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How trade affects high-quality development through spillovers?

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ABSTRACT
This paper derives the empirical estimation model from the endogenous economic growth theory, and tries to provide an effective and reasonable answer to the question 'how trade affects high-quality development through spillovers' from the perspective of spatial interdependence. Based on the data of 69 countries from 2000 to 2015, it is confirmed that there is an obvious spatial correlation between neighboring countries' TFP, the TFP of geographical and economic neighboring countries shows 'competition effect', while the TFP of cultural neighboring countries shows 'first spillover effect, then competition effect'. The R&D capital investment has no spatial effect on TFP of geographically or economically neighboring countries, but it has a significant 'spillover effect' on TFP of culturally neighboring countries. Technology spillovers caused by international trade are not only an important factor for countries to promote TFP, but also the core driving force to achieve high-quality development.

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1. Introduction

Nowadays, the world is in a critical stage of economic transformation between old and new drivers to growth. Under the background of increasingly fierce economic competition among countries, only by improving the quality of products and services can countries successfully overcome difficulties and renew their vitality (Meng et al., 2020). High-quality development, as an emerging development concept, is in essence a development in which innovation has become the primary driving force, coordination has become the endogenous feature, green development has become the universal form, openness has become the necessary way, and sharing has become the fundamental goal (Li et al., 2019). Improving total factor productivity[1] (henceforth, TFP) is key for countries to promote 'high-quality development'. The important components of TFP, namely 'quality' and 'variety', can comprehensively and effectively measure 'high-quality development'. The quality component of TFP mainly reflects

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the gap between a country's existing technology level and the world's technology frontier, which is not only the motivation for trade, but also an important prerequisite for technology spillover (Aghion & Howitt, 1992). The variety component reflects the enhancement effect of increasing product diversities and quantities on TFP, and the strength of this enhancement effect mainly depends on the investment of countries in R&D innovation and talent training (Romer, 1990).

In open economy, international trade is an important channel for transnational technology spillovers. While international trade brings high-quality and diversified products, it also generates dynamic benefits to promote the technological progress in various countries, affecting the TFP level of trading partner countries. Although international trade is beneficial to the diffusion and dissemination of technology among trading partners, its actual effects on technology spillover and TFP of neighboring countries are often influenced by trade costs depending on geographical distance. This often leads to spatial interdependence between neighboring trading partner countries. Besides, technology spillovers occur frequently among trading partners with geographical, economic and cultural proximity (Keller, 2002). Therefore, it is reasonable and appropriate to explore the relationship among international trade, high-quality development and technology spillovers under the premise of spatial interdependence (Ertur & Koch, 2007; Tientao et al., 2016). To this end, this paper derives the empirical estimation model from the endogenous economic growth theory, and tries to provide an effective and reasonable answer to the question 'how trade affects high-quality development through spillovers' from the perspective of spatial interdependence. It is confirmed that there is an obvious spatial correlation between neighboring countries' TFP, the TFP of geographical and economic neighboring countries shows 'competition effect', while the TFP of cultural neighboring countries shows 'first spillover effect, then competition effect'. Technology spillovers caused by international trade are not only an important factor for countries to promote TFP, but also the core driving force to achieve high-quality development.

The main contributions of this paper are shown as follows. First, combining with the existing research design, the endogenous economic growth model is expanded. Both quality component and variety component are organically embedded into the equilibrium of TFP, which can theoretically explore the impact of R&D capital input and human capital input of neighboring countries on TFP. Second, the spatial econometric model is derived from theoretical model. This is not only helpful to capture the effects of technology spillover caused by international trade, but also conducive to the organic combination of theoretical and empirical research, and provides an effective and credible research framework for in-depth study of the impact mechanism of international trade on high-quality development.

2. Literature review

Traditional trade theory explains the comparative advantage effect and the capital accumulation effect on the increase of trade scale from the perspective of 'specialisation' (Romer, 1987). However, new trade theory focuses more on scale economies and product differentiation (Krugman, 1980), and considers that spillovers are the key factor by which the international trade can influence the technological progress, the economic growth and the TFP (Aghion et al., 2009). Although, the influence of international trade on TFP is theoretically 'inconclusive', the following influence channels can still be summarised. First, the international trade increases the varieties of intermediate goods, and improves the quality of inputs, thus raising the TFP level of importing countries. It is worth noting that the influence of increasing product varieties on TFP depends on the elasticity of substitution between products (Broda et al., 2017). Second, the international trade gives importing countries the opportunity to acquire a lot of new technology information by imitating and learning from imported goods, especially for developing countries (Fu et al., 2010). Third, the international trade enables enterprises to make more profits by expanding the market scale, and the enterprises that sell to both domestic and foreign markets are more inclined to invest in R&D to enhance their technical competence (Tang & Liu, 2015). Fourth, through the entry of external enterprises, the international trade can change the local market structure, thus exerting double or multiple influences on technological progress and TFP (Peretto & Smulders, 2002).

Different from the findings of theoretical study, the empirical study reaches the consistent result, that is, international trade can effectively improve TFP (Li & Xu, 2011). The empirical research on relationship between trade and TFP can be traced back to Grossman and Helpman (1991). Grossman and Helpman take the bilateral import share of each country as the weight, and analyse how the R&D capital input of trading partner countries affects the technological progress of their own countries through the technology spillover, which provides guidance for the subsequent empirical analysis. Then, Coe et al. (1997) introduces the permeability and human capital on the framework of Coe and Helpman (1995), and uses the panel data of 77 developing countries to further test the influence of spillover effect brought by international trade on TFP. Besides, Yu and Yu (2006) improves the calculation method of foreign R&D capital stock by combining human capital factors on the basis of Coe and Helpman model; Chen and Liu (2015) analyzes the impact of import on technological progress rate by using bilateral trade data of 47 countries from 2000 to 2011. All these studies confirm that the international trade can significantly improve the TFP of the host country.

Although the above studies can capture the direct impact of international trade on TFP, the investigation of indirect impact of trade remains relatively weak. Lumenga-Neso et al. (2005) theoretically highlights that international trade has an indirect impact on TFP through technology spillovers. However, due to the deficiency of the framework design and the index construction, it is difficult to accurately analyse whether trade affects the TFP through spillovers. Under this circumstance, spatial econometrics undoubtedly become the most suitable method to effectively identify the indirect effects of international trade, thanks to the advantages in dealing with spatial interdependence (Ying, 2000) and spatial heterogeneity (Ertur & Koch, 2006). Ertur and Koch (2007) tries to derive an empirical estimation model with spatial econometric characteristics from economic theory, and the spatial interdependence is introduced into economic growth (Solow) model. Their work not only proves the interdependence of TFP in spatial dimension, but also initiates the transformation between economic theoretical model and spatial econometric model. Subsequently, on the basis of the Schumpeter multi-country economic growth model (Howitt, 2000), Ertur and Koch (2011) further analyzes the evolution process of technology progress by the mutual verification between theory and demonstration. Besides, Ertur and Musolesi (2017) empirically explores the impact of trade on technology progress and TFP based on the theoretical study of Coe et al. (2009).

To sum up, although scholars conduct a gradual and in-depth discussion on the influence of international trade on TFP from 'theoretical study' to 'empirical study' and then to 'combination of theoretical and empirical research', there are still the following shortcomings. First of all, the results of relevant theoretical studies are quite different. The various theories have their reasonable side, but they still cannot fully solve a series of issues, for example, whether trade is beneficial to the improvement of TFP and high-quality development through spillovers. Secondly, although the empirical research has reached a consistent conclusion in most cases, the use of empirical estimation methods is still insufficient, and it is difficult to strictly control the important external factor such as spillovers. Thirdly, there are few studies combining the spatial interdependence with the endogenous economic growth theory, and even few studies realising the mutual verification between theory and practice.

3. Theoretical discussion

Consider that there are n countries in a world economy. There is a fixed number L_i of people for country i, each of whom lives forever and has a constant flow of one unit of labor that can be used in manufacturing. Suppose that people's utility function is only related to consumption (c), namely$c$

$$u(c) = \frac{c^{1-\varepsilon}}{1-\varepsilon} \qquad \varepsilon>0 \tag{1}$$

By Euler equation, we can find the relation between the economic growth rate (g), the interest rate (r) and the consumer preference (η), precisely

$$g = \frac{r-\eta}{\varepsilon} \tag{2}$$

3.1. Final product

Assume that one final product, produced under perfect competition by one unit of labor $L_i(t)$ and a continuum of intermediate products in the interval $[0, M_i(t)]$, and $M_i(t)$ can be used to measure the variety of intermediate product. Following Broda et al. (2017) and Tientao et al. (2016), the production function of the final product is shown as follows

$$Y_i(t) = [A_i(t)L_i(t)]^{1-\alpha}\left[\int_0^{M_i(t)} (x_{i,\nu}(t))^{\nu} d\nu\right]^{\frac{\alpha}{\nu}} \tag{3}$$

where $Y_i(t)$ represents the output of final products produced by the country i in period t, $A_i(t)$ represents the level of productivity for the country i, $\alpha \in [0, 1]$ represents the share of labor in output, and $\nu \in [0, 1]$ is used to measure the elasticity of substitution among various intermediate products $x_{i,\nu}(t)$. Since the production of one unit of intermediate products requires one unit of final products as capital input, the capital stock that needs to be consumed in the production of intermediate products is as follows

$$K_i(t) = \int_0^{M_i(t)} x_{i,\nu}(t) d\nu \tag{4}$$

At equilibrium, each intermediate is demanded to the same extent $x_i(t) = x_{i,\nu}(t)$ (Grossman & Helpman, 1991). The expression of capital stock can be further simplified as $K_i(t) = M_i(t)x_i(t)$, and the production function of final products can be written as follows

$$Y_i(t) = A_i(t)^{1-\alpha} L_i(t)^{1-\alpha} M_i(t)^{\left(\frac{1-\nu}{\nu}\right)\alpha} K_i(t)^{\alpha} \tag{5}$$

According to $\frac{\partial Y_i(t)}{\partial M_i(t)} = \alpha\left(\frac{1-\nu}{\nu}\right)\frac{Y_i(t)}{M_i(t)} > 0$, it can be inferred that the output of final products increases with an increase in the variety of intermediate products.

3.2. Intermediate product

There are many kinds of intermediate products, and each kind of intermediate produced by the most efficient enterprise in industry. The (monopoly) enterprise seeks to maximise its profit in period t, namely

$$\Pi_{i,\nu}(t) = p_{i,\nu}(t)x_{i,\nu}(t) - x_{i,\nu}(t) \tag{6}$$

where $p_{i,\nu}(t)$ represents the price of intermediate product. This price is related to the marginal productivity of final products, namely

$$p_{i,\nu}(t) = \frac{\partial Y_i(t)}{\partial x_{i,\nu}(t)} = \alpha[A_i(t)L_i(t)]^{1-\alpha} x_{i,\nu}^{\alpha-1}(t) \tag{7}$$

The monopoly enterprise maximises its profit by making output decision $x_i(t)$, and the first order condition can be found

$$\frac{\partial \Pi_{i,\nu}(t)}{\partial x_{i,\nu}(t)} = \alpha^2[A_i(t)L_i(t)]^{1-\alpha} x_{i,\nu}^{\alpha-1}(t) - 1 = 0 \tag{8}$$

By simplifying the above equation, we obtain the optimal output of intermediate products, namely

$$x_i(t) = A_i(t)L_i(t)\alpha^{\frac{2}{1-\alpha}} \tag{9}$$

Substituting Equations (7) and (9) into Equation (6), we obtain

$$\Pi_{i,\nu}(t) = \left[\alpha[A_i(t)L_i(t)]^{1-\alpha}\left[A_i(t)L_i(t)\alpha^{\frac{2}{1-\alpha}}\right]^{\alpha-1} - 1\right]A_i(t)L_i(t)\alpha^{\frac{2}{1-\alpha}} = \frac{1-\alpha}{\alpha}A_i(t)L_i(t)\alpha^{\frac{2}{1-\alpha}} \tag{10}$$

3.3. Total factor productivity

Following Coe and Helpman (1995) and Coe et al. (2009), the production function of final products (Equation 5) can be rewritten as follows

$$TFP_i(t) = \frac{Y_i(t)}{L_i(t)^{1-\alpha}K_i(t)^{\alpha}} = A_i(t)^{1-\alpha}M_i(t)^{\frac{(1-\nu)\alpha}{\nu}} \tag{11}$$

According to the above equation, $TFP_i(t)$ is composed of two parts: the quality component $A_i(t)^{1-\alpha}$ and the variety component $M_i(t)^{\frac{(1-\nu)\alpha}{\nu}}$. On the one hand, TFP will increase with technological progress ($A_i(t)$); on the other hand, TFP will increase with the enrichment of the variety of intermediate products ($M_i(t)$).

3.3.1. Quality component of TFP

Generally, the closer one country's technology is to the world's technology frontier, the higher its level of technology will be, and the less the benefit from other countries through technological externalities (Coe & Helpman, 1995). Referring to the existing research designs (Ertur & Koch, 2011; Tientao et al., 2016), the quality component of TFP ($A_i(t)^{1-\alpha}$) is defined as the following form:

$$A_i(t)^{1-\alpha} = \zeta\prod_{j=1}^{n}\left(\frac{TFP_j(t)}{TFP_i(t)}\right)^{\gamma w_{ij}} \tag{12}$$

where $\gamma \in [-1, 1]$ represents the degree of technology diffusion, and w_{ij} indicates the spatial correlation between countries. More details about w_{ij} will be shown later. The world's technology frontier[2] is defined by the average TFP level of all countries in the world. $TFP_j(t)$ represents the TFP level of country j, where $j \neq i$ and $j = 1, 2, \ldots, n$. Further, substituting the Equation (12) into Equation (11), we can obtain

$$TFP_i(t) = \zeta\prod_{j=1}^{n}\left(\frac{TFP_j(t)}{TFP_i(t)}\right)^{\gamma w_{ij}} M_i(t)^{\frac{(1-\nu)\alpha}{\nu}} \tag{13}$$

3.3.2. Variety component of TFP

For the variety component of TFP, Grossman and Helpman (1991) assume that one country's TFP depends on its own R&D and human capital stock as well as on the R&D and human capital efforts of its trading partners. Based on this, the following formula is used to describe the variety component

$$M_i(t)^{\frac{(1-\nu)\alpha}{\nu}} = R_i^{\theta}(t)H_i^{\psi}(t)\prod_{j=1}^{n}\left(R_j^{\theta}(t)H_j^{\psi}(t)\right)^{\gamma w_{ij}} \tag{14}$$

where R_i is the R&D capital investment of country i, R_j is the R&D capital investment of its trading partner countries; H_i and H_j capture the human capital investment for country i and its trading partner countries j with $j = 1, 2, \ldots, n$; $\theta > 0$ represents the elasticity of R&D capital investment to technology progress, $\psi > 0$ represents the elasticity of human capital investment to technology progress. Plugging Equation (14) into Equation (13), the expression of TFP with quality component and variety component can be rewritten as follows

$$TFP_i(t) = \zeta\prod_{j=1}^{n}\left(\frac{TFP_j(t)}{TFP_i(t)}\right)^{\gamma w_{ij}} R_i^{\theta}(t)H_i^{\psi}(t)\prod_{j=1}^{n}\left(R_j^{\theta}(t)H_j^{\psi}(t)\right)^{\gamma w_{ij}} \tag{15}$$

3.4. Spatial econometric framework

By taking the above formula in logarithm form, we have

$$\begin{aligned}\ln TFP_i(t) = \beta_0 + \beta_1 \ln R_i(t) + \beta_2 \ln H_i(t) + \rho\sum_{j=1}^{n} w_{ij} \ln TFP_j(t) \\ + \lambda_1\sum_{j=1}^{n} w_{ij} \ln R_j(t) + \lambda_2\sum_{j=1}^{n} w_{ij} \ln H_j(t)\end{aligned} \tag{16}$$

where $\sum_{j=1}^{n} w_{ij}$ is the interaction matrix ($n \times n$), in other terms, spatial weight matrix, and elements w_{ij} indicate the way country i is spatially connected to country j. In order to normalise the outside influence upon each country, the weight matrix is standardised such that the elements of a row sum up to 1. Besides, $\rho \equiv \frac{\gamma}{2} > 0$ is the autoregressive coefficient which captures the impact of neighboring trading partner country's TFP on the country i's TFP; $\beta_1 \equiv \frac{\theta}{2} > 0$ and $\beta_2 \equiv \frac{\psi}{2} > 0$ are the coefficients which captures the impact of R&D capital investment and that of human capital investment; $\lambda_1 \equiv \frac{\gamma\theta}{2} > 0$ and $\lambda_2 \equiv \frac{\gamma\psi}{2} > 0$ measure, respectively the average impact of R&D capital investment and that of human capital investment for neighboring trading partner countries on the country i's TFP, $\beta_0 \equiv \frac{\ln\zeta}{2} > 0$ is a constant term. Therefore, it can be seen that Equation (16) contains the spatial lag terms of both dependent variable (TFP) and independent variables (R&D capital investment and human capital investment), which is consistent with the characteristics of Spatial Dubin Model constructed by LeSage and Pace (2009).

4. Empirical analysis

4.1. Variable definition and data source

The research sample covers 69 countries from 2000 to 2015, mainly including TFP, R&D capital investment, human capital investment, import, export and others. The related data are from the WDI database of the World Bank and the latest Groningen Growth and Development Penn World Table from the University of Groningen, the Netherlands. The variable definition is described in Table 1.

4.2. Distance setting and spatial weight matrix

The spatial weight matrix is commonly used in spatial econometrics to describe the spatial interdependencies between observations. In this study, we use geographic distance (*Dist*), economic distance (*Eco*) and cultural distance (*Cul*) to build the spatial weight matrix.

4.2.1. Geographic distance

Consider that the increase of geographic distance accelerates the decay of spatial spillover effect, the decreasing function of pure geographical distance between countries is used to construct the spatial weight matrix.

Table 1. Variable definition and description.

	Variable	Symbol	Definition and computation method	Data source
Explained variable	Total factor productivity	*TFP*	The value of CTFP, which is a measure index of TFP from the latest Groningen Growth and Development Penn World Table from the University of Groningen, the Netherlands, is used to measure the TFP of countries. More details about the computation method can be found in Feenstra et al. (2015).	Penn World Table (PWT version 9.1) database
Explanatory variables	R&D capital investment	*R*	The level of R&D capital investment is measured by the R&D expenditure as a percentage of GDP.	The WDI database of the World Bank
	Human capital investment	*L*	Using the human capital index as a proxy variable for human capital investment, the calculation method of the human capital index can be found in Feenstra et al. (2015)	Penn World Table (PWT version 9.1) database
Control variables	Population scale	*P*	Reflecting the share of each country's population in total global population in the year.	The WDI database of the World Bank
	Land area	*S*	The difference in land occupation in each country is reflected by calculating the deviation of the per capital land area of each country from the global average of the year.	The WDI database of the World Bank
	Trade openness	*O*	Based on the proportion of trade in national GDP.	The WDI database of the World Bank
	Economic growth rate	*G*	In order to ensure the comparability of the GDP data of various countries, the US dollar price in 2000 is selected as basis to compute the actual GDP value.	The WDI database of the World Bank

Source: PWT and WDI databases.

$$\begin{cases} w_{ij}^{Dist} = \dfrac{1}{dist_{ij}^2}, & if\, i \neq j \\ w_{ij}^{Dist} = 0, & if\ i = j \end{cases} \tag{17}$$

where $dist_{ij}$ is measured by the distance between the national capitals of countries in the sample, and w_{ij}^{Dist} is the element of spatial weight matrix. Note that the distance between the national capitals of various countries is calculated based on the CEPII database.

4.2.2. Economic distance

Since TFP can be affected by other non-geographical neighboring factors, we try to use economic distance to describe the spatial interdependence of TFP between countries. The form of spatial weight matrix from the perspective of economic characteristics is shown as follows

$$w_{ij}^{Eco} = w_{ij}^{Dist} diag\left(\frac{\overline{GDP_1}}{\overline{GDP}}, \frac{\overline{GDP_2}}{\overline{GDP}}, \ldots, \frac{\overline{GDP_n}}{\overline{GDP}}\right) \tag{18}$$

where $\overline{GDP_i} = \frac{1}{t_1 - t_0 + 1}\sum_{t=t_0}^{t_1} GDP_{it}$, and GDP_{it} represents the average GDP of country i in period t; $\overline{GDP} = \frac{1}{n(t_1 - t_0 + 1)}\sum_{i=1}^{n}\sum_{t=t_0}^{t_1} GDP_{it}$. The advantage of this spatial weight matrix is that both economic and geographical factors can be considered at the same time.

4.2.3. Cultural distance

Language can reflect the level of cultural exchanges between countries. Therefore, by adopting Dunlevy's method (Dunlevy, 2006), we use 'linguistic' variable to measure the cultural distance between 69 countries. To be specific, this variable equals to 1 when two countries have a common language, and it will be 0 if non-common language. Based on the linguistic connection among countries, the (row standardization) spatial weight matrix w_{ij}^{Cul} can be generated. Relevant data are from CEPII database.

4.3. Spatial autocorrelation

Using the global Moran's I index to characterise the spatial autocorrelation of $TFP_i (i = 1, 2, \ldots, 69)$, specifically

$$Moran\text{'s } I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}^{m}\left(TFP_i - \overline{TFP}\right)\left(TFP_j - \overline{TFP}\right)}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}^{m}} \tag{19}$$

where $S^2 = \frac{1}{n}\sum_{i=1}^{n}(TFP_i - \overline{TFP})^2$ and $\overline{TFP} = \frac{1}{n}\sum_{i=1}^{n} TFP_i$; the superscript of w_{ij}^{m} indicates the m types of the spatial weight matrix, including $Dist, Eco$ and Cul. The Moran's I index will be a value between -1 and 1. Positive spatial autocorrelation shows values that are clustered, negative autocorrelation is dispersed, and random is close to zero.

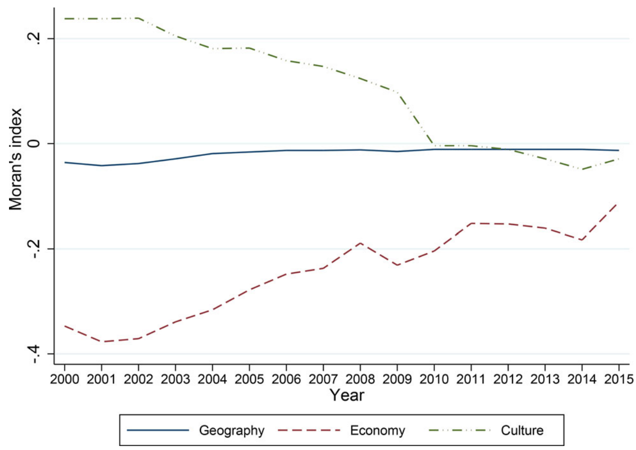

Figure 1. The trend of Moran's I index.
Source: PWT and WDI databases.

Figure 1 shows the trend of the Moran's I on TFP from 2000 to 2015. It is shown that the Moran's I index calculated based on geographical distance and economic distance is always negative, indicating that the variable TFP reflects a 'competition' relation between neighboring trading partner countries to some extent. However, the Moran's I calculated based on cultural distance shows a changing trend of 'first positive and then negative'. Overall, TFP between neighboring countries has a certain spatial autocorrelation. Therefore, it is necessary to introduce spatial factors into subsequent analysis.

4.4. Estimation results

Based on geographical, economic and cultural distance criteria ($\mathbf{W}^{Dist}$, $\mathbf{W}^{Eco}$, $\mathbf{W}^{Cul}$), respectively, the Spatial Durbin Model for panel data (Equation (16)) is estimated. Table 2 shows that the spatial autocorrelation coefficients of TFP ρ are significant under three different types of spatial weight matrix, which indicates that the Spatial Dubin Model derived from theoretical study is effective. Furthermore, the existence of spatial lag and spatial error effects is confirmed by Wald test and LR test.[3] This means that the Spatial Dubin Model derived from economic theory is reasonable. Finally, the results of Hausman test confirm that the Fixed Effect model is more reasonable and reliable for estimation under the three different types of spatial weight matrix.

Due to the spatial lagged factor in the Spatial Durbin Model for penal data, we cannot directly capture the precise influence of R&D capital investment and that of human capital investment on TFP from Table 2. However, we can still draw the following conclusions. First, regardless of the spatial weight matrix, the coefficients of R&D capital investment and human capital investment are always significantly positive, indicating that the innovation investment (both R&D capital input and human capital input) can significantly improve its own TFP level. Second, in the case of $\mathbf{W}^{Dist}$ and $\mathbf{W}^{Eco}$, the coefficients of spatial lagged variable $\mathbf{W}R$ are not significant, while the coefficient of $\mathbf{W}R$ is significantly positive under $\mathbf{W}^{Cul}$. This means that

Table 2. Estimation results of Spatial Durbin Model for panel data.

Explained variable		TFP					
		$\mathbf{W}^{Dist}$		$\mathbf{W}^{Eco}$		$\mathbf{W}^{Cul}$	
Spatial weight matrix		FE	RE	FE	RE	FE	RE
Explanatory variables	R	0.0200**	0.0177*	0.0248***	0.0343***	0.0191**	0.0119
		(0.0086)	(0.0094)	(0.0085)	(0.0094)	(0.0089)	(0.0094)
	L	0.2759***	0.0242	0.3578***	0.1207***	0.2154***	−0.0342
		(0.0493)	(0.0426)	(0.0472)	(0.0396)	(0.0501)	(0.0332)
Spatial lagged variables	$\mathbf{W}R$	−0.2539	0.3831**	0.0506	0.6842***	0.0895***	−0.0226
		(0.2676)	(0.1743)	(0.2124)	(0.0971)	(0.0320)	(0.0304)
	$\mathbf{W}L$	5.2207***	−0.5198***	5.0019***	−0.6904***	0.1393**	−0.0023
		(1.0678)	(0.1763)	(0.8334)	(0.1066)	(0.0582)	(0.0266)
Control variables	P	0.1614**	0.0694**	0.5311***	0.0378***	0.3407***	0.0467*
		(0.0633)	(0.0288)	(0.0619)	(0.0224)	(0.0669)	(0.0306)
	S	1.734***	0.0876***	2.6728***	0.0445***	2.0063***	0.0743***
		(0.2252)	(0.0206)	(0.2268)	(0.0158)	(0.2380)	(0.0211)
	O	0.0011***	0.0014***	0.0686***	0.1178***	0.1181***	0.1295***
		(0.0002)	(0.0002)	(0.0230)	(0.0239)	(0.0239)	(0.0233)
ρ		−1.3810***	−0.4065***	−0.4935***	−0.4231***	0.2724***	0.2591***
		(0.2107)	(0.1484)	(0.1789)	(0.1095)	(0.0474)	(0.0474)
σ^2		0.0077***	0.0106***	0.0075***	0.0106***	0.0085***	0.0106***
		(0.0003)	(0.0005)	(0.0003)	(0.0004)	(0.0004)	(0.0004)
Hausman test		$Chi^2(8) = 350.91$		$Chi^2(8) = 352.14$		$Chi^2(8) = 362.44$	
		$Prob >= Chi^2 = 0.000$		$Prob >= Chi^2 = 0.000$		$Prob >= Chi^2 = 0.000$	
Wald test		$Chi^2(2) = 24.09$		$Chi^2(2) = 48.15$		$Chi^2(2) = 9.88$	
		$Prob > Chi^2 = 0.000$		$Prob > Chi^2 = 0.000$		$Prob > Chi^2 = 0.007$	
LR test		$Chi^2(2) = 20.34$		$Chi^2(2) = 38.73$		$Chi^2(2) = 8.79$	
		$Prob > Chi^2 = 0.000$		$Prob > Chi^2 = 0.000$		$Prob > Chi^2 = 0.012$	

Notes: FE represents fixed effect model; RE represents random effect model; standard error is in brackets (); *** indicates $p < 0.01$, ** indicates $p < 0.05$, * indicates $p < 0.1$; $\mathbf{W}^{Dist}$ represents the spatial weight matrix based on geographic distance, $\mathbf{W}^{Eco}$ represents the spatial weight matrix based on economic distance, $\mathbf{W}^{Cul}$ represents the spatial weight matrix based on cultural distance.
Source: Author's calculation.

R&D capital investment has no spatial effect on TFP of geographically or economically adjacent countries, but it has a significant 'spillover effect' on TFP of culturally adjacent countries. 'Cultural communication' is beneficial to the capability of cooperative innovation in R&D between countries. Third, under three different types of spatial weight matrix, the estimated coefficient of $\mathbf{W}L$ are all significantly positive, indicating that the investment in human capital is conducive to the mutual promotion and synergistic development of TFP between neighboring trading partner countries no matter in geographical, economic or cultural aspects. Fourth, the estimated coefficients of control variables P and S are significantly positive under three different types of spatial weight matrix, indicating that countries with 'more people and more land' are more likely to positively promote their TFP through 'large county effect' (Li & Ouyang, 2016). The influence of trade openness O is significantly positive, indicating that the expansion of international market size and the strengthening pressure of market competition can also effectively improve the local TFP level.

4.5. Robustness

The robustness of the estimated results is tested by adjusting the number of control variables in the Spatial Dubin Model for penal data. According to the estimation

Table 3. Robustness test based on geographical spatial weight matrix.

Explained variable		TFP					
		$\mathbf{W}^{Dist}$					
Spatial weight matrix		FE	FE	FE	FE	FE	FE
Explanatory variables	R	0.0200**	0.0644***	0.0686***	0.0593***	0.0706***	0.0770***
		(0.0086)	(0.0154)	(0.0158)	(0.0153)	(0.0155)	(0.0159)
	L	0.2759***	0.3387***	0.2872***	0.2868***	0.3455***	0.2926***
		(0.0493)	(0.0498)	(0.0506)	(0.0497)	(0.0500)	(0.0510)
Spatial lagged variables	$\mathbf{W}R$	−0.2539	0.4493	0.7035	0.6213**	0.2896	0.5167
		(0.2676)	(0.4498)	(0.7669)	(0.2465)	(0.2465)	(0.5524)
	$\mathbf{W}L$	5.2207***	5.5273***	5.6878***	5.1452***	6.7339***	7.2598***
		(1.0678)	(1.0653)	(1.0909)	(1.0351)	(1.0288)	(1.0534)
Control variables	P	0.1614**	0.2347***	0.2972***	–	–	–
		(0.0633)	(0.0646)	(0.0659)			
	S	1.7340***	1.7827***	–	1.6911***	1.8750***	–
		(0.2252)	(0.2291)		(0.2255)	(0.2286)	
	O	0.0011***	–	–	0.0013***	–	–
		(0.0002)			(0.0002)		
	G	–	–	–	−0.0017*	−0.0008	−0.0011
					(0.0009)	(0.0009)	(0.0009)
ρ		−1.3810***	−1.3856***	−1.3909***	−1.3875***	−1.4304***	−1.4450***
		(0.2107)	(0.2109)	(0.2120)	(0.2095)	(0.2067)	(0.2069)
σ^2		0.0077***	0.0079***	0.0083***	0.0076***	0.0079***	0.0084***
		(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)
Hausman test		$Chi^2(8) = 350.91$ Prob>= Chi^2 = 0.000	$Chi^2(7) = 245.03$ Prob>= Chi^2 = 0.000	$Chi^2(6) = 76.81$ Prob>= Chi^2 = 0.000	$Chi^2(8) = 431.53$ Prob>= Chi^2 = 0.000	$Chi^2(7) = 271.51$ Prob>= Chi^2 = 0.000	$Chi^2(6) = 75.97$ Prob>= Chi^2 = 0.000

Notes: FE represents fixed effect model; *** indicates $p < 0.01$, ** indicates $p < 0.05$, * indicates $p < 0.1$; $\mathbf{W}^{Dist}$ represents the spatial weight matrix based on geographic distance; standard error is in brackets ().
Source: Author's calculation.

Table 4. Robustness test based on economic spatial weight matrix.

Explained variable		TFP					
		$\mathbf{W}^{Eco}$					
Spatial weight matrix		FE	FE	FE	FE	FE	FE
Explanatory variables	R	0.0248***	0.0192***	0.0224	0.0213	0.0288*	0.0340**
		(0.0085)	(0.0056)	(0.0165)	(0.0159)	(0.0162)	(0.0173)
	L	0.3578***	0.3752***	0.2581***	0.2837***	0.3247***	0.1900***
		(0.0472)	(0.0473)	(0.0493)	(0.0483)	(0.0488)	(0.0511)
Spatial lagged variables	$\mathbf{W}R$	0.0506	0.3624*	0.2622	0.3860*	0.5957***	0.5081**
		(0.2124)	(0.2017)	(0.2145)	(0.2076)	(0.2094)	(0.2239)
	$\mathbf{W}L$	5.0019***	5.2248***	4.0323***	4.4667***	4.8574***	3.4596***
		(0.8334)	(0.7382)	(0.7590)	(0.7547)	(0.7621)	(0.7836)
Control variables	P	0.5311***	0.5553***	0.6273***	–	–	–
		(0.0619)	(0.0597)	(0.0633)			
	S	2.6728***	2.7696***	–	2.7374***	2.9838***	–
		(0.2268)	(0.2268)		(0.2334)	(0.2351)	
	O	0.0686***	–	–	0.0012***	–	–
		(0.0230)			(0.0001)		
	G	–	–	–	−0.0007	−0.0001	−0.0002
					(0.0008)	(0.0009)	(0.0010)
ρ		−0.4935***	−0.4964***	−0.4863***	−0.3763***	−0.4092***	−0.3997***
		(0.1789)	(0.1791)	(0.1836)	(0.1833)	(0.1839)	(0.1885)
σ^2		0.0077***	0.0075***	0.0086***	0.0078***	0.0082***	0.0094***
		(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)
Hausman test		$Chi^2(8)=352.14$ Prob>= $Chi^2=0.000$	$Chi^2(7)=410.93$ Prob>= $Chi^2=0.000$	$Chi^2(6)=32.16$ Prob>= $Chi^2=0.000$	$Chi^2(8)=356.17$ Prob>= $Chi^2=0.000$	$Chi^2(7)=341.40$ Prob>= $Chi^2=0.000$	$Chi^2(6)=20.18$ Prob>= $Chi^2=0.003$

Notes: FE represents fixed effect model; *** indicates $p < 0.01$, ** indicates $p < 0.05$, * indicates $p < 0.1$; $\mathbf{W}^{Eco}$ represents the spatial weight matrix based on geographic distance; standard error is in brackets ().
Source: Author's calculation.

Table 5. Robustness test based on cultural spatial weight matrix.

Explained variable		TFP					
		$\mathbf{W}^{Cul}$					
Spatial weight matrix		FE	FE	FE	FE	FE	FE
Explanatory variables	R	0.0191** (0.0089)	0.0386** (0.0160)	0.0432*** (0.0166)	0.0370** (0.0158)	0.0559*** (0.0160)	0.0632*** (0.0167)
	L	0.2154*** (0.0501)	0.2590*** (0.0503)	0.1984*** (0.0517)	0.2095*** (0.0501)	0.2545*** (0.0511)	0.1895*** (0.0526)
Spatial lagged variables	$\mathbf{W}R$	0.0895*** (0.0320)	0.1599*** (0.0450)	0.1281*** (0.0465)	0.1141** (0.0448)	0.1550*** (0.0457)	0.1206** (0.0473)
	$\mathbf{W}L$	0.1393** (0.0582)	0.1948*** (0.0612)	0.2375*** (0.0632)	0.2113*** (0.0592)	0.2894*** (0.0600)	0.3474*** (0.0621)
Control variables	P	0.3407*** (0.0669)	0.3928*** (0.0660)	0.4430*** (0.0682)	–	–	–
	S	2.0063*** (0.2380)	2.1541*** (0.2405)	–	2.0737*** (0.2382)	2.2729*** (0.2434)	–
	O	0.1181*** (0.0239)	–	–	0.0014*** (0.0002)	–	–
	G	–	–	–	−0.0014 (0.0009)	−0.0004 (0.0009)	−0.0006 (0.0009)
ρ		0.2724*** (0.0474)	0.2585*** (0.0488)	0.2390*** (0.0500)	0.2717*** (0.0483)	0.2625*** (0.0491)	0.2426*** (0.0504)
σ^2		0.0085*** (0.0004)	0.0087*** (0.0003)	0.0093** (0.0004)	0.0085*** (0.0003)	0.0089*** (0.0003)	0.0097*** (0.0004)
Hausman test		$Chi^2(8)=362.44$ Prob> = $Chi^2=0.000$	$Chi^2(7)=305.66$ Prob> = $Chi^2=0.000$	$Chi^2(6)=17.41$ Prob> = $Chi^2=0.007$	$Chi^2(8)=345.72$ Prob> = $Chi^2=0.000$	$Chi^2(7)=296.22$ Prob> = $Chi^2=0.000$	$Chi^2(6)=18.43$ Prob> = $Chi^2=0.000$

Notes: FE represents fixed effect model; *** indicates $p < 0.01$, ** indicates $p < 0.05$, * indicates $p < 0.1$; $\mathbf{W}^{Cul}$ represents the spatial weight matrix based on geographic distance; standard error is in brackets ().
Source: Author's calculation.

Table 6. Direct effect and indirect effect.

	$\mathbf{W}^{Dist}$		$\mathbf{W}^{Eco}$		$\mathbf{W}^{Cul}$	
Spatial weight matrix	*R*	*L*	*R*	*L*	*R*	*L*
Direct effect	0.0251***	0.1903***	0.0247***	0.3150***	0.0236**	0.2101***
$[(I-\rho\mathbf{W})^{-1}(\beta_k I_N)]\bar{d}$	(0.0090)	(0.0464)	(0.0083)	(0.0468)	(0.0094)	(0.0489)
Indirect effect	−0.1162	2.1368***	0.0394	3.3627***	0.0877***	0.0738*
$[(I-\rho\mathbf{W})^{-1}(\beta_k I_N)]^{\overline{rsum}}$	(0.1191)	(0.6172)	(0.1502)	(1.0112)	(0.0289)	(0.0578)
Combined effect	−0.0912	2.3272***	0.0641	3.6778***	0.1113***	0.2839***
	(0.1170)	(0.6255)	(0.1512)	(1.0271)	(0.0328)	(0.0847)

Notes: *** indicates $p<0.01$, ** indicates $p<0.05$, * indicates $p<0.1$; standard error is in brackets (); I represents the identity matrix; $\bar{d}$ represents an operator that computes the mean of diagonal elements of the matrix; $\overline{rsum}$ represents an operator that calculating the mean of non-diagonal elements of the matrix; β_k is a coefficient vector of each influencing factor; Combined effect = Direct effect + Indirect effect.
Source: Author's calculation.

results shown in Tables 3–5, the estimation results are robust and the model is reliable.

4.6. Direct effect and indirect effect

Local R&D capital investment and human capital investment will not only affect local TFP (direct effect), but also may indirectly affect neighboring countries' TFP (indirect effect) (Behrens et al., 2007). Therefore, referring to the ideas of Vega and Elhorst (2015), the influence of R&D capital and human capital investment on TFP can be further decomposed into direct effect[4] and indirect effect.[5] Since each variable in the Spatial Dubin Model (Equation (16)) is logarithmic, the estimated results in Table 6 can be interpreted as elasticity.

From the perspective of direct effect, under three different types of spatial weight matrix, both R&D capital investment and human capital investment can play a significant role in promoting the TFP. To be specific, regardless of spatial weight matrix, the positive influences of R&D capital investment on TFP are very close. TFP will increase by 0.023% to 0.025% for every 1% increase in R&D capital investment. Nevertheless, under the spatial weight matrix based on economic distance, the human capital investment generates the strongest promotion effect on TFP. The level of TFP will increase by 0.315% for every 1% increase in human capital investment.

From the perspective of indirect effect, under the spatial weight matrix based on geographical or economic distance, the effect of R&D capital investment on TFP of neighboring countries is not significant. However, under the spatial weight matrix based on cultural distance, R&D capital investment plays a significant positive role in promoting TFP of neighboring countries. For every 1% increase in R&D capital investment, the TFP level of neighboring countries will increase by 0.087%. This finding further confirms the positive role of 'cultural communication' in promoting the collaborative innovation capability between countries.

It is also found that no matter what kind of spatial weight matrix, the human capital investment always promotes TFP of neighboring countries. For every 1% increase in human capital investment, the TFP level of 'economic neighbors' will increase by 3.363%. This shows that when countries have similar economic conditions and there is a certain economic exchange foundation, the human capital investment can play a strong 'synergy'. In addition, the influence intensity of human capital investment can be order as 'economic distance > geographical distance > cultural distance'. It is worth noting that the indirect effect of human capital investment on TFP is stronger than the direct effect. This can be explained by the 'diffusion effect' and 'reflux effect' of Myrdal (1957). One country's investment in human capital will play an exemplary and driving role for its economic neighbors (diffusion effect). This will often accelerate the TFP improvement of neighboring countries, and bring a strong positive spillover effect. Especially when the TFP level of neighboring countries is high, human capital often flows from the less developed country to the higher TFP country (reflux effect), which further intensifies the indirect effect of human capital investment on TFP. Besides, when there is only a strong basis for language and cultural exchange between countries, the TFP level of 'cultural neighbors' will only increase 0.074% for every 1% increase in human capital input. This shows that language and culture can promote the flow of human capital between countries, and then promote the TFP of cultural neighboring countries. However, compared with 'economic neighbors', the impacts of human capital investment on 'cultural neighbors' are still insufficient.

5. Conclusion and policy suggestions

In the context of spatial interdependence between countries, the paper uses a new method to estimate technology externalities. Using economic theory to derive the empirical estimation model is not only beneficial to better explain the technological externalities through international trade and inter-country distance (geographical distance, economic distance and cultural distance), but also conducive to solve a series of problems from the perspective of spatial correlation. In this paper, based on endogenous economic growth model, the TFP is divided theoretically into two parts: quality component and variety component. The former mainly reflects the gap between a country's existing technological level and the world's technology frontier, while the latter reflects the enhancement effect of increasing product diversities and quantities on TFP. In the empirical analysis, based on the geographic, economic and cultural spatial weight matrix, respectively, we investigate the spatial correlation between neighboring countries' TFP and the impact of R&D capital investment and human capital investment on the TFP of 69 countries from 2000 to 2015 by using the deduced Spatial Dubin Model. It is found that (1) there is an obvious spatial correlation between neighboring countries' TFP, the TFP of geographical and economic neighboring countries shows 'competition effect', while the TFP of cultural neighboring countries shows 'first spillover effect, then competition effect'. (2) No matter from the perspective of geographical proximity, economic proximity or cultural proximity, the human capital investment of neighboring countries is conducive to realising the mutual promotion and synergistic development of TFP between neighboring countries. (3) The cultural communication can promote the flow of human capital between countries and then promote the TFP of cultural neighboring countries. However, compared with 'economic neighbors', the impacts of human capital investment on 'cultural neighbors' are still insufficient. In general, technology spillovers caused by international trade are not only an important factor for countries to promote technological progress, but also the core driving force to achieve high-quality development. According to the main conclusions of the paper, the following suggestions are put forward:

First, improving TFP is the key to promoting 'high-quality development'. Relevant government departments should actively expand the import scale of high-tech products to promote domestic R&D innovation and narrow the gap with the world's technology frontier, so as to improve the TFP level.

Second, relevant government departments should actively pay attention to the depth of imported products and the breadth of market development, promote the development of international trade by expanding the scope of zero-tariff goods, perfecting the information platform of imported goods and other ways, in order to gain the benefits of international trade through spillovers.

Third, coordinated development between countries is beneficial to promoting technology spillovers, therefore, relevant government departments could pay attention to the diversified and coordinated development of trade partner countries, actively strengthen bilateral trade relations with neighboring countries, to improve the 'welfare' brought by technological externalities.

Fourth, human capital is crucial to promoting high-quality development, relevant government departments should further increase human capital investment, vigorously develop higher education and train more high-quality talents to enhance the country's ability to absorb the world's technology frontier.

Notes

1. Total factor productivity is a measure of productivity calculated by dividing economy-wide total production by the weighted average of inputs. TFP can not only directly reflect the contribution of scientific and technological progress and resource allocation efficiency, measure the quality of development, but also provide a basic path to improve the quality of development.
2. In general, the world's technology frontier is commonly defined by the two methods: first, compute the geometric mean of TFP in all countries; second, select the United States' technological level as the world's technology frontier.
3. By Wald test and LR test, it is possible to determine whether the Spatial Durbin Model is degraded to a Spatial Error Model through testing $\lambda = -\rho\beta$, and whether it can be degraded to a Spatial Autoregressive Model through testing $\lambda = 0$.
4. The direct effect is the overall influence of a factor change on the TFP of neighboring countries, which also includes the spatial feedback effect.
5. Indirect effect refers to the influence of a factor change on the TFP of neighboring countries, that is, the spatial spillover effect of influencing factors.

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