.526^{***}
	(0.124)
lnFE	0.0402
	(0.236)
lnHC	0.594^{***}
	(0.202)
ρ	0.544^{***}
	(0.0433)
Observations	390
R-squared	0.419

Note: ***, **, * indicates significant at the level of 1%, 5%, 10%.

On the basis of SLM with fixed effects, it further decomposed the total spatial effects [33] of explanatory variables such as bidirectional FDI collaboration on digital divide bridging into direct effects and indirect effects through the partial differential method of spatial regression model (see Table 11). The direct effect measures the influence of the change of explanatory variables such as bidirectional FDI cooperation on the dependent variable of its own region, and includes the feedback effect, that is, the impact on other regions will in turn affect the region. Indirect effects (i.e., spatial spillover effects) measure the influence of changes in explanatory variables such as bidirectional FDI cooperation on the surrounding region dependent variables, which can be divided into spatial agglomeration effect and spatial diffusion effect. Diffusion effect is a positive spillover effect, that is, more developed regions drive the digital divide bridging ability of less developed regions through bidirectional FDI cooperation. Agglomeration effect is a negative spillover effect (also known as siphon effect), that is, more developed areas introduce production factors from less developed areas into the local through bidirectional FDI cooperation and the development of digital economy, making developed areas more developed and backward areas more backward.

Table 11: Decomposition results of spatial effects

Variables	Direct effect (1)	Indirect effect (2)	Total effect (3)
lnIDFDI	0.128^{***}	0.128^{**}	0.256^{***}
	(0.0475)	(0.0513)	(0.0967)
lnGDP	0.415^{***}	0.414^{***}	0.829^{***}
	(0.137)	(0.140)	(0.269)
lnSGDP	-0.0242	-0.0250	-0.0492
	(0.0356)	(0.0375)	(0.0727)
lnCCE	0.576^{***}	0.574^{***}	1.150^{***}
	(0.128)	(0.130)	(0.243)
lnFE	0.0467	0.0460	0.0927
	(0.249)	(0.255)	(0.502)
lnHC	0.663^{***}	0.664^{***}	1.327^{***}
	(0.215)	(0.228)	(0.431)
Observations	390	390	390
R-squared	0.419	0.419	0.419

Note: ***, **, * indicates significant at the level of 1%, 5%, 10%.

As shown in Table 11, the direct effect coefficient of bidirectional FDI cooperation is 0.128, which is significant at 1% level, indicating that bidirectional FDI cooperation has a significant positive direct effect on digital divide bridging, and the growth of bidirectional FDI cooperation level in a certain province has a significant positive impact on the improvement of its own digital divide bridging ability. And the influence on other provinces will in turn improve the province's ability to bridge the digital divide, with a "positive feedback effect"; At the same time, the indirect effect coefficient of bidirectional FDI cooperation is also 0.128, which is significant at the level of 5%, indicating that bidirectional FDI cooperation has a significant positive spatial spillover effect, that is, the higher development level of bidirectional FDI cooperation in neighboring provinces can promote the growth of the digital divide bridging ability of neighboring provinces. However, the "bridging effect" is slightly less powerful in the neighboring region than in the local region. The direct and indirect effects of financial efficiency are not significant, which means that the lag of financial development leads to its feedback and spillover effects on the bridging of the digital divide. The development level of the tertiary industry also fails to pass the significance test, indicating that although the collaborative and integrated development of high-tech manufacturing industry and producer service industry has an important impact on the improvement of total factor productivity and the bridging of the digital divide, the high-tech manufacturing industry is not yet mature. The influence of the development level of the tertiary industry on the bridging of the digital divide in the surrounding region has not been fully brought into play. The estimated coefficients of direct effect between economic development level and per capita communication capability are 0.415 and 0.576 respectively, and both are significant at 1% level, indicating that both economic development level and per capita communication capability have a positive impact on bridging the digital divide in the region. Economic development level is measured by regional GDP, and per capita communication capability is described by per capita communication expenditure. The promotion effect of regional GDP and per capita communication expenditure on regional digital technology progress is a gradual accumulation process. With the continuous increase of GDP and per capita communication expenditure, the influence of economic development level and per capita communication capability on digital gap bridging will gradually increase. In addition, the indirect effect coefficient of the two also passes the significance test of 1%. The results show that the positive effects of economic development level and per capita communication capability on digital divide bridging are not limited to the local area, but have full positive spillover effect. The estimated coefficient of direct and indirect effects of human capital is much higher than that of other explanatory variables, reflecting the status and role of human capital in improving regional digital divide bridging ability, and the indirect effect coefficient is 0.001 percentage points higher than the direct effect coefficient. It shows that the positive spillover effect of human capital on digital gap bridging is slightly higher than the positive feedback effect.

4.3. Robustness test

In order to ensure the robustness of empirical analysis results, and according to the models and data used in this paper, it adopts five methods in two parts to test the robustness of panel regression model (Table 12) and spatial econometric model (Table 13) respectively.

4.3.1. Robustness test of panel regression model

Considering the possibility of endogeneity, the one-stage lag of bidirectional FDI coordination was selected as the instrumental variable [34], and the two-stage least square method (2SLS) was used for empirical regression, and the instrumental variable passed the weak instrumental variable test. The regression results are shown in Table 12 (1). The bidirectional FDI coordination of explanatory variables in the baseline regression is calculated using the coupling measure. In order to ensure the robustness of the regression results, per capita disposable income ($\ln CPI_{\mathrm{it}}$) is selected as a new explanatory variable to conduct the robustness test of the replacement explanatory variables, as shown in Table 12 (2). Since most economic indicators may have lagging effects, the control variables were selected to lag one stage for further robustness test, and the results are shown in Table 12 (3). In summary, the influence of core explanatory variables on the bridging of digital divide is still robust, which further supports the conclusion of this paper. The bidirectional FDI cooperation will significantly promote the bridging of digital divide.

4.3.2. Robustness test of spatial lag model

The robustness of the spatial measurement model was tested by further deleting control variables and replacing the spatial weight matrix. The results are shown in Table 13. In the table, column (1) - (4) are the results of changing the spatial weight matrix to test the robustness. Specifically, the adjacency matrix is replaced by the geographical distance weight matrix, and the coefficient changes of explanatory variables before and after the replacement are compared. After replacing the weight matrix, the variable coefficient symbols and significance sizes in the estimation results are highly consistent with space overflow regression results of the adjacency matrix in Table 10 and Table 11, and the overall estimation results remain stable. In column (5), the results of deleting control variables are also highly consistent with the results of adjacency matrix regression mentioned above, and the core conclusions have not changed. Therefore, the results of the spatial lag model estimated in this paper are robust.

Table 12: Robustness test results of panel regression model

Variables	$ln\,DDI$		
	Endogeneity test	Alternative explanatory variable	The one-stage lag of the control variable
	(1)	(2)	(3)
lnIDFDI	1.701***		0.197**
	(0.168)		(0.0930)
lnCPI		1.425***	
		(0.0876)	
lnGDP	0.115*	-0.160**	
	(0.0679)	(0.0805)	
lnSGDP	0.0445	-0.0144	
	(0.0337)	(0.0166)	
lnFE	-0.513***	-0.316***	
	(0.100)	(0.117)	
lnCCE	0.232***	-0.0424**	
	(0.0448)	(0.0185)	
lnHC	-0.0810	0.285***	
	(0.0559)	(0.103)	
L.lnGDP			0.645***
			(0.0733)
L.lnFE			-0.915***
			(0.135)
L.lnHC			0.676***
			(0.140)
L.lnCCE			0.0263
			(0.0212)
L.lnSGDP			0.0814***
			(0.0198)
Constant	-1.505***	-14.48***	-14.59***
	(0.492)	(1.117)	(1.506)
R-squared	0.597	0.934	0.882

Note: ***, **, * indicates significant at the level of 1%, 5%, 10%.

Table 13: Robustness test results of spatial lag model

Variables	Replacement of weight matrix				Deletion of control variable
	SLM	Spatial effect decomposition			SLM
	(1)	(2)	(3)	(4)	(5)
	$ln\,DDI$	Direct effect	Indirect effect	Total effect	$ln\,DDI$
lnIDFDI	0.0928**	0.102**	0.263**	0.365**	0.246***
	(0.0387)	(0.0429)	(0.122)	(0.162)	(0.0390)
lnGDP	0.186	0.195	0.487	0.682	
	(0.119)	(0.125)	(0.322)	(0.441)	
lnSGDP	-0.0270	-0.0258	-0.0687	-0.0944	
	(0.0308)	(0.0321)	(0.0900)	(0.121)	
lnCCE	0.213*	0.229*	0.569**	0.798**	
	(0.116)	(0.120)	(0.287)	(0.401)	
lnFE	-0.00558	-0.00390	-0.0154	-0.0193	
	(0.215)	(0.225)	(0.599)	(0.820)	
lnHC	0.670***	0.736***	1.899***	2.635***	
	(0.184)	(0.193)	(0.609)	(0.769)	
ρ	0.738***				0.836***
	(0.0406)				(0.0206)
control variable	YES	YES	YES	YES	NO
Observations	390	390	390	390	390
R-squared	0.583	0.583	0.583	0.583	0.772
Number of id	30	30	30	30	30

Note: ***, **, * indicates significant at the level of 1%, 5%, 10%.

5.0 Conclusion

Based on the panel data of 30 provinces in China from 2008 to 2020, this paper firstly constructs an econometric model with bidirectional FDI collaboration as the threshold variable, empirically tests the nonlinear relationship between bidirectional FDI collaboration and digital divide bridging, and discusses the multiple heterogeneity characteristics of this effect at different economic factors according to the nature of digital divide. Secondly, the spatial lag model is used to verify the spatial spillover effect of this influence. The following conclusions are drawn:

First, bidirectional FDI cooperation has a single threshold effect on digital divide bridging, which is manifested by the non-linear feature of increasing marginal efficiency. When bidirectional FDI cooperation is lower than the threshold value 0.6376, the "bridging effect" of digital divide is uncertain. When it crosses the threshold value 0.6376, it plays a significant role in promoting the bridging of the digital divide. Therefore, only when bidirectional FDI cooperation is greater than 0.6376, the promotion effect of bidirectional FDI cooperation on digital divide bridging can be brought into play.

Second, the "bridging effect" of bidirectional FDI cooperation on the digital divide has a triple heterogeneity at the level of economic development, urbanization and human capital. In the central and western regions where the level of economic development is relatively weak, the "bridging effect" has greater space and more obvious role; The "bridging effect" of the southeast half of the region with "Hu Huanyong line" as the boundary is higher than that of the northwest half of the region with low urbanization level because of its urbanization level. There is a negative correlation between the number of high-tech talents and this "bridging effect". In areas with fewer high-tech talents, the development of digital economy and digital facilities is relatively weak, and the bridging space is larger. Therefore, the positive effect of two-way FDI cooperation on bridging the digital divide is more obvious.

Third, the bridging effect of bidirectional FDI cooperation on the digital divide is characterized by high clustering in the eastern coastal region and low clustering in the western region, and the spatial positive feedback effect and positive spillover effect are fully manifested. Both direct effect and indirect effect are significantly positive, which are positive feedback effect and positive spillover effect. The level of economic development, per capita communication capacity and human capital can significantly promote the effective bridging of the digital divide between the region and its neighbors, and give full play to the positive spatial correlation.

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