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Effects of financial agglomeration on green total factor productivity in Chinese cities: Insights from an empirical spatial Durbin model

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ABSTRACT

Green Total Factor Productivity (GTFP) is a critical indicator for measuring the development and transformation of green economy, with profound implication for achieving a win-win situation of conserving energy, reducing emissions, and developing economy. The promotion of GTFP cannot be separated from the financial support and guarantee provided by financial agglomeration. According to the theory of new economic geography and agglomeration, this study uses location entropy and directional SBM-DEA methods to calculate the financial agglomeration level and GTFP of 283 cities at prefecture-level and above in China from 2003 to 2018. A temporal and individual two-way fixed-effect model and a spatial measurement model are constructed to empirically study direct and spillover impacts of financial agglomeration on GTFP. The empirical results show that financial agglomeration facilitates GTFP growth in a given city, but it significantly reduces GTFP in surrounding areas of the city. Divided the cities by their geolocations in eastern, central, and western regions, we find that, in each region, financial agglomeration can significantly promote GTFP of a city but does not have a significant impact on its surrounding areas, indicating a weak spillover effect. Cities with a population of less than 3 million are associated with higher GTFP. Industrial structure, foreign direct investment and human capital play a positive role in GTFP growth, but the role of urban infrastructure construction appears trivial.

1. Introduction

Green development is a promising means to solve the problems arisen from the contradiction between economic growth and environmental conservation and is often regarded as an effective strategy to realize China's economic transformation towards high-quality development. With fast industrialization, environmental pollution caused by the economically extensive model has been a critical issue that China urgently needs to solve. According to the Report “Atmospheric China 2020: China's air pollution prevention and control process[1]”, despite environmental regulations, the concentration levels of $PM_{2.5}$, NO_x, CO of 337 cities in 2019 remained at the same level as 2018 with continuing ozone deterioration. For long, the Chinese government has paid special attention to environmental improvement and resource protection, aiming to achieve harmonious development of resource, environment, and economy. The core goal is to realize green development. Meanwhile, China is at a crucial period of economic transformation and optimization (Li et al., 2020). To establish a harmonious people-nature relationship, there is an impetus to continuously increase total factor productivity. The 2019 government work report reiterated that it is necessary to reform policies concerning both the environment and economy, strengthen financial development incorporating green components, cultivate a group of specialized environmental protection backbone enterprises, and enhance the capability of green development. The goal of promoting green total factor productivity becomes increasingly central in economic development. The characteristics of the financial industry in Chinese cities are “power types” and “clean types”, which are essential for realizing green development. Due to intensified competition, financial institutions tend to conduct production and transactions through coordination among enterprises, gathering related resources and gradually forming a financial agglomeration area. These financial institutions rely on the existing economic foundation in the area to share information, materials, services, and public infrastructures (Park, 1989; Yuan, 2020). Such processes may reinforce the flow of financial resource

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elements, along with optimized allocation of resources, as well as increase in economies of scale, knowledge spillover effects, and spatial spillover effects on green production efficiency. The purpose of the present study is to assess the impacts of financial agglomeration on Green Total Factor Productivity (GTFP) and to inform policymakers with implications for how China can optimize the development model of financial agglomeration to enhance the green developing efficiency.

Studies on financial agglomeration and GTFP mainly focus on three aspects. The first aspect is the study of financial agglomeration. Some studies emphasized financial functions (Stiglitz, 1986; Levine, 1999; Buera et al., 2011; Chava et al., 2013), financial liberalization (Brown et al., 2012), financial system (King and Levine, 1993), and methods of measuring financial agglomeration including EG index (Ellison and Glaeser, 1997), spatial Gini coefficient (Krugman, 1991) and location entropy (Holmes and Stevens, 2004; Ye et al., 2018). Others discussed the relationship between financial agglomeration and production efficiency. Rodriguez (2017) found that financial agglomeration can accelerate economic growth by restraining exchange rate changes. Nguyen et al. (2019) argued that financial agglomeration has different promoting effects on economic growth at different stages of economic development. Through research in China, studies showed that financial agglomeration can promote regional productivity growth through direct financial agglomeration effects (Zhang et al., 2020), spatial spillover effects (Xu et al., 2018; Xu and Zheng, 2020), and technological innovation (Li et al., 2015; Li and Ma, 2021). The second aspect emphasizes GTFP. According to the neoclassical economic growth theory (Solow, 1957), earlier economists generally defined total factor productivity as the efficiency of the development of human society and the utilization of resources, including human, material, and financial resources (Gordon, 1987; Jorgenson et al., 2016). Research suggested that the total factor productivity measured by traditional methods ignores the non-market costs caused by environmental damage and degradation (Chung et al., 1997). However, environmental degradation may offset a large amount of traditional GDP growth, so the concept of GTFP that takes environmental pollution and energy consumption into account is further proposed (Rusiawan et al., 2015; Zhao et al., 2015). The last aspect is the relationship between financial agglomeration and TFP. Some scholars argued that the efficiency of financial resource allocation is an important factor affecting the differences in regional economic development (Wurgler, 2000; Dixon, 2011). Others proposed that financial innovation can benefit the innovation of enterprise-level technology and patented products, thereby promoting total factor productivity (Brown et al., 2012; Amore et al., 2013). Several studies examined the impact of financial resource misallocation on technological innovation and measured the degree of financial resource misallocation caused by financial market friction from different levels, as well as their detrimental effects on TFP (Midrigan and Xu, 2014; Moll, 2014).

Overall, studies on the economic outcomes of financial agglomeration as reviewed above form a solid basis for analyzing productivity, yet few studies focused on how financial agglomeration affects the development of green economy efficiency. The existing papers mainly measured total factor productivity using traditional methods, ignoring the GTFP including environmental pollution and energy consumption when examining financial agglomeration effects. In addition, fewer studies consider both the direct impact and spatial spillover effects of financial agglomeration on GTFP and address heterogeneity across regions and urban scales. In view of this, the value of the present study lies in: 1) filling the gaps in theoretical research in the aforementioned areas by examining the effect of financial agglomeration on GTFP; 2) using the SBM-DEA method to measure GTFP with introduction of environmental pollution and energy consumption; 3) systematically exploring the impact, including spillover, of financial agglomeration on GTFP with regional difference and urban scale heterogeneity.

The paper presents empirical findings in Chinese cities that contribute to the existing knowledge. Empirical results support that agglomeration facilitates GTFP growth in a given city, but significantly reduces GTFP of the surrounding areas. When dividing the cities by their geolocations in eastern, central, or western regions, financial agglomeration can significantly promote GTFP of a city but does not have a significant impact on the surrounding areas, suggesting a weak spillover effect in each geographic region. Cities categorized in type II large (i.e., population ranging 1–3 million), medium (population ranging 0.5–1 million) and small sizes (population below 0.5 million) are associated with higher GTFP.

This remaining structure of this article proceeds as follow. Section 2 formulates mechanism analysis and theoretical hypotheses. Section 3 describes in detail the empirical model, variable measurement, and data description. Section 4 interprets the empirical modeling results while Section 5 tests the robustness of the outcomes. Section 6 analyzes the regional heterogeneity and urban scale heterogeneity. Finally, we draw major conclusions and provide policy implications in Section 7.

2. Mechanism analysis and hypothesis

2.1. Financial agglomeration affects GTFP through knowledge or technology spillover

One accompanying feature of industrial agglomeration is knowledge spillover, which is a process of spreading by means of a certain method among organizations or enterprises. It may exponentially increase the knowledge stock of the cluster and the possibility of creating new knowledge, a fundamental reason why industrial clusters can improve their innovation capabilities and gain competitive advantages (Grossman and Helpman, 2001). Financial agglomeration allows accurate dissemination of knowledge and information between upstream and downstream, reducing information asymmetry and optimizing resource allocation for a more abundant capital environment (Audretsch and Feldman, 2004; Cotter et al., 2021). Technology spillover may be another feature associated with financial agglomeration. In countries with strict institutional arrangements, the development of capital markets and the banking industry can introduce higher-quality foreign direct investment (FDI), and improve the host country's green production technology by means of FDI technology spillover, thereby reducing resource consumption and environmental pollution (Tamazian et al., 2009). Hence, Hypothesis 1 (**H1**) is:

H1. : Financial agglomeration promotes GTFP growth through effects of knowledge or technology spillover.

2.2. Financial agglomeration affects GTFP through economies of scale

Financial agglomeration is a phenomenon resulting from financial deepening development. Currently, the flow of financial resources between regions is accelerating, showing a trend of high concentration of financial activities and financial institutions. The agglomeration of financial institutions can improve the cross-regional allocation efficiency of financial resources and reduce transaction costs. It is also conducive to use the shared network infrastructure to avoid information asymmetry and hence achieve economies of scale (Zhao, 2003). As such, financial agglomeration may accelerate the realization of innovation and technological progress through external economies of scale, replacing more energy-intensive resource technologies with low-emission energy-saving technologies benign to the environment (Ma and Stern, 2008). Other mechanisms may include the expansion of enterprise production scale with reduced environmental pollutants per unit of output, and the restriction of loans for (or investment in) polluting enterprises with funds flow to low-emission enterprises (Wang et al., 2021). Thus, Hypothesis 2 (**H2**) is:

H2. : Financial agglomeration benefits GTFP growth by exerting economies of scale.

2.3. Spatial spillover effects of financial agglomeration on GTFP

The gathering of financial institutions and activities in a certain area in the pursuit of regional resources can from a city-centric pattern of financial agglomeration. The strong liquidity of financial capital, along with the wide spread of industries and regions, can be associated with a notable spatial spillover effect of financial agglomeration on economic growth (Ye et al., 2018). First, financial agglomeration is featured by spatial agglomeration of financial resources in a certain place such as a megacity, hence involving spillover effects on the nearby places (Baldwin et al., 2003). Under this circumstance, the accelerated of financial centers via "magnet effects" and "spillover effects" can improve the liquidity and allocation efficiency of capital elements (Bernat, 2006), further affecting the quality and level of green development. Due to the rapid development of the "central area" as financial clusters, numerous capital elements, talent elements, and technological innovations constantly flow into the regional financial clusters. Such a process may be amplified by the "siphon effects", namely, the "profit-driven" characteristic extends the influencing boundary of surrounding areas and then reduces the allocation efficiency of production factors and the associated productivity (Ewers et al., 2018). The last hypothesis, Hypothesis 3 (**H3**), is:

H3. : Financial agglomeration can restrict the growth of green total factor productivity in surrounding areas through spatial spillover effect.

3. Measurement model setting and data description

3.1. Data collection

In this paper, panel data of 283 cities at and above the prefecture level in China from 2003 to 2018 were finally selected for analysis (Xie et al., 2019b). The data come from the 2004–2019 China Urban Construction Statistical Yearbook, China Urban Statistical Yearbook, and China Statistical Yearbook.

3.2. Variable selection

3.2.1. Outcome variable

The outcome variable is Green Total Factor Productivity (GTFP), which is calculated following the approach by (Chung et al., 1997), namely the directional SBM-DEA method. Among the variables used for the GTFP calculation, the GDP of the secondary and tertiary industry of the cities at all levels is the expected output, and the urban sulfur dioxide emission and carbon emission is the unintended output. The calculation of carbon emission refers to the method of (Xie et al., 2017). The input elements are indicators including labor, energy input, and capital stock. Labor force is represented by employee number at the end of the year in each city; energy input is measured by referring to (Xie et al., 2017); capital stock is calculated following the method of perpetual inventory described in (Han and Ke, 2013).

3.2.2. Key explanatory variable

The key explanatory variable is financial agglomeration. Location entropy, which has the characteristics of simple calculation and wide applications (Yuan et al., 2020), is used to characterize the agglomeration level of financial industry in various cities with the formula written as follows:

$$Q_{ij} = \frac{q_{ij}/q_j}{q_i/q} \tag{1}$$

Among them, i denotes the financial industry, and j denotes the prefecture-level city; Q_{ij} represents the location entropy of financial industry i of prefecture-level city j in the country; q_{ij} expresses the number of employees in financial industry i within prefecture-level city j, and q_j indicates the number of employees in all units within prefecture-level city j; q_i is the number of employees in financial industry units nationwide, and q is the number of employees in all units nationwide.

3.2.3. Control variables

Four control variables, including industrial structure, foreign direct investment, urban infrastructure, and human capital, are selected. Their descriptions and justifications are provided below.

3.2.3.1. Industrial structure. Recently, the industry structure in China is continuously optimized with strengthened informatization under urbanization. As production factors gradually gather in geographically advantageous areas, the industrial production efficiency is constantly improved. This process improves the market liquidity of resource flow from high-pollution to low-pollution enterprises and eliminates backward production capacity. Here, the model controls for the proportion of the secondary industry's GDP of cities at prefecture-level and above in the regional GDP to measure the industrial structure.

3.2.3.2. Foreign direct investment (FDI). Foreign finance is often invested to industries possessing greater development potentials and better structural levels. An expanded FDI can benefit urban industries for improving development quality and sustainability (Asghari, 2013). Here, the analysis controls for the actual use of foreign investment throughout the year in each city to represent foreign direct investment.

3.2.3.3. Urban infrastructure. The "new economic geography" (Krugman, 1991) points out that completed infrastructure and substantial development foundation of a city promotes the comprehensive improvement of the city. Urban road traffic is essential to measuring the level of urban infrastructure since it facilitates the exchange of capital, technology, talent, and products through offering superior transportation services relevant to economic productivity. The present study chooses the per capita urban road area as an indicator of the urban infrastructure status.

3.2.3.4. Human capital. The concentration of human resources is a critical phenomenon of socioeconomic development filled with sufficient knowledge, high-tech and innovative industries. The proportion of students in colleges and ordinary middle schools in each city in the total population is used to measure human capital.

Table 1 reports the statistics of financial agglomeration, GTFP and other variables in the sampled cities.

3.3. Model design

This study considers the dual fixed effects OLS regression model of individual and time to analyze the panel data with their characteristics described above (Shen et al., 2021). Given the geographical interdependence of cities at various levels, spatial spillover effects may exist for the relationships between financial agglomeration and GTFP. Therefore, the analysis also conducts spatial econometric models based on the benchmark fixed effect model.

Table 1
Descriptive statistics of financial agglomeration, GTFP and other variables in sampled cities.

Variable	Mean	Std. Dev.	Min.	Max.
Financial Agglomeration (ln*QWS*)	0.135	0.436	−3.613	1.161
Green Total Factor Productivity (ln*GTFP*)	−0.402	0.270	−2.187	0.000
Industrial Structure (ln*DSCY*)	−0.759	0.255	−3.948	−0.051
Foreign Direct Investment (ln*FDI*)	10.671	3.658	−6.017	16.543
Urban Infrastructure (ln*DLMJ*)	2.195	0.632	−1.171	4.714
Human Capital (ln*XSSL*)	−2.680	0.328	−4.962	−0.943

3.3.1. Benchmark fixed effects measurement model

The present study establishes the following regression model as the benchmark model:

$$lnGTFP_{it} = \beta_0 + \beta_1 lnQWS_{it} + \beta_2 lnDSCY_{it} + \beta_3 lnFDI_{it} + \beta_4 lnDLMJ_{it} + \beta_5 lnXSSL_{it} + V_t + U_i + \varepsilon_{it} \tag{2}$$

Among them, i, t are the city and the year, respectively. $GTFP_{it}$ represents green total factor productivity, and QWS_{it} represents financial agglomeration. For control variables, $DSCY_{it}$ characterizes industrial structure, FDI_{it} is foreign direct investment, $DLMJ_{it}$ is urban infrastructure, and $XSSL_{it}$ is human capital. V_t represents the fixed time effect that measures the time trend and does not change with the city. U_i is an individual fixed effect that does not change with time, reflecting individual differences at the city level. Finally, ε_{it} is the random interference item.

3.3.2. Spatial econometric model

The spatial econometric model is specified as follows:

$$lnGTFP_{it} = \alpha + \rho \sum_{j=1, j\neq i}^{N} W_{ij} lnGTFP_{jt} + \beta X_{it} + \sum_{j=1, j\neq i}^{N} W_{ij} X_{ijt} \theta + \mu_i + V_t + \varepsilon_{it}$$

$$\varepsilon_{it} = \varphi \sum_{j=1, j\neq i}^{N} W_{ij} \varepsilon_{jt} + \phi_{it} \tag{3}$$

Among them, ε_{jt} denotes the error term; μ_i, V_t are unobservable regional effects and temporal effects, respectively; ρ and φ are coefficients corresponding to spatial lag and spatial error; W_{ij} denotes the geographic distance spatial weight matrix; X includes financial agglomeration and others Independent variable vector including control variable. Eq. (3) is a model in the general form. Whether to choose a spatial lag explanatory variable or a spatial Durbin model based on the general model required further tests as described in the following sections.

4. Spatial metrological inspection and empirical results

4.1. Spatial metrological inspection

Moran's I statistic (Moran, 1950) is used to explore the spatial autocorrelation of GTFP among prefecture-level cities. The spatial weight matrix of geographical distance measured by Latitude and Longitude is selected to describe the spatial interrelation of observation data sets accurately. The range of *Moran's I* statistic is [−1,1], of which a positive value indicates a positive spatial correlation (i.e., spatial agglomeration); a negative value indicates a negative correlation (i.e., a phenomenon called spatial exclusion); a value of 0 indicates that urban GTFP is not spatially correlated, exhibiting an irregular random distribution. The panel *Moran's I* for GTFP is calculated to be 0.092. statistically significant at the 1% significance level, suggesting a positive spatial correlation of GTFP among the cities.

Based on the basic two-way fixed effect analysis, the present study uses spatial measurement methods to conduct further statistical tests on the relationship between financial agglomeration and GTFP that shows regional agglomeration and spatial spillover. Table 2 shows the test results. Following the ideas by (Elhorst, 2012), results from likelihood ratio (LR), Lagrange multipliers (LM) and Hausman tests suggest that the spatial lag model and the spatial error model cannot be decomposed into the simplified form of the spatial measurement model, making the fixed effect model more suitable for the analysis here (Wang et al., 2021). Therefore, the spatial Durbin model with time and space dual fixed effects is used for the empirical analysis in this research.

Table 2
Spatial econometric inspection results.

Model for test	Statistics	Adjoint probability
LM-lag	31.8665***	0.000
R-LM-lag	17.2892***	0.000
LM-err	38.2202***	0.000
R-LM-err	23.6429***	0.000
SFE-LR	3823.8856***	0.000
TFE-LR	384.7285***	0.000
Hausman test	20.9161**	0.034

Note: **, *** denote significant levels at 5% and 1%, respectively.

4.2. Results from benchmark measurement models

The results of the benchmark OLS regression model and the estimated results after adding individual fixed effects and time fixed effects item by item are showed in Table 3. Model 1 represents simple OLS model; Model 2 adds individual fixed effects, while Model 3 adds both individual and time fixed effects; Model 4 uses robust standard errors based on Model 3. Across all the four models, results show that financial agglomeration has a consistently and significantly positive effect on GTFP in Chinese cities (coefficient = 0.069– 0.084, $p < 0.01$) even after controlling for the other covariates. This may be because financial agglomeration guides the flow of capital to enterprises with high energy use efficiency and resource allocation efficiency, forcing enterprises with highly polluted and energy-consumed characteristics to improve technology, resulting in a reduction in pollution emissions and energy consumption and thus improving the GTFP in the city.

Regarding control variables, industrial structure also exhibits a significant positive effect on cities' GTFP for all models (coefficient = 0.121– 0.150, $p < 0.01$), which is expected. As China's industrial production efficiency improves, the industrial structure tends to be optimized, associated with eliminated outdated capacity and enhanced energy conservation and emission reduction effect (Hou and Song, 2021). Although urban infrastructure and human capital show statistically significant effects on GTFP in Model 1 and Model 2, their effects diminish after considering the individual and time fixed effects. Foreign investment makes trivial contribution.

Hypotheses 1 and 2 of this paper states that financial agglomeration can enhance GTFP by exerting knowledge spillover effect or scale economy effect. To test the mechanisms, we add the interaction terms of financial agglomeration with knowledge spillover and economies of scale to in empirical regression models. Among them, science budget expenditure (ln*RD*) is used to represent knowledge spillover effect, and industrial gross output value (ln*IO*) is used as the substitution variable of scale economy effect. From the results of Model (5) and Model (6) in Table 3, financial agglomeration (coefficient = 0.133 or 0.196, $p < 0.01$), knowledge spillover effect (coefficient = 0.005, $p < 0.05$) and scale economy effect (coefficient = 0.010, $p < 0.05$) of single variable all have a significantly positive effect on GTFP. However, interaction items ln*QWS* * ln *RD* and ln*QWS* * ln *IO* failed the 5% significance test, suggesting neutral effects of the two hypothesized variables on how financial agglomeration on GTFP. Thus, Hypothesis 1 (**H1**) and Hypothesis 2 (**H2**) are not confirmed.

4.3. Results based on spatial econometric modeling

Table 4 shows the estimated results of the spatial Durbin fixed effects model considering the significant spatial correlation of GTFP. In terms of the effects of financial agglomeration of key interest on GTFP, results suggest that the direct effect is positive (coefficient = 0.083), but the indirect effect is negative (coefficient = −0.115), both statistically significant ($p < 0.01$). Hypothesis 3 (**H3**) is confirmed. This indicates that although financial agglomeration significantly promotes the improvement of GTFP in a given city, it significantly reduces the GTFP in surrounding areas of the city. Financial agglomeration significantly reduces the GTFP of surrounding areas, which may be because the scarcity of financial resources will make financial resources gather in a region and thus reduce the financial resources in surrounding areas, restricting the

Table 3
Estimation results of benchmark measurement model.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
ln*QWS*	0.069***	0.070***	0.084***	0.084***	0.133***	0.196**
	(0.008)	(0.009)	(0.011)	(0.022)	(0.036)	(0.087)
ln*DSCY*	0.121***	0.150***	0.134***	0.134***	0.150***	0.142***
	(0.020)	(0.021)	(0.023)	(0.044)	(0.021)	(0.022)
ln*FDI*	0.001	0.002	0.001	0.001	0.002	0.002
	(0.001)	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)
ln*DLMJ*	0.025***	0.025***	0.007	0.007	0.015	0.0134
	(0.007)	(0.007)	(0.009)	(0.015)	(0.009)	(0.009)
ln*XSSL*	0.032**	0.037**	0.023	0.023	0.041***	0.044***
	(0.014)	(0.015)	(0.015)	(0.021)	(0.016)	(0.016)
ln*RD*	/	/	/	/	0.005**	/
	/	/	/	/	(0.002)	/
ln*QWS* * ln *RD*	/	/	/	/	−0.007	/
	/	/	/	/	(0.004)	/
ln*IO*	/	/	/	/	/	0.010**
	/	/	/	/	/	(0.004)
ln*QWS* * ln *IO*	/	/	/	/	/	−0.008
	/	/	/	/	/	(0.005)
Constant	−0.300***	−0.274***	−0.390***	−0.390***	−0.288***	−0.396***
	(−0.047)	(−0.048)	(−0.054)	(−0.081)	(0.048)	(0.069)
Observations	4528	4528	4528	4528	4528	4528
R-squared	/	0.028	0.107	0.107	0.030	0.030
Number of cities	283	283	283	283	283	283

Note: **, *** denote significant levels at 5% and 1%, respectively; Standard errors are in parentheses.

Table 4
Estimation results of spatial Durbin fixed effects model.

Variables	Direct effect	Indirect effect	Total effect
ln*QWS*	0.083***	−0.115***	−0.031
	(8.175)	(−2.870)	(−0.756)
ln*DSCY*	0.153***	−0.231***	−0.077
	(6.070)	(−3.105)	(−1.043)
ln*FDI*	0.002	0.016**	0.017**
	(1.271)	(2.308)	(2.510)
ln*DLMJ*	0.009	−0.033	−0.023
	(1.039)	(−1.017)	(−0.708)
ln*XSSL*	0.032**	−0.035	−0.003
	(2.087)	(−0.624)	(−0.048)
Observations	4528	4528	4528
R-squared	0.602	0.602	0.602
Number of cities	283	283	283

Note: **, *** indicate significant levels of significance at 5% and 1%, respectively; the t statistic is in brackets.

GTFP growth in nearby cities.

Regarding control variables, the results of the industrial structure suggest that the direct effect is positive (coefficient = 0.153), but the indirect effect is negative (coefficient = −2.31), both statistically significant ($p < 0.01$). This indicates that although industrial structure significantly promotes the improvement of GTFP in a given city, it significantly reduces the GTFP in surrounding areas of the city. In the process of promoting industrial production efficiency and technological innovation intensity in this region, the rapid industrial upgrading has led to the transfer of technical talents and capital from surrounding areas to the city. This has made the surrounding areas lack of production factors for industrial innovation and upgrading, thereby weakening GTFP in nearby areas. FDI significantly promotes the improvement of GTFP in surrounding areas. Surrounding regions will also carry out technological innovation and reform, through countervailing the spillover of given cities' technologies, talents, and capital, to improve GTFP. Human capital can significantly promote the growth of GTFP. Through knowledge accumulation and independent innovation, human capital carries out green technology innovation and application, to significantly improve energy efficiency and ultimately promote GTFP. Whether direct or indirect, the role of urban infrastructure construction on GTFP is far smaller than the other controlling factors.

5. Robustness test

The modeling results above show that the stronger the financial agglomeration in a region (city), the higher the GTFP level in that region (city). Here, the robustness of the estimations is tested from four aspects: 1) changing the spatial measurement model (Model 1), 2) changing the spatial weight matrix (Model 2), 3) using alternative measurement index of financial agglomeration (Model 3), and 4) using alternative financial agglomeration indicators (Model 4). The results are provided in Table 5.

5.1. Replacement of spatial measurement model

Using the spatial lag explanatory variable model (Model 1 in Table 5), all variables show stable effects on GTFP as those based on the spatial Durbin model. For instance, the coefficient of financial agglomeration is 0.085 ($p < 0.01$), suggesting a strong robustness level even with an alternative model. Similar outcomes are also observed for the two control variables: industrial structure and urban infrastructure.

5.2. Replacement of spatial weight matrix

The spatial Durbin model is based on the widely used geographic distance matrix, which may not completely match the correlation between the cities at different levels. The spatial spillover effect between

Table 5
Results of robustness test.

Variable	(1)	(2)	(3)	(4)
ln*QWS*	0.085***	0.084***	0.052***	0.004***
	(8.011)	(8.157)	(3.220)	(2.826)
ln*DSCY*	0.136***	0.134***	0.131***	0.124***
	(5.926)	(6.000)	(2.962)	(5.302)
ln*FDI*	0.002	0.002	0.002	0.002
	(1.020)	(1.200)	(0.659)	(1.200)
ln*DLMJ*	0.008***	0.007	0.005	0.005
	(0.895)	(0.844)	(0.343)	(0.576)
ln*XSSL*	0.022	0.022	0.021	0.019
	(1.434)	(1.502)	(0.979)	(1.214)
Observations	4528	4528	4528	4528
R-squared	0.599	0.023	0.103	0.096
Number of cities	283	283	283	283

Note: *** denote significant levels at 1%; t statistics are in brackets.

financial agglomeration and GTFP may originate from economic links between regions, such as traffic conditions and actual economic relationships, instead of geographic relationships. Thus, one robustness check involves the replacement of the weight matrix using the economic distance (Feng and Chen, 2018). From the regression results of Model 2 in Table 5, the influencing degree of financial agglomeration persists when the estimation is weighted by economic distance, with a statistically significant coefficient of 0.084. This further demonstrate the robust effects of financial agglomeration on GTFP.

5.3. Alternative measurement of financial agglomeration index

The third method uses the improved industrial diversification index (Combes, 2000) as an alternative indicator for the level of financial agglomeration, expressed as:

$$Q_i = \sum_f \frac{P_{if}}{P_i}\left[\frac{1\Big/\sum_{f'=1,f'\neq f}^{n}\left[P_{if'}/(P_i-P_{if})\right]^2}{1\Big/\sum_{f'=1,f'\neq f}^{n}\left[P_{f'}/(P-P_f)\right]^2}\right] \tag{4}$$

Among them, P_i is the total employee number in city i, P_{if} is the employee number in financial industry f of city i, P_f' represents the employee number in the financial industry f except for city i, P' is the total employee number in China excluding city i, P_f represents the employee number in national financial industry f, and P denotes the total employee number in China.

Using the alternative financial agglomeration indicator, although the coefficient is in a relatively small magnitude, financial agglomeration is shown to significantly promote GTFP growth (Model 3, Table 5), which is consistent with the conclusion of Qu et al. (2020).

5.4. Indicator of financial agglomeration with different component

Last, the number of financial institutions is used as a substitute of the number of employees for calculating the financial agglomeration indicator. The data come from the number of prefecture-level city banking institutions of the China Banking and Insurance Regulatory Commission during 2003–2018. As shown in Model 4 of Table 5, the effect of financial agglomeration on the improvement of GTFP remains significant despite a rather small magnitude.

6. Analysis of heterogeneity by geographic region and city scale

6.1. Regional heterogeneity

The eastern, central, and western regions have different factor endowments, policy trends, technological input levels, and economic development status, while the model of financial agglomeration and GTFP can be affected due to regional differences. The following analysis draws on the method of (Xie et al., 2019b) to classify the sampled cities into those in eastern, central, and western regions, and then fits the spatial Durbin model separately.

According to the estimated results by regions (Table 6), the positive direct effect of financial agglomeration on GTFP growth is evident in all the three geographic regions, suggesting a persistent benign relationship between the two variables. However, there exist differences in terms of the indirect and total effect. In eastern and central regions, the negative indirect effects of financial agglomeration are detected but they are not statistically significant suggesting a negative yet weak impact of a central city to its surrounding areas; financial agglomeration in western cities, in contrast, reveals a positive indirect effect, although the coefficient is also insignificant. The “central areas” of early financial agglomeration mainly existed in large cities in the eastern region. A large amount of capital, talent elements, technological innovation and other factors are constantly pouring into the central area of regional financial clusters (Yuan et al., 2020), and through the use of technology spillover effects or knowledge spillover effects, the GTFP of the region is continuously improved. In the central region, due to the incompleteness of China's credit market, the development of the financial industry still has a strong local preference. The spatial spillover effect of financial agglomeration is constrained by local protectionism and the division of administrative boundaries (Porteous, 1999; Yuan et al., 2020), which ultimately leads to the impact of financial agglomeration on GTFP showing a certain regional boundary in space. Financial agglomeration is always distributed in the cities with relatively good economic conditions in the eastern and central regions. In the western region, the urban infrastructure construction, and the industrial factors suitable for the development of the financial industry are not perfect. Therefore, the financial agglomeration in the western region only has a significant impact on the GTFP of the region.

A distinguishable regional difference is reflected from the total effect of financial agglomeration on GTFP. Compared to eastern and central regions where the total effect (slightly positive) is not significant, the western region shows a significant positive effect (coefficient = 0.139, $p < 0.05$) as strengthened by the direct and indirect effects (both positive). The total effect is the sum of the direct effect and the indirect effect. That

Table 6
Estimation results for eastern, central, and western regions.

Region		ln*QWS*	ln*DSCY*	ln*FDI*	ln*DLMJ*	ln*XSSL*
Eastern region	Direct Effect	0.066***	0.174***	0.015**	0.020	−0.017
		(3.344)	(3.392)	(2.167)	(1.385)	(−0.537)
	Indirect Effect	−0.057	0.413***	−0.023	0.052	0.221**
		(−0.804)	(2.700)	(−1.275)	(0.856)	(2.255)
	Total Effect	0.009	0.588***	−0.008	0.073	0.203**
		(0.122)	(3.752)	(−0.456)	(1.123)	(2.089)
Central region	Direct Effect	0.072***	0.027	−0.001	−0.061***	0.017
		(4.486)	(0.711)	(−0.066)	(−3.632)	(0.515)
	Indirect Effect	−0.030	−0.316**	−0.008	0.162**	0.081
		(−0.436)	(−2.414)	(−0.687)	(2.417)	(0.781)
	Total Effect	0.042	−0.289**	−0.008	0.101	0.097
		(0.558)	(−2.180)	(−0.638)	(1.373)	(0.908)
Western region	Direct Effect	0.091***	0.127***	0.001	0.033**	0.040
		(4.520)	(2.940)	(0.603)	(2.185)	(1.524)
	Indirect Effect	0.048	0.263**	0.011	−0.002	−0.064
		(0.802)	(2.139)	(1.527)	(−0.047)	(−1.018)
	Total Effect	0.139**	0.391***	0.012	0.031	−0.024
		(2.178)	(3.252)	(1.553)	(0.552)	(−0.399)

Note: **, *** denote significant levels at 5% and 1%, respectively; t statistics are in brackets.

is, for every one-unit positive change in financial agglomeration in the western region, the GTFP of all regions increases by 13.9%. As financial agglomeration not only significantly promotes the growth of GTFP in the region, but also has an uplifting effect on surrounding areas.

6.2. Heterogeneity of city scale

The relationship of financial agglomeration and GTFP may be different among by city scales, which leads to another theme of further analysis. According to the requirements of the "Notice on the Adjustment of the Criteria for City Size Classification" (Xie et al., 2019a), the sampled Chinese cities are classified into those small (population: < 0.5 million), medium (population: 0.5– 1 million), type II large (population: 1– 3 million), and type I large and above (population: $\geq$ 3 million) (Zhong and Li, 2020).

Table 7 shows the estimated results for cites in different sizes. The direct effect coefficients of the financial agglomeration of type II large, medium, and small cities on GTFP growth are 0.043, 0.091, and 0.141 respectively, both statistically significant ($p < 0.05$). Due to the advanced level of public services and superior location conditions, type II large cities have obvious advantages in urban management and information exchange and dissemination. Through sharing infrastructure and network system, they can realize accurate information exchange, accelerate innovation and technological progress. The direct effect of financial agglomeration in small and medium-sized cities on GTFP is higher than that of type II large cities. The reason may be that compared with the open economy of type II large cities, industrial agglomeration under the relatively closed economic conditions of medium and small cities is more likely to promote the growth of green economy. The relatively close geographical distance makes it possible to save transaction costs and is conducive to reducing credit costs. As an industry is highly dependent on the development of the credit system, financial agglomeration also exhibits remarkable characteristics of closure. The effect of financial agglomeration on GTFP of cities of type I large and above is positive but does not pass the significance test, which may be because the sample size of 18 cities kept after screening is relatively small.

7. Conclusions and policy recommendations

According to the theory of agglomeration and "new economic geography", this study analyzes the mechanisms of how financial agglomeration affects Green Total Factor Productivity (GTFP) to fill the gaps in theoretical research in this area. Moreover, based on introducing environmental pollution and energy consumption, the SBM-DEA method is used to measure GTFP. Using the data of 283 prefecture-level and above cities in China from 2003 to 2018, the benchmark fixed-effects and the spatial Durbin models are used for empirical tests of the direct and spillover impacts of financial agglomeration on GTFP. It is found that for every additional unit of financial agglomeration, the GTFP will increase by 8.4%. Through spatial econometric analysis, financial agglomeration can significantly accelerate the GTFP of the city, and significantly weaken the GTFP of nearby areas. This research further systematically explores the impact, including spillover, of financial agglomeration on GTFP with regional heterogeneity and urban scale heterogeneity. Whether in the eastern, central, or western regions, financial agglomeration can significantly promote the GTFP of the region, but it did not have a significant influence on the surrounding areas. Cities with a population of less than 3 million are found to be associated with higher GTFP. In addition, industrial structure, foreign direct investment, and human capital play a positive role in GTFP growth, but the role of urban infrastructure construction appears trivial. A series of robustness tests further show that the estimation results of the benchmark model in this paper have strong robustness.

Based on the above research, the empirical conclusion of this article has the following important policy implications for local cities to optimize the development mode of financial agglomeration and improve the quality of urban green development. First, it is suggested to establish a regional financial center leading group that aims to promote green economic growth. According to the basic situation of each region, the corresponding documents will be issued to carry out the top-level design of the regional financial centers, and the targeted, differentiated, and systematic financial development system will be introduced to provide regional policy guarantees for the financial centers. Policies should increase the financial support of financial institutions for green technological innovation, and actively guide financial capital to invest more in industries with high operational efficiency and low environmental pollution. Driven by resource conservation and innovative development,

Table 7
Estimation results of city scale.

City scale		ln*QWS*	ln*DSCY*	ln*FDI*	ln*DLMJ*	ln*XSSL*
Large (Type I and above)	Direct Effect	0.067	−0.231	0.001	0.156**	−0.064
		(1.418)	(−1.251)	(0.054)	(2.422)	(−0.709)
	Indirect Effect	0.148	−1.366***	0.094**	0.207	0.120
		(1.228)	(−2.754)	(1.986)	(1.103)	(0.618)
	Total Effect	0.215	−1.598***	0.095	0.363**	0.055
		(1.640)	(−3.009)	(1.893)	(1.964)	(0.294)
Large (Type II)	Direct Effect	0.043**	0.106**	−0.007**	−0.026	0.038
		(2.460)	(2.184)	(−2.125)	(−1.735)	(1.375)
	Indirect Effect	−0.280	0.280	0.113**	−0.232	0.248
		(−1.412)	(0.742)	(2.335)	(−1.394)	(0.795)
	Total Effect	−0.237	0.386	0.106**	−0.258	0.287
		(−1.169)	(1.040)	(2.159)	(−1.537)	(0.924)
Medium	Direct Effect	0.091***	0.137***	0.004	0.011	0.016
		(5.425)	(4.131)	(1.460)	(0.691)	(0.620)
	Indirect Effect	−0.211	0.771	0.039	−0.326	−0.594
		(−0.488)	(0.884)	(0.455)	(−0.865)	(−1.152)
	Total Effect	−0.121	0.908	0.043	−0.315	−0.577
		(−0.275)	(1.032)	(0.502)	(−0.828)	(−1.112)
Small	Direct Effect	0.141***	0.120**	0.003	0.028	0.041
		(5.486)	(2.397)	(1.383)	(1.817)	(1.598)
	Indirect Effect	−0.199	0.739***	0.033**	0.231**	−0.061
		(−1.173)	(2.298)	(2.533)	(2.101)	(−0.358)
	Total Effect	−0.057	0.859***	0.036***	0.261**	−0.019
		(−0.326)	(2.636)	(2.742)	(2.321)	(−0.112)

Note: **, *** denote significant levels at 5% and 1%, respectively; t statistics are in brackets.

the central government and local governments should promote the development of green industry and continuously improve the level of green economy development. Second, measures need to be adapted to local conditions to reasonably formulate differentiated financial development strategies. Localities should rationally allocate financial resources according to the economic development stages of different regions. For example, important cities in countries with more mature financial development, including the eastern region, need to improve the quality of financial services to real economy and their support for technologically innovative enterprises. However, national important cities in western and central regions with relatively low financial development level should continue to improve the institutional and cultural environment for financial investment, infrastructure construction, and substantialize talent and technology flow mechanisms, introduce preferential policies and encourage new financial businesses and high-quality financial talents. Finally, it is suggested to propose intergovernmental relationships by closely leveraging cities' advantages to strengthen the synergy of financial agglomeration between cities. According to the scale of different cities, different financial agglomeration development models are formulated to promote the matching of financial agglomeration level with the city's total economic volume and population size and realize the benign interaction and coordinated development of the financial industry and green production efficiency. Specifically, megacities and large cities should further promote the agglomeration and development of the financial industry to provide a strong guarantee for the rational flow of financial resources across regions. Small and medium-sized cities should build a specialized financial system and vigorously support the development of a small number of standardized manufacturing industries.

This paper has shortcomings in the process of empirical research, which direct to future work. This study is mainly based on the macro sample data of 283 Chinese cities from 2003 to 2018 at the overall level to study the impact of financial agglomeration on GTFP, with a wide range of research. The other potential mechanism may include how specific banking, insurance, securities and other businesses, capital use, and personnel activity characteristics affect the GTFP at the local scale in the process of financial agglomeration, which requires more in-depth study in the sub-regional or local level with lower-level data. Further discussion can focus on the micro data at the specific industry or enterprise level to clarify the fields and industries in which financial agglomeration funds are invested, and the impact of enterprise development under financial capital agglomeration on GTFP. We leave these avenues for future work.

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Appendix A. Supplementary data

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