



Knowledge Spillovers and Regional Economic Growth in China: An Empirical Study Based on Four Regional Divisions

Gu Luoluo*

Faculty of Economics, Thammasat University, Bangkok, 10200 Thailand

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Abstract

This study investigates the impact of knowledge spillovers on regional economic growth in China, focusing on technology flow and R&D personnel investment as key drivers of industrial GDP. The research aims to evaluate the influence of these factors on industrial GDP, analyze regional disparities in industrial development and knowledge spillovers, and propose policy recommendations to promote balanced growth. Drawing on secondary data from 31 provinces spanning 2000 to 2021, the analysis employs a fixed-effects regression model, which demonstrates strong explanatory power, with adjusted R^2 values ranging from 0.938 to 0.964 across regions. The results show that R&D investment contributes significantly to industrial GDP in all regions, increasing output by approximately 4% to 7%, depending on the level of regional development. Technology flow, however, exhibits greater regional variation: it accounts for up to 25% of industrial growth in the Northeast region, around 15% in the Western region, shows minimal effect in the Central region, and has a slightly negative impact in the Eastern region. These results underscore how regional conditions mediate the effectiveness of knowledge spillovers and innovation strategies, highlighting the need for tailored policies to strengthen R&D ecosystems and technology transfer mechanisms. The insights contribute to the broader literature on regional economic growth and provide practical guidance for policymakers seeking to address disparities and foster sustainable growth.

Introduction

China's rapid economic transformation over the past few decades has highlighted significant regional disparities in industrial development, technology diffusion, and research and development (R&D) investment. These disparities, influenced by historical, economic, and policy factors, present unique challenges and opportunities for different regions (Fan et al., 2011). The eastern coastal regions, which benefited early from China's reform and

opening-up policies, have seen substantial industrial growth and technological advancements. For instance, during the first two decades of reforms, foreign direct investment (FDI) into the eastern regions accounted for over 85% of the national total, contributing to rapid economic expansion and modernization (Naughton, 2007). By 2021, Guangdong province alone attracted over \$170 billion in cumulative FDI, leveraging these investments to integrate advanced manufacturing

* Corresponding Author
email: gu.luo@st.econ.tu.ac.th

technologies and enhance export-oriented industries. In contrast, the central, western, and northeastern regions have experienced slower development due to varied historical and policy contexts (Dihai, 2023).

The success of the eastern coast in fostering economic growth and industrialization stems from its access to international markets, foreign investments, and cutting-edge technologies. For instance, provinces like Guangdong, Jiangsu, and Zhejiang stand out with industrial GDPs of approximately 5 trillion yuan, 4.5 trillion yuan, and 3 trillion yuan, respectively in 2023. In stark contrast, Gansu, Qinghai, and Ningxia—representative of the less-developed western regions—recorded industrial GDPs of about 1 trillion yuan, 300 billion yuan, and 250 billion yuan, respectively (NBSC, 2023). These disparities underscore the critical role of regional advantages and targeted development policies in shaping economic outcomes.

During the planned economy period, the Chinese government emphasized heavy industry development in the northeast, creating an industrial base. Concurrently, the "Third Front" construction strategy aimed to enhance national defense and industrial infrastructure in the central and western regions. While these policies-initiated industrialization, they also led to structural inefficiencies and technological lags (Lin, 2011). With the advent of market-oriented reforms, the eastern coastal regions attracted significant foreign investments and advanced technologies, propelling rapid economic growth. However, the central, western, and northeastern regions lagged in market reforms and technology adoption, resulting in slower economic development and widening regional disparities (Dihai, 2023).

To address these disparities, the Chinese government has implemented initiatives such as "Rise of Central China," "Western Development," and "Revitalization of the Northeast." These strategies aim to foster coordinated national development through technology diffusion and increased R&D investment. Knowledge spillovers, involving the transfer of advanced technologies and knowledge across regions, play a pivotal role in these strategies (Audretsch & Feldman, 2004). By leveraging the technological and managerial experiences of more developed regions, less developed areas can accelerate their industrialization and modernization processes (Jaffe et al., 2002).

This study examines the impact of knowledge spillovers on regional economic growth in China, with a focus on understanding regional disparities and

proposing policy recommendations. By analyzing the effects of technology flow and R&D personnel investment on industrial GDP across different regions, this research aims to provide insights into the specific challenges and opportunities each region faces. The findings contribute to the broader literature on regional economic growth and development, offering valuable implications for policymakers seeking to promote balanced and sustainable growth across China.

Objectives

1. Examine the Impact of Technology Flow and R&D Personnel Investment on Industrial GDP: Investigate how technology flow and R&D personnel investment influence industrial GDP across different regions in China, highlighting the regional disparities and unique economic conditions.

2. Analyze Regional Disparities in Industrial Development and Knowledge Spillovers: Explore the variations in industrial development and the effects of knowledge spillovers across the eastern, central, western, and northeastern regions, providing insights into the specific challenges and opportunities each region faces.

3. Provide Policy Recommendations for Balanced Regional Development: Develop actionable policy recommendations aimed at enhancing technology transfer mechanisms, increasing R&D investment, and promoting coordinated regional development to address economic disparities and foster sustainable growth across China.

Literature Review

This literature review provides a comprehensive review of the theoretical and empirical literature relevant to knowledge spillovers, technology flow, and R&D investment. The review explores how these factors influence industrial GDP, examines their role in regional economic disparities, and considers the contextual challenges and opportunities for balanced development in China.

Technological progress is a critical driver of economic development and industrial output. Solow (1957) emphasized the importance of total factor productivity (TFP), attributing sustained growth to advancements in technology. This theoretical framework highlights the transformative potential of technology flow, particularly in regions with the capacity to adopt and implement innovations. Empirical research reinforces these insights. Keller (2004) demonstrated that

technology flow enhances productivity by reducing production costs and fostering competitiveness, especially in regions with robust infrastructure and institutions. Jaffe et al. (2002) found that geographic proximity among firms facilitates technology transfer, amplifying regional productivity. In the Chinese context, the eastern coastal provinces have leveraged strong technology transfer mechanisms to achieve higher industrial GDP, while less-developed regions often face barriers to technology adoption. This study builds on these findings to investigate the contribution of technology flow to regional economic growth and productivity across China.

Research and development (R&D) personnel investment is crucial for fostering innovation and sustaining economic growth. Romer (1990) emphasized R&D as a driver of technological progress, while Lucas Jr (1988) highlighted the role of human capital in enhancing productivity. R&D personnel decisions depend on wages, local price levels, and relocation costs. Krugman (1991) noted that skilled workers migrate to regions offering better net benefits. Saxenian (2006) and Moretti (2012) further showed that living costs and market conditions shape regional innovation capacity. Full-Time Equivalent (FTE) is widely used to measure R&D personnel investment, capturing time dedicated to research and enabling cross-regional comparisons. Bloom et al. (2013) validated its relevance for assessing resource allocation and innovation impact. Studies by Coe & Helpman (1995) and Peri (2005) showed that R&D spillovers enhance productivity, especially where innovation is prioritized. In China, eastern provinces lead in R&D, while less-developed regions struggle. This study examines FTE-based R&D investment and its impact on industrial GDP, revealing regional disparities in innovation-driven growth.

The distribution of knowledge spillovers and their economic impacts vary significantly across regions due to disparities in infrastructure, human capital, and institutional support. The New Economic Geography (NEG) framework (Fujita, Krugman, & Venables, 2001) explains how agglomeration benefits regions with dense networks of firms and research institutions, while less-developed regions face challenges in integrating these benefits. Empirical studies illustrate these dynamics. Ottaviano & Peri (2005) found that regions with higher innovation capacity and stronger institutional frameworks benefit more from knowledge spillovers, while regions with weaker infrastructure struggle to capitalize on these advantages. Fujita & Thisse (2002) demonstrated that

proximity to research institutions and industries amplifies the economic benefits of spillovers, further entrenching regional disparities. In the context of China, the advanced eastern regions are better positioned to leverage knowledge spillovers, while the central, western, and northeastern regions face persistent structural barriers. This study explores the regional dynamics of technology flow and R&D investment to understand how these disparities influence industrial GDP and to identify strategies for fostering balanced development.

Hypotheses and Conceptual Framework

Hypothesis

Building on the theoretical and empirical insights discussed in the preceding section, this study proposes three hypotheses to examine the effects of technology flow and R&D personnel investment on industrial GDP, as well as their regional disparities.

Technological progress is critical for industrial growth. Solow (1957) identified technological advancement as a key driver of productivity, while Keller (2004) showed that technology flow reduces costs and enhances competitiveness. In China, regions with strong technology absorption capacity, such as the eastern provinces, exhibit significant economic gains from technology flow. Therefore:

Hypothesis 1: Technology flow has a significant positive impact on industrial GDP.

R&D personnel investment fosters innovation and drives productivity. Romer (1990) and Lucas Jr (1988) emphasized that human capital and R&D efforts are central to sustaining economic growth. Empirical evidence from Coe & Helpman (1995) and Peri (2005) showed that R&D spillovers significantly boost industrial performance. Thus:

Hypothesis 2: R&D personnel investment has a significant positive impact on industrial GDP.

Regional disparities significantly mediate the impacts of technology diffusion and R&D investment. Fujita et al. (2001) and Ottaviano & Peri (2005) emphasize that regions endowed with superior infrastructure and higher levels of human capital tend to realize greater productivity gains from knowledge spillovers. In the context of China, the eastern provinces disproportionately benefit from these dynamics, while the central, western, and northeastern regions continue to encounter structural constraints that limit their capacity to absorb and capitalize on technological advances. Hence:

Hypothesis 3: The impacts of technology flow and R&D personnel investment on industrial GDP vary significantly across regions.

Conceptual Framework

This study's conceptual framework, as illustrated in Figure 1, demonstrates how technology flow and R&D personnel investment impact industrial GDP, emphasizing the role of regional disparities. It combines perspectives from classical and endogenous growth theories, the New Economic Geography (NEG) framework, and studies on knowledge spillovers to provide a comprehensive understanding of these dynamics.

The transfer of advanced knowledge through technology flow boosts productivity. Solow (1957) highlighted technological progress as a fundamental factor driving total factor productivity (TFP), and Keller (2004) demonstrated that regions with greater absorptive capacity gain more advantages, leading to cost reductions and enhanced competitiveness. This research considers technology flow a pivotal factor in contributing directly to industrial GDP.

R&D personnel investment, expressed as Full-Time Equivalent (FTE), represents the commitment of human resources to innovation. It plays a vital role in fostering sustained economic growth by driving innovation and technological advancements. FTE serves as a standardized measure, enabling meaningful comparisons across regions, with higher investment generally linked to stronger industrial GDP growth due to improved innovation capacity.

However, regional disparities influence the outcomes of such investments. Developed regions often benefit more from agglomeration effects and advanced infrastructure, while less-developed areas face challenges such as limited resources and structural constraints. Regions with robust infrastructure and skilled human capital tend to gain more from knowledge spillovers, further amplifying these disparities.

This study highlights that technology flow and R&D personnel investment significantly enhance industrial GDP, with regional characteristics shaping their effectiveness. Advanced regions are positioned to capitalize on these benefits, whereas lagging regions may require targeted strategies to build absorptive capacity and foster innovation. This approach provides a foundation for understanding how knowledge diffusion interacts with regional economic differences.

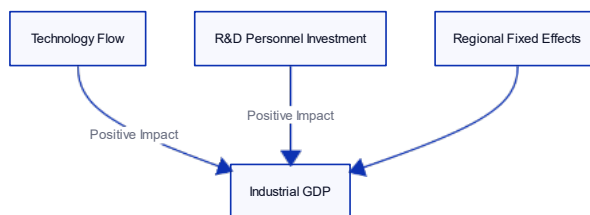


Figure 1 Conceptual Framework

Research Methodology

Population and Sample

The study uses secondary data sourced from the China Statistical Yearbook on Science and Technology, published by the National Bureau of Statistics of China (NBSC), focusing on data related to regional economic development, technology flow, and R&D Full-Time Equivalent (FTE). The dataset covers the period from 2000 to 2021, providing a comprehensive view of the industrial development in various regions of China.

For each model in the study, data from 31 provincial-level regions (including municipalities and autonomous regions) are used. The variables of interest include:

FTRED (R&D Full-Time Equivalent): FTRED represents the number of full-time equivalent personnel dedicated to research and development (R&D) activities within a region. This metric aggregates the total working hours of all individuals involved in R&D and normalizes it to the equivalent of a full-time workload.

TechFlow (Technology Flow): TechFlow refers to the total number of technology transfer contracts, including both technology inflow (imports) and technology outflow (exports), signed within a region during a given year. These contracts typically cover activities such as licensing, joint ventures, and technological services.

GDP-Industrial Value (Industrial GDP): GDP-Industrial Value refers to the gross domestic product (GDP) generated by the industrial sector within a specific region. This includes output from manufacturing, mining, construction, and utilities.

Each variable is measured annually across the sample period, resulting in a sample size of 31 regions x 22 years = 682 observations per variable.

Data Analysis

Firstly, the FTERD data highlights the growth and distribution of research and development personnel across regions. Notably, In Figure 2 the Eastern region consistently shows the highest numbers, with a significant upward trend from approximately 50,000 in 2000 to over

350,000 by 2021. This sharp increase underscores the concentration of R&D resources and activities in this region. In contrast, other regions like the Western and Northeast exhibit slower, albeit steady, growth, reflecting regional disparities in R&D investment and capacity.

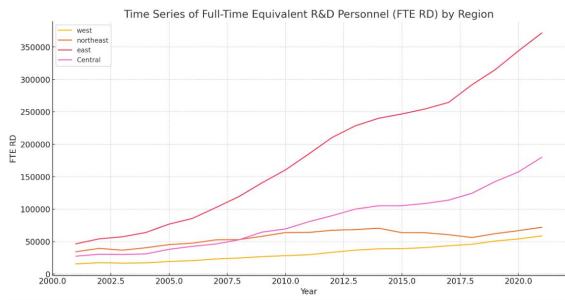


Figure 2: Time Series of R&D Full-Time Equivalent by Region

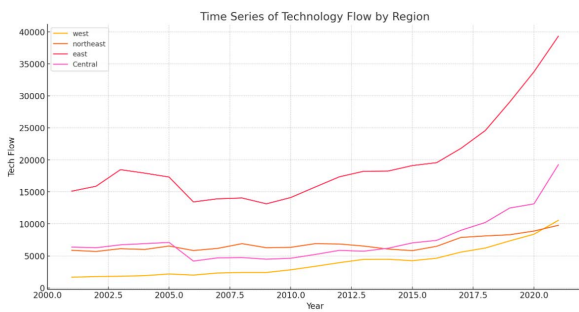


Figure 3: Time Series of Technology Flow by Region

Figure 3 presents Technology Flow, another vital indicator, that demonstrates a similar pattern. The Eastern region again leads with a substantial increase from around 15,000 in 2000 to nearly 40,000 in 2021, indicating a robust technological exchange and innovation output. The Central region follows, showing significant growth, particularly post-2010, while the Western and Northeast regions lag, suggesting uneven technological advancements and diffusion.

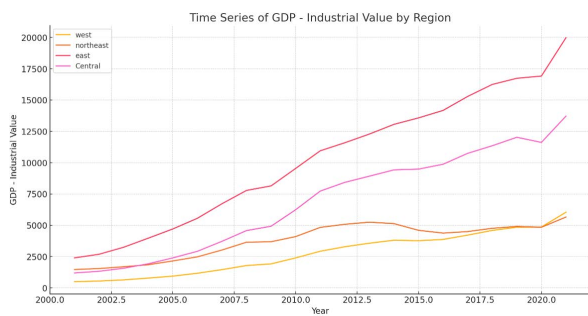


Figure 4: Time Series of GDP - Industrial Value by Region

GDP - Industrial Value presents a critical economic measure, with the Eastern and Central regions again showing the highest values. From 2000 to 2021, the Eastern region's industrial GDP surged from approximately 2,500 to nearly 20,000, reflecting its dominant economic position as shown in Figure 4. The Central region also exhibits strong growth, while the Western and Northeast regions, although growing, remain significantly behind, illustrating persistent regional economic disparities.

Regression Model

The Fixed Effects Model (FEM) is selected for its ability to control for unobserved, time-invariant heterogeneity across regions. Unlike random effects models, FEM assumes that regional characteristics such as cultural norms, infrastructure quality, or geographic advantages are correlated with independent variables like R&D investment. By accounting for these fixed factors, FEM ensures more reliable estimates of the impacts of R&D and technology flow.

The Fixed Effects Model is specified as:

$$\text{GDP-IndustrialValue}_{it} = \alpha_i + \beta_1 \text{FTERD}_{it} + \beta_2 \text{TechFlow}_{it} + \gamma_t + \epsilon_{it} \quad (1)$$

Where:

$\text{GDP-IndustrialValue}_{it}$: The industrial GDP of region i at time t , representing the dependent variable.

α_i : Region-specific fixed effects accounting for unobservable, time-invariant regional characteristics.

β_1, β_2 : Coefficients for R&D Full-Time Equivalent (FTERD) and technology flow (TechFlow), measuring their marginal impacts on industrial GDP.

γ_t : Time-fixed effects capturing external macroeconomic shocks, such as national policies or global economic crises.

ϵ_{it} : Error term capturing random disturbances.

This specification focuses on within-region variations over time, isolating the impacts of R&D and technology flow while controlling for fixed regional characteristics and temporal shocks.

To ensure the reliability of the fixed-effects regression results, several statistical diagnostics were conducted. Model fit was evaluated using R^2 , adjusted R^2 , AIC, BIC, and F-statistics, revealing strong explanatory power across regions. The Durbin-Watson statistic was used to test for autocorrelation, with values ranging from 1.672 to 2.910, indicating minimal autocorrelation in most models. Variance Inflation Factor (VIF) tests confirmed no severe multicollinearity, with all VIFs for independent variables reported at below

3. All regression estimates were robust with significance levels reported at $p < 0.01$, $p < 0.05$, and $p < 0.10$. These metrics confirm the model's adequacy in capturing the relationship between industrial GDP and the explanatory variables.

Table 2 OLS Regression Results for Four Regions

Variable	East Coef. (β) & Sig.	Central Coef. (β) & Sig.	Northeast Coef. (β) & Sig.	West Coef. (β) & Sig.
Intercept	-7058.279 ***	-1538.385 **	-2184.194 ***	-1058.756 ***
C(Year)[T.2001]	130.068	127.053	396.130	200.314
C(Year)[T.2002]	96.743	124.172	119.465	125.538
C(Year)[T.2003]	623.596	378.594	369.070	249.304
C(Year)[T.2004]	1013.964	692.982	269.099	354.781
C(Year)[T.2005]	1123.839	835.184	69.831	330.639
C(Year)[T.2006]	1393.524	1168.772 *	399.683	504.735
C(Year)[T.2007]	1799.860 *	1799.264 **	471.055	586.088 *
C(Year)[T.2008]	2069.206 *	2360.636 ***	880.695	800.729 **
C(Year)[T.2009]	1395.551	2158.643 ***	686.118	796.877 **
C(Year)[T.2010]	1910.900 *	3248.691 ***	634.551	1115.290 ***
C(Year)[T.2011]	2245.409 *	4223.688 ***	1213.891 *	1473.746 ***
C(Year)[T.2012]	1777.380 *	4489.970 ***	1221.144 *	1505.889 ***
C(Year)[T.2013]	1667.074	4515.719 ***	1385.973 *	1490.268 ***
C(Year)[T.2014]	1899.469 *	4781.340 ***	1221.284	1597.608 ***
C(Year)[T.2015]	2145.843 *	4829.204 ***	1279.023 *	1582.863 ***
C(Year)[T.2016]	2400.858 **	5058.172 ***	893.789	1509.441 ***
C(Year)[T.2017]	3146.800 ***	5683.666 ***	910.874	1527.215 ***
C(Year)[T.2018]	2963.904 **	5799.983 ***	1444.749 **	1660.031 ***
C(Year)[T.2019]	2566.747 **	5627.799 ***	1096.211	1415.904 ***
C(Year)[T.2020]	1596.302	4528.525 ***	525.746	1063.744 ***
C(Year)[T.2021]	3626.111 ***	5546.470 ***	728.347	1607.856 ***
East region				
C(Area)[T.Fujian]	9110.045 ***	—	—	—
C(Area)[T.Guangdong]	10660.044 ***	—	—	—
C(Area)[T.Hainan]	5525.512 ***	—	—	—
C(Area)[T.Hebei]	9700.802 ***	—	—	—
C(Area)[T.Jiangsu]	11470.044 ***	—	—	—
C(Area)[T.Shandong]	11960.045 ***	—	—	—
C(Area)[T.Shanghai]	6770.296 ***	—	—	—
C(Area)[T.Tianjin]	5296.901 ***	—	—	—
C(Area)[T.Zhejiang]	7728.729 ***	—	—	—
Central region				
C(Area)[T.Henan]	—	3643.871 ***	—	—
C(Area)[T.Hubei]	—	1121.029 ***	—	—
C(Area)[T.Hunan]	—	987.887 **	—	—
C(Area)[T.Jiangxi]	—	1032.821 **	—	—
C(Area)[T.Shanxi]	—	1011.419 **	—	—
Northeast region				
C(Area)[T.Jilin]	—	—	-384.347	—
C(Area)[T.Liaoning]	—	—	-2107.116 ***	—
West region				
C(Area)[T.Gansu]	—	—	—	-440.638
C(Area)[T.Guangxi]	—	—	—	643.752 **
C(Area)[T.Guizhou]	—	—	—	551.189 *
C(Area)[T.Inner Mongolia]	—	—	—	1140.521 ***
C(Area)[T.Ningxia]	—	—	—	72.083
C(Area)[T.Qinghai]	—	—	—	38.283
C(Area)[T.Shaanxi]	—	—	—	-1866.058 ***
C(Area)[T.Sichuan]	—	—	—	-661.377 *
C(Area)[T.Tibet]	—	—	—	23.572
C(Area)[T.Xinjiang]	—	—	—	1058.995 ***
C(Area)[T.Yunnan]	—	—	—	560.266 *
FTERD	0.0467 ***	0.0460 ***	0.0768 ***	0.0638 ***
TechFlow	-0.0443 *	0.0068	0.2468 ***	0.1562 ***

Notes: Statistical significance is denoted by asterisks: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Coefficients with higher significance levels provide stronger evidence of a nonzero effect.

Results and Discussion

Regression Results

The regression analysis, as shown in Table 2, uncovers significant regional disparities in the roles of R&D Full-Time Equivalent (FTRED) and Technology Flow (TechFlow) in driving industrial GDP across China. These differences highlight the varying levels of industrial maturity and technological capabilities among the Eastern, Central, Northeast, and Western regions. By comparing these regions, the study underscores the need for diverse strategies to achieve balanced industrial growth.

The Eastern region demonstrates a strong reliance on internal R&D investment, reflecting its advanced industrial maturity. The coefficient for FTRED is highly significant ($\beta = 0.0467$, $p < 0.01$), indicating that local innovation capacity plays a dominant role in driving industrial GDP. In contrast, TechFlow exhibits a negative coefficient ($\beta = -0.0443$, $p < 0.1$), suggesting minimal reliance on external technology. These results align with Naughton (2007), who emphasized the East's robust self-sustaining innovation ecosystem. The advanced industrial infrastructure in this region enables firms to focus on internal R&D activities, making external technology less critical. This finding suggests that policymakers should continue supporting local R&D initiatives to sustain the East's industrial leadership and global competitiveness.

In the Central region, R&D investment also plays a crucial role, but external technology flow has not yet made a significant impact. The FTRED coefficient ($\beta = 0.0460$, $p < 0.01$) highlights the importance of local R&D in fostering industrial growth, while the insignificant TechFlow coefficient ($\beta = 0.0068$) points to the underutilization of external technology. These findings resonate with Fan et al. (2011), who observed that the Central region's industrial base remains in transition, with a growing but underdeveloped capacity to integrate external innovations. Policy efforts in the Central region should aim to enhance mechanisms for technology transfer while maintaining robust support for R&D development.

The Northeast region exhibits a unique dependency on external technology flow to overcome its aging industrial infrastructure. Both FTRED ($\beta = 0.0768$, $p < 0.01$) and TechFlow ($\beta = 0.2468$, $p < 0.01$) are highly significant, but the latter demonstrates a much stronger influence. This finding strongly supports Lin's (2011) argument that regions with lagging industrial

bases require substantial external inputs to modernize and improve productivity. The high dependence on TechFlow highlights the region's reliance on external technological upgrades to compensate for its structural inefficiencies. Policymakers should focus on facilitating technology transfer through partnerships, subsidies, and knowledge-sharing platforms, while gradually building local R&D capacity for long-term sustainability.

In contrast, the Western region benefits from a balanced reliance on both R&D and technology flow. The coefficients for FTRED ($\beta = 0.0638$, $p < 0.05$) and TechFlow ($\beta = 0.1562$, $p < 0.01$) indicate that both internal and external factors are essential for industrial growth. This balanced approach reflects the West's diverse industrial landscape and moderate level of technological development. The results align with Jaffe et al. (2002), who highlighted the importance of combining local innovation and external knowledge to foster regional economic growth. Policies in the Western region should prioritize a dual strategy that strengthens local R&D while encouraging external collaborations to modernize and diversify the regional economy.

The model diagnostics, as shown in Table 3, indicate varying levels of model fit across the regions. The Eastern region exhibits the highest R^2 (0.969) and adjusted R^2 (0.964), suggesting that the model explains industrial GDP variation effectively in this region. The Central region follows closely with R^2 (0.966) and adjusted R^2 (0.957), also indicating a strong explanatory power. In contrast, the Northeast ($R^2 = 0.962$) and West ($R^2 = 0.950$) regions show lower model fit, with the Western region particularly affected by potential data heterogeneity or missing variables.

Table 3 Model Diagnostics by Region

Metric	East	Central	Northeast	West
R^2	0.969	0.966	0.962	0.950
Adjusted R^2	0.964	0.957	0.938	0.943
F-statistic	184.8	106.0	40.43	128.7
p-value (F-statistic)	1.85×10^{-12}	1.85×10^{-12}	1.13×10^{-6}	3.72×10^{-21}
AIC	3975.0	2218.0	1040.0	4232.0
BIC	4087.0	2301.0	1097.0	4357.0
Durbin-Watson	1.672	1.728	2.910	2.043
VIF (Constant)	2.58	3.20	6.79	1.85
VIF (FTRED)	1.73	1.67	2.57	2.79
VIF (TechFlow)	1.73	1.67	2.57	2.79

The F-statistics for all regions are significant ($p < 0.001$), confirming that the selected variables have a substantial effect on industrial GDP. The Eastern region has the highest F-statistic (184.8), reflecting the strong explanatory power of its model. However, the Northeast

region has the lowest F-statistic (40.43), suggesting a weaker overall model performance in that region.

Regarding model fit, the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) values show that the Central region has the best model fit, with the lowest AIC (2218.0) and BIC (2301.0). The Eastern region follows with an AIC of 3975.0 and BIC of 4087.0, while the Western region, with an AIC of 4232.0 and BIC of 4357.0, shows the poorest fit, possibly due to higher regional disparities.

For autocorrelation, the Durbin-Watson statistics indicate that the Northeast region (2.910) has the ideal value, suggesting minimal residual autocorrelation. The Western region also shows low autocorrelation (2.043). However, the Eastern (1.672) and Central (1.728) regions exhibit slight positive autocorrelation, which may warrant further examination with time-series models.

Regarding multicollinearity, the Variance Inflation Factor (VIF) values indicate that the Northeast region has a notably higher VIF for the constant term (6.79), likely due to its smaller sample size and more homogeneous industrial structure. Despite this, the VIF values for the independent variables (R&D investment and Technology flow) are within acceptable limits across all regions, suggesting that multicollinearity is not a significant concern overall.

Regional Disparities

China's industrial development exhibits stark regional disparities, driven by variations in R&D Full-Time Equivalent (FTRED) and Technology Flow (TechFlow). These disparities reflect differences in industrial maturity, innovation capabilities, and the ability to absorb external technology. By analyzing the Eastern, Central, Northeast, and Western regions, this section evaluates the unique developmental pathways of each region while verifying the proposed hypotheses.

Eastern Region: Innovation-Driven Industrial Powerhouse

The Eastern region, comprising provinces such as Guangdong, Jiangsu, and Shanghai, leads China's industrial landscape with its advanced innovation ecosystem. Empirical data reveal a strong positive relationship between FTRED and industrial GDP ($\beta = 0.0467$, $p < 0.01$), highlighting the region's reliance on local R&D for sustained growth. In contrast, TechFlow's contribution is negative ($\beta = -0.0443$, $p < 0.1$), indicating minimal dependence on external technology and, in some cases, potential substitution effects. These findings align with Hypothesis 1 (H1) and Hypothesis 3 (H3): in regions

with advanced technological capabilities, industrial growth is primarily driven by local R&D rather than external technology flow. The Eastern region benefits from robust infrastructure, a highly skilled workforce, and established innovation networks, enabling self-sufficiency in industrial development. As Naughton (2007) observed, the East's innovation-driven approach underpins its competitive edge. However, the Eastern region faces new challenges in maintaining its leadership amidst rapid global technological advancements. While continuing to prioritize local R&D, it should strategically explore external collaborations in emerging technologies to bridge potential gaps.

Central Region: Potential for Leapfrogging Growth

Unlike the Eastern region mature industrial ecosystem, the Central region—comprising provinces such as Henan, Hubei, and Jiangxi—demonstrates a developmental trajectory characterized by untapped potential. Empirical evidence shows a significant positive impact of FTRED on industrial GDP ($\beta = 0.0460$, $p < 0.01$), reflecting growing reliance on local innovation. However, TechFlow remains statistically insignificant ($\beta = 0.0068$), indicating limited utilization of external technological inputs. This partially supports Hypothesis 2 (H2) and Hypothesis 3 (H3). As a transitional region, the Central region relies increasingly on R&D investment but has yet to fully harness external technological contributions. The underutilization of TechFlow may stem from inefficiencies in technology transfer mechanisms or limited absorptive capacity among local firms. To unlock its full industrial potential, the Central region must adopt a dual strategy. On one hand, policies should encourage partnerships with external technology providers to bridge the existing gap. On the other hand, continued investment in local R&D can enable the region to transition toward innovation-driven industrial growth.

Northeast Region: External Dependence for Industrial Revival

The Northeast region, including provinces such as Liaoning and Jilin, represents a contrasting case with its reliance on external technology for industrial revitalization. The empirical analysis demonstrates that both FTRED ($\beta = 0.0768$, $p < 0.01$) and TechFlow ($\beta = 0.2468$, $p < 0.01$) significantly contribute to industrial GDP, with TechFlow playing a more dominant role. These results strongly support Hypothesis 1 (H1) and Hypothesis 3 (H3): lagging regions with structural challenges depend heavily on external

technology for growth. The Northeast's aging industrial base, coupled with limited innovation capacity, necessitates reliance on technology inflows to bridge developmental gaps. This observation resonates with Lin's (2011) argument that external support is essential for revitalizing traditional industrial regions. However, overreliance on external technology is not a sustainable long-term strategy. The Northeast region must gradually invest in local R&D infrastructure and talent development to reduce dependence on external inputs and establish a more self-sufficient industrial base.

Western Region: Balanced Growth and Modernization

The Western region, encompassing provinces like Sichuan and Xinjiang, showcases a balanced approach to industrial development. Empirical evidence reveals that both FTRED ($\beta = 0.0638$, $p < 0.05$) and TechFlow ($\beta = 0.1562$, $p < 0.01$) significantly contribute to industrial GDP, reflecting a dual reliance on local R&D and external technology. This balanced strategy validates Hypothesis 1 (H1), Hypothesis 2 (H2), and Hypothesis 3 (H3). The West's industrial trajectory underscores the importance of integrating internal innovation with external technological inputs, aligning with Jaffe et al. (2002) findings that such integration fosters regional development. The region's industrial diversification and modernization reflect its potential to combine the strengths of both local and external resources effectively. For the Western region, future growth lies in further strengthening its local R&D ecosystem while fostering international collaborations. By leveraging this dual approach, the region can overcome its developmental challenges and accelerate industrial modernization.

A comparative analysis of the four regions reveals distinct patterns of R&D Full-Time Equivalent (FTRED) and technology flow (TechFlow), reflecting their varying industrial maturity and development stages. The Eastern and Central regions both show high local R&D investment, but the Eastern region relies less on external technology due to its high industrial maturity. In contrast, the Northeast region is heavily dependent on external technology to modernize its aging industrial base, while also investing in R&D. The Western region, with its moderate R&D investment and technology flow, requires both local and external inputs to foster industrial growth and diversification.

The following table summarizes the key characteristics of each region, incorporating their

dependence on external technology, importance of local R&D, and level of industrial maturity:

Table 4 Comparative Analysis of Regional Industrial Characteristics

Region	R&D Investment (FTRED)	Technology Flow (TechFlow)	Dependence on External Technology	Local R&D Importance	Industrial Maturity	Key Industrial Characteristics
Eastern	High	Low	Low	High	High	Advanced Tech, High Innovation
Central	High	Low	Low	High	Moderate	Rapid Growth, Developing Infrastructure
Northeast	High	High	High	Moderate	Low	Aging Infrastructure, Needs Technology Upgrade
Western	Moderate	Moderate	Moderate	Moderate	Moderate	Diversification, Needs External Support

Table 4 and Table 5 together provide a comprehensive summary, illustrating the relationship between local R&D investments, technology flow, and regional industrial characteristics. They highlight the alignment of the findings with the hypotheses and emphasize the need for tailored policy interventions to address the unique industrial development challenges and opportunities in each region.

Table 5 Summary of Hypotheses and Regional Support

Hypothesis (H)	Description	Support
H1: In regions with advanced technology, local R&D investment has a greater impact on industrial GDP than technology flow.	Eastern	Supported in Eastern regions, as their strong local R&D reduces dependence on external technological flow.
H2: In regions with moderate development, R&D investment is crucial for industrial growth, but external technology flow has not yet reached its full potential.	Central	Partially supported in Central regions, where local R&D investment significantly impacts industrial growth, but the role of technological flow remains limited.
H3: In regions with technological lag, technology flow has a greater impact on industrial growth than local R&D investment.	Northeast and Western	Supported in Northeast and Western regions, where technological flow plays a key role in driving industrial growth, especially in Northeast, where its impact outweighs local R&D.

Conclusion

Summary of Findings

This study examines the role of R&D Personnel Investment (R&D Full-Time Equivalent: FTRED) and Technology Flow in driving industrial growth across different regions in China, revealing significant regional disparities in their impacts. The

findings highlight how industrial maturity and technological infrastructure shape regional economic outcomes, fulfilling the study's objectives. FTRED and TechFlow significantly influence industrial GDP, with their roles varying across regions, addressing Objective 1. Clear regional disparities in industrial development and knowledge spillovers fulfill Objective 2, while tailored policy recommendations for balanced growth meet Objective 3. The results validate H1 in the Eastern region, where local R&D dominates; partially support H2 in the Central region, where external technology remains underutilized; and confirm H3 in the Northeast and Western regions, where technology flow is more impactful. These findings emphasize the importance of region-specific strategies for achieving balanced and sustainable industrial development.

Collectively, the empirical analyses and regional policy insights presented in this study comprehensively address the three research objectives outlined in the introduction. First, the econometric results establish the distinct contributions of R&D personnel investment and technology flow to regional industrial GDP, thereby fulfilling Objective 1. Second, the disaggregated regional findings reveal substantial disparities in innovation capacity and knowledge absorption across China's Eastern, Central, Western, and Northeast regions, addressing Objective 2. Finally, Objective 3 is fulfilled through the formulation of region-specific, evidence-based policy recommendations aimed at strengthening local innovation systems and facilitating coordinated regional development. This alignment between research design, empirical validation, and actionable outcomes enhances both the academic and practical contributions of the study.

Regional Insights

In the Eastern region, where industrial maturity is high, R&D Full-Time Equivalent (FTRED) plays a pivotal role in driving growth. The region's well-developed technological base minimizes its dependence on external technology flows. This aligns with Naughton (2007), who described the East's innovation ecosystem as self-reliant, driven by strong local R&D and advanced infrastructure. The findings reaffirm the East's ability to sustain industrial leadership through internal innovation rather than external inputs.

The Central region demonstrates the importance of FTRED in fostering industrial growth, but external technology flow does not significantly contribute. This reflects the region's transitional state, where technological

capabilities are developing but have not yet fully matured. As observed by Fan et al. (2011), this underutilization of external technology can be attributed to limited absorptive capacity and inefficiencies in technology transfer mechanisms. These findings suggest that the Central region is positioned for growth but requires targeted policies to unlock its potential.

In the Northeast region, the critical role of technology flow stands out as the region's aging infrastructure necessitates substantial external support. This result supports Lin & Monga (2010) assertion that lagging regions with structural inefficiencies must rely heavily on external technological inputs to modernize. However, the Northeast also benefits from FTRED, indicating that local R&D efforts are contributing but remain secondary to external technology in driving industrial growth. These findings highlight the urgency for balanced strategies that address both short-term modernization needs and long-term local innovation development.

The Western region benefits from a balanced reliance on FTRED and technology flow, suggesting that internal and external factors complement each other in driving growth. This dual approach is consistent with the work of Jaffe et al. (1993), who emphasized the role of combining local innovation with external knowledge for regional economic diversification. In the West, this balance reflects its evolving industrial landscape, which requires both internal capacity-building and external collaboration to achieve sustainable growth.

Suggestions

For the Eastern Region: Policymakers should continue to prioritize investments in local R&D ecosystems to maintain the region's industrial leadership. Strategic external collaborations in emerging technologies, such as AI and renewable energy, could further strengthen competitiveness in global markets.

For the Central Region: Efforts should focus on enhancing technology transfer mechanisms and building absorptive capacity among firms. Initiatives like targeted subsidies, joint R&D programs, and regional innovation hubs could help integrate external technology flow into industrial growth.

For the Northeast Region: Policies should prioritize facilitating external technology inflows through partnerships with leading technology firms and knowledge-sharing platforms. Simultaneously, investments in local R&D infrastructure and workforce

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development are essential to reduce long-term dependence on external inputs.

For the Western Region: A dual approach is recommended, combining strengthened local R&D efforts with the promotion of external collaborations. Special attention should be given to industrial diversification strategies to overcome economic reliance on a few sectors and foster modernization.

National-Level Policy: To address regional disparities, the central government could consider designing a coordinated regional innovation strategy that aligns the strengths of each region with national industrial goals. This might include differentiated funding schemes, inter-regional knowledge-sharing platforms, and performance-based incentives for firms and research institutions.

Limitations

Despite providing significant insights, this study has several limitations that should be acknowledged:

Limited Timeframe of Data: Compared to developed economies in Europe and North America, China's reform and opening-up period is relatively short. As a result, the available data does not cover as long a time horizon, potentially limiting the ability to analyze long-term trends and dynamics.

Exclusion of Hong Kong, Macau, and Taiwan: While Hong Kong, Macau, and Taiwan are among the most important sources of capital investment for mainland China, this study does not include their contributions.

Impact of National Security Considerations: Certain provinces in China prioritize industries critical to national security, such as nuclear and defense industries, which may require sacrificing some economic efficiency. These unique constraints are not fully addressed in this study but should be factored into future analyses of regional industrial performance.

Rise of Remote Workers: The increasing number of remote workers in China, especially after the COVID-19 pandemic, may alter regional economic dynamics, including the flow of human capital and industrial development. This emerging trend is not accounted for in the current study and requires further exploration in future research.

Future Research Directions

Future research could expand on this study by exploring sector-specific variations in the relationship

between R&D Personnel Investment (R&D Full-Time Equivalent: FTRED) and Technology Flow. For example, investigating how manufacturing industries versus service sectors respond to these variables could offer deeper insights into their differential impacts. Additionally, cross-country comparisons could help contextualize the findings and inform regional development strategies in diverse industrial contexts. Longitudinal studies would also provide more clarity on the causal mechanisms by examining how technological infrastructure evolves over time and affects industrial performance.

In conclusion, the study emphasizes the importance of tailoring regional development strategies to the unique technological needs and industrial stages of different regions. Regions such as the East, with advanced industrialization, can continue to focus on R&D Full-Time Equivalent (FTRED) as the primary driver of growth. In contrast, less developed regions like the Northeast and West require external technology flows to complement their internal R&D investment for industrial upgrading. Understanding these regional disparities and their respective needs for R&D Full-Time Equivalent (FTRED) and technology transfer will be critical in fostering balanced and sustainable industrial growth across China.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, the author used ChatGPT (OpenAI) to improve language clarity and readability. The final content was reviewed and edited by the author, who takes full responsibility for the accuracy and integrity of the publication.

Conflict of interests

The author declares no conflict of interest.

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