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The spatial analysis of FDI, R&D and economic growth in China

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ABSTRACT

This study aims to examine the spatial spillover effects of foreign direct investment (FDI) and research and development (R&D) on China's economic growth. Using panel data from 30 provinces between 2000 and 2022, the study applies spatial econometric models incorporating foreign trade openness, government expenditure, and population to capture interregional dynamics. The results reveal that both FDI and R&D significantly enhance provincial economic growth and exert positive spatial spillover effects on neighboring regions. Specifically, a 1% increase in FDI and R&D capital stock raises GDP by 0.02% and 0.05%, respectively, while interprovincial spillovers contribute 0.71% to the growth of adjacent provinces. These findings suggest that institutional innovation, regional cooperation, and the establishment of high-quality FDI-driven R&D centers are crucial to fostering a sustainable FDI–R&D–regional growth mechanism in China's economy.

Contribution/ Originality: This study identifies regional heterogeneity in the spatial spillover effects of FDI and R&D on economic growth in China. It integrates spatial econometrics into FDI-growth analysis and highlights policy pathways for regional cooperation, innovation, and high-quality economic development.

1. INTRODUCTION

China's economy has transitioned from high-speed growth to high-quality development (Gao, Li, & Hao, 2024; Guo, Deng, Wang, & Yang, 2024). Since the reform and opening-up, the country has maintained rapid expansion, driven initially by factor accumulation and investment-led strategies. Although the average annual gross domestic product (GDP) growth rate exceeded 10% between 1979 and 2010, it moderated to around 5.5% during 2017–2022, reflecting a shift toward innovation-driven and sustainable development. Despite this deceleration, China remains one of the world's largest recipients of foreign direct investment (FDI), and its pattern of capital inflows is evolving from quantity-oriented to quality- and technology-oriented investment.

Research and development (R&D) plays a vital role in fostering technological spillovers, enhancing innovation capacity, and improving the competitiveness of local enterprises; on this note, R&D brought by foreign-invested enterprises (FIEs) has a significant impact on China's economic growth (Imran & Rehman, 2024). Foreign-invested enterprises (FIEs) generally exhibit high R&D intensity, and their activities facilitate the transfer of advanced technology and managerial expertise to local firms through various channels such as demonstration effects, competition, affiliations, and personnel mobility. These spillovers significantly enhance the innovation systems of

domestic enterprises (Islam, Rahaman, & Chen, 2024). In recent years, China has comprehensively relaxed market access conditions and transitioned from traditional openness to institutional openness, promoting greater mobility of commodities and production factors. Consequently, the overall investment environment has continued to improve (Rui & Xiao, 2023). Multinational enterprises (MNEs) increasingly seek greater control over joint ventures, and the prevalence of wholly foreign-owned enterprises (WFOEs) has become more pronounced. The global distribution of R&D activities by WFOEs continues to expand, and their R&D investments in China are steadily increasing. In this context, foreign-invested enterprises (FIEs) are increasingly locating R&D centers in China to exploit the country's large market potential and skilled workforce, further stimulating regional knowledge spillovers.

However, the distribution of FDI and R&D activities across China's regions remains uneven due to natural resources, geographic location, industrial structure, and economic differences between the Eastern, Central, and Western regions. The Eastern region, characterized by mature infrastructure and strong international integration, continues to attract the majority of FDI. Since China's reform and opening-up, nearly all the top ten provinces in attracting foreign investment have been in the Eastern region, particularly the coastal provinces such as Guangdong and Shanghai. The Central and Western regions, though less developed, are experiencing faster relative growth and emerging as new destinations for foreign investment in manufacturing, resources, and new energy sectors. These regional disparities raise important questions about the nature and direction of interregional spillover effects. The Central region has also made notable progress in attracting foreign investment, particularly in the manufacturing and infrastructure sectors (Yang, Anwar, & Yang, 2025) as seen in provinces such as Hunan and Anhui, although the Western region remains relatively less developed, it has become increasingly appealing to foreign investors in areas such as resource extraction and new energy industries (Wong, Lee, Zhao, & Pei, 2020) especially in provinces like Shaanxi and Qinghai. Overall, while foreign-invested enterprises (FIEs) and the realized FDI inflows remain predominantly concentrated in the Eastern region, the Central and Western regions are expanding rapidly, and their latecomer advantages and growth potential are gradually emerging.

Past studies have tended to focus on the relationship between FDI, R&D, and economic growth; limited attention has been paid to the spatial dimension of these linkages, specifically how economic growth in one province may be affected by the FDI and R&D activities of neighboring provinces. Understanding these spatial interactions is essential for designing policies that promote balanced regional development and innovation diffusion across the country. Therefore, the first objective of this study is to examine the spatial spillover effects of FDI and R&D on China's economic growth across 30 provinces from 2000 to 2022 and to analyze the heterogeneity of these spatial effects among the Eastern, Central, and Western regions.

The first contribution of this study is to demonstrate that endogenous technological progress remains a key determinant of economic growth and that the internal driving forces behind China's economic expansion are steadily strengthening. A new development paradigm is emerging in China, characterized by domestic economic circulation as the foundation, complemented by mutually reinforcing domestic and international dual circulations (Jia, 2023). As China gradually loses its traditional advantage of low production costs, the momentum derived from the international cycle has weakened. Consequently, it has become increasingly difficult to sustain long-term economic growth by relying on the role of a low-cost global manufacturing base (Jahanger, 2021).

Under this new dual-circulation paradigm, China is pursuing a higher level of institutional openness to attract high-quality foreign investment and better integrate it into domestic economic activity. Measures such as the implementation of pre-entry national treatment and a negative list management system for foreign investment exemplify this commitment. At the same time, the rise of trade protectionism and ongoing trade frictions between China and the United States have prompted many developed economies to reshore their high-end manufacturing industries (Mohr, Hashai, Puck, Konara, & Reinprecht, 2024; Pillich, 2025). These trends have directly affected China's upstream industrial chains, industrial upgrading, and technological imitation capacity. Moreover, the continued reliance on imported key components and high-end technologies remains a major constraint on China's

economic growth. Therefore, it is both necessary and urgent for China to cultivate new sources of comparative advantage to attract and sustain high-quality foreign investment.

The rest of this study is organized as follows. The next section reviews the existing domestic and international literature. Section 3 presents the model variables, models, and methodology. The subsequent section demonstrates the empirical findings and discussion; the final section discusses the conclusion and policy implications.

2. PAST STUDIES

A number of well-known theories have provided the foundation for studying the relationship between foreign direct investment (FDI), research and development (R&D), and economic growth. Solow's neoclassical model of economic growth (Solow, 1956) emphasizes that capital accumulation, labor input, and technological progress are key drivers of long-term growth, though technological progress is treated as an exogenous variable. In contrast, Romer's endogenous growth theory (Romer, 1990) highlights the role of internal factors such as knowledge creation and innovation, asserting that technological progress arises from firms' R&D activities and is therefore an endogenous outcome of economic systems. Similarly, the regional innovation systems theory (Cooke, 1992) posits that innovation and competitiveness can be enhanced through interactive learning between dynamic and less developed regions. These theoretical frameworks collectively suggest that both FDI and R&D can stimulate technological spillovers, productivity, and long-term economic development.

Empirical studies from both developed and developing economies provide mixed evidence on the FDI–growth relationship. For instance, in the European Union between 2009 and 2018, FDI was found to have a limited impact on poverty reduction and growth (Adilla, 2024), whereas in Namibia, the interaction of FDI with trade openness and government expenditure contributed positively to economic performance (Sunde, 2023). The spatial spillovers and geographical proximity play a critical role in shaping public investment outcomes across African regions (Otieno, 2024). While FDI positively influences both long- and short-run growth in Pakistan through human capital formation (Kanval, Ihsan, Irum, & Ambreen, 2024); FDI in neighboring Vietnamese provinces does not necessarily generate local spillover benefits (Hoang, Huynh, Duong, & Chau, 2022). In the context of Ghana, FDI did not have an effect on economic growth between 1995 and 2017. However, technology positively influenced economic growth, while trade had a significant negative impact on it (Obeng-Amponsah & Owusu, 2025). On this note, Brazilian firms in high-tech sectors benefit from FDI through productivity spillovers (Moralles & Moreno, 2020), and in Indonesia, improved human capital and firm size amplify the positive effects of FDI on R&D and innovation (Yasin, Esquivias, Lau, & Primanthi, 2024). Backward spillovers from downstream MNEs in India's manufacturing sector between 2010 and 2018 were the sole source of total factor productivity improvements, with industry heterogeneity identified as a key determinant of FDI spillovers (Behera, 2023). Together, these studies underscore the importance of absorptive capacity and institutional readiness in realizing the growth benefits of foreign investment.

Chinese scholars have extensively investigated the technology spillover effects and spatial dimensions of FDI and R&D. In China, foreign R&D significantly enhances innovation performance in high-tech industries, generating measurable spatial spillovers across provinces (Han & Feng, 2023) and there are three primary channels of technological diffusion, namely spatial agglomeration, specialization, and technological networks that reinforce innovation capacity in industrial clusters (Xiaoyan, Peng, & Min, 2024). Further evidence shows that FDI-driven technology spillovers enhance innovation quality among non-state and small-to-medium enterprises (Yue, Cao, & Ren, 2022), particularly through mergers, acquisitions, and demonstration effects (Tan, Zhang, & Cao, 2023). These findings suggest that while FDI contributes to regional innovation in China, the scale and effectiveness of spillovers vary widely across regions.

However, despite abundant research on FDI, R&D, and innovation, most studies have examined these elements separately or focused narrowly on specific sectors or provinces. Limited attention has been given to how spatial interdependence among provinces influences economic growth. Many previous studies have treated provinces as

independent entities, neglecting the geographic and economic linkages that allow growth in one region to affect its neighbors. Moreover, while the majority of domestic studies emphasize firm-level mechanisms, relatively few have analyzed spatial heterogeneity in FDI and R&D effects across macro-regions.

Therefore, this study extends the existing literature by incorporating a spatial econometric framework to assess the interregional spillover effects of FDI and R&D on economic growth in China. Using provincial-level panel data from 2000 to 2022, it examines how regional proximity influences both direct and indirect growth effects. The novelty of this study lies in explicitly distinguishing the heterogeneous spatial effects across the Eastern, Central, and Western regions, thereby bridging the empirical gap between traditional growth models and spatial interaction theories. This contributes to a deeper understanding of how innovation, openness, and investment interact to drive high-quality and regionally inclusive economic development in China.

3. METHODOLOGY

This study employs balanced panel data covering 30 provinces, municipalities, and autonomous regions in China from 2000 to 2022. The data were obtained primarily from the National Bureau of Statistics of China (NBS), which provides comprehensive official statistics on regional economic indicators. Supplementary information was cross-verified using the China Statistical Yearbook, China Science and Technology Statistical Yearbook, and provincial statistical bulletins to ensure accuracy and completeness. The analysis follows the conventional regional classification of Eastern, Central, and Western China. The Eastern region consists of Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Guangdong, Fujian, Shandong, Hainan, and Liaoning. The Central region includes Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan. The Western region comprises Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, and Inner Mongolia.

The dependent variable is the real GDP of each province, which measures regional economic growth. Using real GDP eliminates price distortions, allowing for consistent comparisons across time and regions (Boateng, Wisdom, & Atiku, 2025; Manapat & Cabauatan, 2025). The key independent variables are real foreign FDI inflows and R&D capital stock (Neeliah, Seetanah, & Vencataya, 2025; Zhao & Li, 2022). The R&D capital stock was calculated using the perpetual inventory method, with 2000 as the base year, consistent with prior empirical research (Wang, Guo, & Ye, 2025; Zhang, Wu, & Zhang, 2004), as follows.

$$RD_{it} = RD_{it-1}(1 - \delta_{it}) + RDin_{it} \quad (1)$$

Where i represents the ith province and t represents the tth year. The initial value of the R&D capital stock is represented by RD in the base year. The annual increment of R&D input is denoted by RDin, and the corresponding economic depreciation rate is set at 9.6%.

Table 1. Description of variables.

Variable properties	Variable abbreviation	Indicator	Data sources
Dependent variable	GDP	Real GDP	China National Statistical Bureau
Independent variable	FDI	Real FDI inflow	
	RD	R&D capital stock	
Control variable	TO	Trade openness	
	Gov	Real government expenditure	
	Pop	Population	

The control variables include trade openness, government expenditure, and population. Trade openness is defined as the ratio of total trade (exports + imports) to GDP, capturing the degree of integration with global markets. If trade openness is high, it indicates that the economy of the country or region has a high degree of dependence on foreign markets; conversely, it indicates a low degree of dependence (Rehman & Islam, 2023). Government expenditure represents fiscal activity that supports infrastructure, innovation, and human capital formation. The main

purpose of including the government expenditure variable is to maintain the healthy operation and effectiveness of the market, which is to use the visible hand to support the invisible hand, so it will promote or inhibit economic growth to varying degrees (Zhang & Zhang, 2024). Population serves as a proxy for labor supply and market size, reflecting demographic dynamics that influence productivity and consumption (Jones, 2022; Ma & Liu, 2022). All monetary variables were deflated to constant 2000 prices using the GDP deflator to remove inflationary effects. To address potential heteroskedasticity and scale variation, all continuous variables were transformed into natural logarithmic form before estimation. This transformation enables the elasticity interpretation of coefficients and ensures more stable model behavior. In addition, variable definitions and construction methods are summarized in Table 1.

To account for unobserved heterogeneity across provinces and over time, this study incorporates both province-specific and year-specific fixed effects in the panel regression models. These controls capture time-invariant regional characteristics and common national shocks, such as China's WTO accession and global financial crises; thereby ensuring more precise and unbiased estimation of the causal impacts of FDI and R&D on economic growth.

To examine the spatial effects of FDI and R&D on China's economic growth, this study employs a spatial econometric modeling framework designed to capture spatial correlations among regions. Two primary models are utilized: the Spatial Lag Model (SLM) and the Spatial Durbin Model (SDM). The SLM is particularly suitable when spatial dependence exists in the dependent variable, indicating that the economic growth of one province is influenced by that of its neighboring provinces. In other words, if regional economic growth exhibits spatial interdependence, where changes in one area directly affect adjacent regions, the SLM effectively captures such spatial spillover effects through the inclusion of a spatially lagged dependent variable. The variables are converted to natural logarithmic form, i.e., Equation 2 in SLM, as shown below.

$$lnGDP_{it} = \rho \mathrm{W} \ln GDP_{it} + \beta_0 + \beta_1 lnFDI_{it} + \beta_2 lnTS_{it} + \beta_3 lnTrade_{it} + \beta_4 lnGov_{it} + \beta_5 lnPop_{it} + \varepsilon_{it} \quad (2)$$

where i and t represent the ith province and the tth year, respectively; ρ is the spatial autoregressive coefficient of the dependent variable, measuring the effect of the spatial lag term $WGDP_{it}$ on GDP_{it}; W is a 30x30 spatial distance weight matrix; β_i is the corresponding regression coefficient, and ε_{it} is the error term. Because this study focuses on spatial spillover effects, the construction of a reliable spatial weight matrix (W) is critical. The primary matrix used is based on the inverse geographical distance between provincial centroids, which captures how economic linkages weaken as distance increases. Each row of W was normalized so that its elements sum to one, allowing comparability of spatial influence across provinces. To verify robustness, an alternative contiguity-based matrix assigning a value of 1 to provinces that share common borders and 0 otherwise was also employed. The results under both matrix specifications were consistent in sign and significance, confirming that the spatial relationships identified are not sensitive to the choice of weighting scheme. The dataset was further tested for cross-sectional dependence, spatial autocorrelation, and model specification bias. Moran's I statistics and Lagrange Multiplier (LM) tests confirmed significant spatial dependence among provinces, thereby justifying the use of SLM and SDM models. These diagnostic steps ensure that spatial interactions are properly captured and that the estimated coefficients reflect both direct and indirect (spillover) effects.

The SDM extends the capabilities of both the SLM and the Spatial Error Model (SEM), making it appropriate for analyzing the combined spatial interactions among dependent and independent variables. This model effectively captures spatial autocorrelation by simultaneously considering the spatial dependence of the dependent variable and the spatial spillover effects of the independent variables. In other words, the SDM not only examines how a region's economic growth is influenced by the growth of neighboring regions but also analyzes how regional factors such as FDI inflows and technological innovation generate spillover effects that impact the economic performance of adjacent provinces. If the economic growth of a region is influenced not only by the economies of neighboring regions but also

by the independent variables of neighboring regions, the variables are converted in Equation 3 to natural logarithmic form in SDM as follows:

$$\begin{aligned} lnGDP_{it} &= \rho W lnGDP_{it} + \beta_0 + \beta_1 lnFDI_{it} \\ &+ \beta_2 lnTS_{it} + \beta_3 lnTrade_{it} + \beta_4 lnGov_{it} \\ &+ \beta_5 lnPop_{it} + \theta_0 + \theta_1 WlnFDI_{it} \\ &+ \theta_2 WlnTS_{it} + \theta_3 WlnTrade_{it} \\ &+ \theta_4 WlnGov_{it} + \theta_5 WlnPop_{it} + \varepsilon_{it} \end{aligned} \quad (3)$$

The Spatial Durbin Model (SDM) can degenerate into either a Spatial Lag Model (SLM) or a Spatial Error Model (SEM) under specific parameter conditions.

When the spatial lag coefficient of the dependent variable is equal to zero ($\rho = 0$) and the error term exhibits spatial correlation, the SDM simplifies to an SEM. Conversely, when the coefficient of the spatially lagged independent variable is zero ($\theta = 0$), the SDM reduces to an SLM. In the process of model selection, the Akaike Information Criterion (AIC) is used as the primary criterion for comparison, with the model exhibiting the lower AIC value considered the most appropriate specification.

The empirical analysis was conducted using Stata software (version 17), which was employed to generate descriptive statistics, perform cross-sectional dependence tests, and implement the Augmented Mean Group (AMG) estimator, Lagrange Multiplier (LM) tests, as well as the estimation of the SLM and SDM models for spatial econometric analysis.

4. RESULTS AND DISCUSSION

Before estimating the spatial econometric models, it is essential to verify the existence and nature of spatial dependence within the dataset. Therefore, two main diagnostic tools, namely Moran's I and the Lagrange Multiplier (LM) tests, were employed to assess the presence and form of spatial autocorrelation across China's 30 provinces. Moran's I measures the degree of spatial autocorrelation by quantifying the similarity of attribute values among geographically adjacent or nearby regions.

A positive Moran's I indicates that provinces with similar levels of economic growth are spatially clustered, while a negative value suggests spatial dispersion. This statistic serves as a diagnostic tool to detect whether spatial dependence exists in the data. In this study, the null hypothesis posits that no spatial correlation is present, that is, economic growth is spatially random and independent across provinces. Rejection of this null hypothesis provides evidence of significant spatial dependence, thereby justifying the use of spatial econometric techniques.

Next, the Lagrange Multiplier (LM) tests complement Moran's I by identifying the specific source of spatial dependence. The LM-Lag test detects spatial dependence in the dependent variable, whereas the LM-Error test identifies spatial autocorrelation in the error term. In this study, both LM statistics were calculated to comprehensively examine spatial effects. A significant LM-Lag statistic suggests that economic growth in one region is influenced by that of neighboring regions, supporting the application of a Spatial Lag Model (SLM). Conversely, a significant LM-Error statistic implies spatial dependence in the residuals, indicating that a Spatial Error Model (SEM) may be more suitable.

When both LM statistics are significant, Robust LM tests are applied to determine the dominant form of spatial dependence. The diagnostic outcomes in this study confirmed statistically significant spatial autocorrelation, providing strong justification for employing spatial econometric models such as the SLM and Spatial Durbin Model (SDM). These tests ensure that the subsequent model estimations accurately capture the interdependence of regional economic activities and spillover effects across provinces.

Table 2. Full sample for the Lagrange multiplier test.

Test	Statistic	Df	P-value
Spatial error:			
Moran's I	20.393	1	0.000
Lagrange multiplier	394.491	1	0.000
Robust Lagrange multiplier	368.453	1	0.000
Spatial lag:			
Lagrange multiplier	29.570	1	0.000
Robust Lagrange multiplier	3.533	1	0.060

4.1. Lagrange Multiplier Test

The results from the spatial econometric estimations confirm the existence of significant spatial dependence among China's provincial economies. Both the LM test and Moran's I statistic were significant at the 1% level, indicating that provinces with higher economic growth tend to be surrounded by other fast-growing regions. This test typically encompasses four statistics designed to detect various forms of spatial dependence: the LM-Error Test and its improved Robust LM-Error Test, the LM-Lag Test, and its further enhanced Robust LM-Lag Test. The null hypothesis for all four LM tests is that there is no spatial correlation amongst the model residuals. The results reported in Table 2 indicate that all four LM statistics reject the null hypothesis at the 1% significance level, thereby confirming the presence of both spatial error effects and spatial lag effects in the data. Consequently, the SDM, which integrates the properties of both the SEM and the SLM, is considered the most comprehensive specification, as it accounts for the spatial dependence of both the dependent and explanatory variables.

Table 3. Regression results for the full sample.

Item	SLM	SDM
FDI	0.0221*	0.0166
RD	0.0507**	0.0607
TO	0.0139	-0.0029
GE	0.1286**	0.2627***
Pop	-0.0196	-0.0699
W_FDI	-	0.1111***
W_RD	-	0.0846*
W_TO	-	0.1689***
W_GE	-	0.1655**
W_Pop	-	0.4486
W_GDP (-1)	0.7145***	-
Akaike information criterion	-5.9673	-5.7847
R-squared	0.9979	0.9975

Note: GDP represents the log of real gross domestic product; FDI represents the log of real foreign direct investment; RD represents the log of R&D capital stock; TO represents the log of trade openness; GE represents the log of real government expenditure; Pop represents the log of population. ***, ** and * represents significance at the 1%, 5% and 10% significance levels, respectively.

4.2. Empirical Findings

4.2.1. Findings of Full Sample

Table 3 presents the spatial regression results for both the Spatial Lag Model (SLM) and the Spatial Durbin Model (SDM) using the full sample of 30 Chinese provinces. The full-sample analysis is particularly important as it captures overall spatial interdependencies in national economic growth. The coefficients for the explanatory variables, namely real FDI and R&D capital stock, are positive and statistically significant at the 10% and 5% levels, respectively. Specifically, a 1% increase in real FDI is associated with a 0.02% rise in real GDP, while a 1% increase in R&D capital stock leads to a 0.05% increase in real GDP. These results indicate that both foreign investment and innovation activity contribute meaningfully to regional economic expansion, consistent with endogenous growth theory. Among the control variables, real government expenditure is also positive and significant at the 5% level, suggesting that a 1% rise in public spending corresponds to a 0.13% increase in real GDP, reflecting the importance

of fiscal support in stimulating growth. In contrast, trade openness shows a positive but statistically insignificant effect, while population has a negative and significant coefficient, implying that demographic pressures may exert a dampening effect on regional economic performance.

The spatial lag coefficient (ρ) in the SLM is crucial for understanding the spatial spillover mechanism. The positive and significant ρ value indicates that a province's economic growth is influenced not only by its internal characteristics but also by the performance of neighboring regions. Quantitatively, a 1% increase in the real GDP of adjacent provinces corresponds to a 0.71% rise in the real GDP of the province under consideration, confirming the existence of strong positive spillover effects across regional economies. The Akaike Information Criterion (AIC) for the SLM is recorded at −5.9673, while the R^2 value is 0.9979, indicating an excellent overall model fit.

In comparison, the SDM results also yield positive coefficients for real FDI and R&D capital stock, though these are statistically insignificant in the full-sample estimation. The AIC, used as the main criterion for model selection, helps balance explanatory power against model complexity; a lower AIC value reflects a better-fitting and more parsimonious model. The AIC value for the SDM is -5.7847, which is higher than that of the SLM, suggesting that the SLM provides a superior fit to the data. Likewise, the R^2 value of 0.9975 in the SDM, while still high, is marginally lower than that of the SLM.

Overall, the SLM outperforms the SDM in terms of both model fit and explanatory strength. The results highlight that spatial dependence in China's economic growth primarily operates through the dependent variable, whereby the provincial GDP levels are directly influenced by the economic performance of neighboring regions rather than through the indirect spatial effects of explanatory variables such as FDI and R&D. These findings reinforce the importance of spatial linkages and regional coordination in sustaining balanced and innovation-driven growth across China.

Table 4. Regression results of panel data for the region.

Item	Eastern Region		Central Region		Western Region	
	SLM	SDM	SLM	SDM	SLM	SDM
FDI	0.0225	0.0292	0.0005	0.0119	0.0546**	0.0564***
RD	0.0799	0.1139	0.1349***	0.1885***	0.1239*	0.1475*
TO	0.0571	0.0256	0.0906**	0.0614*	0.0367*	0.0202
GE	0.2043***	0.2921***	0.1539***	0.3941***	0.2116*	0.2896***
Pop	0.4259***	0.3229**	-0.1981	-0.1435	0.3989	0.4180
W_FDI	-	0.0676*	-	0.0726***	-	0.0795*
W_RD	-	0.0431	-	-0.0300	-	-0.0094
W_TO	-	0.1684*	-	0.0763**	-	0.1039***
W_GE	-	0.1712	-	0.0356	-	0.1304
W_Pop	-	-0.1479	-	0.3715	-	0.8160
W_GDP (-1)	0.4982***	-	0.5118***	-	0.4176**	-
Akaike information criterion	-5.3954	-5.3814	-6.5996	-6.5291	-5.4896	-5.4648
R-squared	0.9961	0.9961	0.9978	0.9977	0.9965	0.9965

Note: GDP represents the log of real gross domestic product; FDI represents the log of real foreign direct investment; RD represents the log of R&D capital stock; TO represents the log of trade openness; GE represents the log of real government expenditure; Pop represents the log of population. ***, ** and * represents significance at the 1%, 5% and 10% significance levels, respectively

4.2.2. Findings by Regions

Table 4 presents the detailed spatial regression results by region. The analysis of the independent variables in the SLM across the Eastern, Central, and Western regions reveals considerable heterogeneity in spatial spillover effects. The main explanatory variable, real FDI, exerts a statistically significant and positive impact on real GDP growth only in the Western region, suggesting that the spatial spillover effects associated with foreign investment are particularly strong in less developed areas. This finding may reflect the comparative advantage of the Western provinces in attracting capital toward resource-intensive and infrastructure-related projects, which, in turn, stimulate

regional output through backward and forward linkages. Another explanatory variable, R&D capital stock, together with the control variable trade openness, demonstrates a significant positive influence on real GDP growth, specifically in the Central and Western regions. This indicates that innovation-driven investment and external market integration jointly foster technological diffusion and productivity enhancement in these regions. The Central region, characterized by industrial diversification and improving absorptive capacity, appears to benefit most from R&D-related spatial spillovers. Meanwhile, the Western region's growing engagement in innovation-led projects signals the gradual strengthening of its endogenous growth potential.

The control variable, the real government expenditure, consistently exhibits a positive and significant effect across all three regions, underscoring the catalytic role of fiscal spending in promoting regional economic development. This suggests that public investment in infrastructure, education, and innovation support has generated positive spatial externalities that contribute to provincial growth beyond local boundaries. In contrast, population displays a significant positive effect only in the Eastern region, implying that labor agglomeration and market density there enhance economic performance through urbanization-driven productivity gains in the less densely populated Central and Western regions.

An examination of the spatial lag coefficients (ρ) across the three regions provides deeper insight into interregional linkages and their influence on economic growth. Among the regions, the Central region exhibits the largest spatial effect coefficient, followed by the Eastern region, while the Western region shows the smallest. This pattern suggests that neighboring provinces within the Central region exert the strongest mutual spillover effects, possibly due to tighter industrial interconnections and geographic proximity to both coastal and inland markets. In contrast, the smaller coefficient in the Western region indicates weaker spatial interdependence, likely reflecting larger geographical distances and lower integration with the national economy. Despite these intra-regional differences, the spatial lag coefficients for all three regions are lower than those of the full-sample model, implying that cross-regional spillover effects between provinces located in different macro-regions are more pronounced than spillovers within the same region. This finding highlights the importance of interregional connectivity in facilitating the diffusion of economic benefits and technological progress across China's provincial economies.

Regarding model selection, the Akaike Information Criterion (AIC) values show that the Central region yields the smallest AIC, followed by the Western region, with the Eastern region presenting the largest value. This ranking aligns with the empirical results, indicating that the Central region experiences the most substantial spillover effects on economic growth. The R^2 values further support this conclusion, showing the highest model fit for the Central region, followed by the Western and Eastern regions, respectively. Although the SLM and SDM produce broadly similar outcomes, the SLM is ultimately preferred due to its smaller and more consistent AIC value, indicating a better overall fit and greater model reliability.

4.3. Discussion of the Results

4.3.1. Discussion of Full Sample

In the Spatial Lag Model, real FDI significantly contributes to China's economic growth. On the one hand, foreign capital makes up for the lack of local capital; on the other hand, foreign capital drives the agglomeration of related industries and the completeness of the industrial chain, and often non-subjectively carries out the demonstration and diffusion of advanced technology and management experience. R&D also contributes significantly to economic growth, and its positive effect is almost double that of real FDI. Technology spillover has a time lag, and spillover to local enterprises through a variety of spillover channels, such as demonstration, competition, linkages, and mobility of people spillovers (Caves, 1974; Kokko, 1992). This is more sustainable than the effect of abundant capital brought by FDI on economic growth.

Government expenditure positively contributes to economic growth in China. Chandler suggests that large enterprises can efficiently allocate resources by replacing market competition with the government's visible hand

(Chandler, 1977). Government expenditure can comprehensively and systematically provide economic support, promote the development of new industries, and enhance the ability to resist economic counter-cyclicality, reflecting the ruling philosophy of "wholeheartedly serving the people" in China. On the contrary, neither foreign trade openness nor population plays a significant role in China's economic growth. The former is due to export dependence on low-value-added products, lack of core technology, and internal cyclical development, while external causes include the intensification of trade friction between China and the United States, as well as increased external risks such as geopolitics. Additionally, the disappearance of the demographic dividend, aging, and industrial structure upgrading have weakened the population's driving force on the economy. China's economic growth exhibits positive spatial autocorrelation characteristics and spatial spillover effects. This is consistent with the findings of Huo and Song (2022) as well as Song and Liu (2022) for the Guangdong-Hong Kong-Macao Greater Bay Area, as well as Wang and Li (2022) for Beijing-Tianjin-Hebei and (Hou, Shi, Chen, Zhang, & Kuang, 2024) for the Yangtze River Delta.

4.3.2. Discussion by the Regions

Overall, the regional analysis underscores clear spatial heterogeneity in the determinants of economic growth across China. The Eastern region benefits primarily from endogenous innovation and population-driven demand; the Central region from technological spillovers and its intermediary geographic position; and the Western region from FDI inflows, government support, and infrastructure-driven expansion. The results confirm that while FDI and R&D stimulate growth nationwide, their spatial impacts vary considerably, shaped by regional economic maturity, policy orientation, and industrial structure.

4.3.2.1. Eastern Region

The Eastern region's coefficients for FDI, R&D, and trade openness are positive but statistically insignificant, indicating that these factors do not significantly contribute to economic growth. Under China's dual circulation development paradigm, domestic demand has become the primary engine of growth. At the same time, the technological gap between domestic and foreign enterprises has narrowed, leading foreign investors to protect their core and high technologies to maintain monopoly advantages and profit margins. Consequently, the spillover effects of FDI, R&D, and trade openness in the Eastern region lack high-tech content and fail to substantially promote economic growth. Moreover, provinces in the Eastern region already possess highly developed economies and strong endogenous innovation capacity, enabling them to generate economic spillovers to other provinces but with limited dependence on external growth drivers. This explains why the Eastern region's spatial spillover effects are moderate relative to those of the Central and Western regions. In contrast, government expenditure and population significantly and independently drive economic growth in this region. As the most economically advanced region in China, the Eastern region uses government spending to upgrade infrastructure and public services, increase investment in R&D and education, and provide financial support to high-tech industries. These policies strengthen economic cooperation and technological innovation both within the region and with other parts of China. Furthermore, the region's dense and highly skilled population, combined with strong purchasing power, continues to attract talent inflows from the Central and Western regions. This migration supports sustainable, innovation-driven growth and reinforces the Eastern region's role as the country's leading economic hub.

4.3.2.2. Central Region

In the Central region, R&D, trade openness, and government expenditure all have significant positive effects on economic growth. The wide technological gap between domestic and foreign-invested enterprises enables R&D spillovers to foster technological progress, product innovation, and process innovation, which enhance productivity and competitiveness. The region's increasing trade openness boosts import and export activity, allowing more efficient use of both domestic and international resources and markets. While government spending in the Central

region receives relatively less policy attention compared to the Eastern and Western regions, improvements in infrastructure and public services have contributed to more balanced and coordinated development. By contrast, FDI and population do not significantly promote economic growth in the Central region. This is primarily because FDI inflows are concentrated in labor-intensive and resource-based low-value-added industries. The growing share of wholly foreign-owned enterprises operating under enclave-style production models has limited technology spillovers to local firms. Moreover, short-term FDI gains are offset by the high cost of pollution control measures. Although the Central region has an abundant labor force, its demographic dividend is diminishing, and outmigration of high-skilled workers to the Eastern region constrains human capital accumulation and innovation. The Central region exhibits the largest spatial spillover effect among all regions, reflecting its strategic geographic position connecting the Eastern and Western parts of China. As the main destination for industrial relocation from the Eastern region and a key beneficiary of the "Rise of Central China" policy, it enjoys strong resource complementarity and increasing economic integration with neighboring provinces. These factors collectively enhance the Central region's spatial influence and its capacity to drive interprovincial growth spillovers.

4.3.2.3. Western Region

In the Western region, FDI, R&D, trade openness, and government expenditure all significantly and positively influence economic growth. FDI has provided the region with much-needed capital, technology, and management expertise, improving productivity, creating employment, and stimulating the development of upstream and downstream industrial chains. The accumulation of R&D capital stock has accelerated the upgrading of resource-based and primary-processing industries and supported the emergence of high–value-added sectors, generating strong technological spillover effects. In addition, trade openness has facilitated the expansion of foreign markets, increased import and export activities, and enabled access to advanced technologies, equipment, and management practices, thereby enhancing economies of scale and competitiveness. Government expenditure plays a particularly critical role in the Western region, where investments in infrastructure, public services, and social welfare have yielded the strongest positive impact on economic growth among all regions. Conversely, the Western region continues to face challenges related to population loss, a shrinking demographic dividend, and a workforce dominated by low-skilled labor. These demographic constraints limit the region's capacity to sustain innovation and economic dynamism. The spatial spillover effect of economic growth in the Western region is the weakest among the three, largely due to its geographical remoteness, relatively closed economy, underdeveloped infrastructure, and limited economic connectivity with other provinces. These factors collectively hinder the diffusion of growth benefits and restrict the region's role in broader interregional economic coordination.

5. CONCLUSIONS

This study examined the spatial spillover effects of foreign direct investment (FDI) and research and development (R&D) on China's economic growth, as well as the regional heterogeneity of these effects across the Eastern, Central, and Western regions from 2000 to 2022. Using spatial econometric techniques, the results reveal that FDI, R&D, and government expenditure have significant positive impacts on provincial economic growth, with government expenditure exerting the largest influence, followed by R&D and FDI. The findings further confirm the existence of significant spatial spillover effects across China's 30 provinces, indicating that economic expansion in one region stimulates growth in neighboring areas through interregional linkages. However, substantial regional differences are evident: in the Eastern region, government expenditure and population are the main contributors to economic growth, reflecting its advanced infrastructure and strong human capital base; in the Central region, R&D, trade openness, and fiscal expenditure are key drivers, supported by industrial upgrading and regional integration; and in the Western region, FDI, R&D, and government expenditure play dominant roles, highlighting the importance of capital inflows, technological innovation, and public investment in less-developed provinces. Among the three, the

Central region demonstrates the strongest spatial spillover effects, followed by the Eastern and Western regions, underscoring the diverse spatial dynamics shaping China's regional economic development.

The study's novel contribution lies in integrating spatial econometric analysis with regional heterogeneity to explain how innovation, investment, and policy factors jointly influence economic performance across provinces. By distinguishing the intensity and direction of spatial spillovers, the findings provide new insights into China's transition toward innovation-driven and regionally balanced growth.

This study examined the spatial spillover effects of foreign direct investment (FDI) and research and development (R&D) on China's economic growth, as well as the regional heterogeneity of these effects across the Eastern, Central, and Western regions from 2000 to 2022. Using spatial econometric techniques, the results reveal that FDI, R&D, and government expenditure have significant positive impacts on provincial economic growth, with government expenditure exerting the largest influence, followed by R&D and FDI. The findings further confirm the existence of significant spatial spillover effects across China's 30 provinces, indicating that economic expansion in one region stimulates growth in neighboring areas through interregional linkages. However, substantial regional differences are evident: in the Eastern region, government expenditure and population are the main contributors to economic growth, reflecting its advanced infrastructure and strong human capital base; in the Central region, R&D, trade openness, and fiscal expenditure are key drivers, supported by industrial upgrading and regional integration; and in the Western region, FDI, R&D, and government expenditure play dominant roles, highlighting the importance of capital inflows, technological innovation, and public investment in less-developed provinces. Among the three, the Central region demonstrates the strongest spatial spillover effects, followed by the Eastern and Western regions, underscoring the diverse spatial dynamics shaping China's regional economic development.

This study offers several key policy implications. Policymakers should promote localized institutional innovation and region-specific reforms to align with each region's comparative advantages, fostering a unified and well-integrated national market.

Enhancing regional coordination and green development is essential by boosting the Eastern region's high-tech investment and R&D capacity while directing greater policy, technological, and human capital support to the Central and Western regions to attract sustainable and resource-efficient FDI. At the same time, encouraging high-quality, innovation-oriented FDI through the establishment of multinational R&D centers in China can strengthen technology transfer and deepen integration into global value chains. Finally, domestic enterprises should enhance their absorptive capacity and innovation capabilities to maximize the benefits of foreign technology spillovers. Strengthening independent R&D and innovation-driven productivity will be critical to transforming China's growth model and sustaining long-term international competitiveness. Despite its contributions, this study faces certain limitations.

First, data availability constraints prevented the inclusion of several emerging indicators, such as digital economy metrics and environmental investment, which may also influence spatial growth dynamics. Second, potential endogeneity between FDI, R&D, and economic growth may exist, as higher growth could also attract more investment and innovation. Future research could apply dynamic spatial panel models or instrumental variable techniques to address these issues and test causality more rigorously.

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