Economic Systems 47 (2023) 101025

Contents lists available at ScienceDirect

Economic Systems

journal homepage: www.elsevier.com/locate/ecosys

The effects of agglomeration externalities on urban green total-factor productivity in China

Zhonghua Cheng[a,b,c,*], Xiang Li[a,b], Yeman Zhu[a,b], Meixiao Wang[c]

[a] China Institute of Manufacturing Development, Nanjing University of Information Science & Technology, Nanjing 210044, China
[b] School of Management Science and Engineering, Nanjing University of Information Science & Technology, Nanjing 210044, China
[c] Reading Academy, Nanjing University of Information Science & Technology, Nanjing 210044, China

ARTICLE INFO

JEL Classification:
O3
Q5
R1

Keywords:
Agglomeration externalities
Marshall-Arrow-Romer externality
Jacobs externality
Porter externality
Green total-factor productivity

ABSTRACT

For China's urban industrial layout and green development, determining which types of agglomeration externalities are most advantageous to the rise of green total-factor productivity has both theoretical and practical relevance. This research experimentally studies the effects of three types of agglomeration externalities on urban green total-factor productivity using the data of 285 Chinese cities from 2003 to 2018. The findings demonstrate that urban green total-factor output is rising, albeit with certain differences during different time periods. Both the Jacobs externality and the Porter externality are favorable for increasing urban green total-factor production when all cities are evaluated together, although the latter has a stronger promoting influence. The effect of the Marshall-Arrow-Romer externality, on the other hand, is not significant. Furthermore, these effects also depend on the stage of economic development and population size.

1. Introduction

As China gradually pushes for more energy saving and emissions reduction, the pressure to turn around a falling economic growth rate is also growing. In China, figuring out how to effectively support green and sustainable development is critical for both economic growth and carbon reduction. Endogenous growth theory holds that the growth of total factor productivity (TFP) is the key to long-term sustainable growth (Romer, 1986). However, traditional TFP ignores both energy input and undesirable output and this may result in an overvaluation of the economic situation. Green total-factor productivity (GTFP) can be defined as improved TFP while operating within environmental limits (Li and Lin, 2017). Because GTFP not only maintains the characteristics of traditional TFP, but also incorporates energy input and undesirable output into its measurement, it is the growth of GTFP that will enable China to upgrade its economic growth model and achieve long-term sustainable economic growth.

---

[*] Corresponding author at: China Institute of Manufacturing Development, Nanjing University of Information Science & Technology, Nanjing 210044, China.

E-mail address: chengzhonghua0106@163.com (Z. Cheng).

https://doi.org/10.1016/j.ecosys.2022.101025
Received 23 October 2020; Received in revised form 18 March 2022; Accepted 24 March 2022

Although there are a lot of factors influencing both TFP and GTFP, such as, inter alia, human capital, FDI, infrastructure, environmental regulation and government intervention (Cheng et al., 2020), industrial agglomeration is also an important factor influencing both TFP and GTFP (Cainelli and Ganau, 2018). Because externalities might occur as a result of agglomeration, several scholars have looked into the consequences of agglomeration externalities on productivity (Beaudry and Schiffauerova, 2009; Cainelli et al., 2015). Despite the fact that all of these studies consider TFP in their analysis, they do not consider the GTFP that incorporates energy input and undesirable output. They do not fully reflect either the energy over-consumption or the pros and cons of energy consumption, which could lead to a skewed assessment of economic performance and social welfare. This paper not only empirically analyzes the effects of three kinds of agglomeration externalities on urban GTFP, but also does further research on whether these effects have heterogeneities of economic development stage and urban scale.

2. Literature review

Whether or not industrial agglomeration can promote the growth of TFP has always been the focus of new economic geography. Three kinds of agglomeration externalities can be generated by industrial agglomeration, with each having a different way of influencing TFP (de Groot et al., 2016). The first kind of externality is the MAR (Marshall - Arrow - Romer) externality, the second kind of externality is the Jacobs externality proposed by Jacobs (1969) and the third kind of externality is the Porter externality, proposed by Porter (1990).

A lot of studies have conducted empirical tests on the effects of externalities on TFP but the results differ significantly. These can be summed up by the following three viewpoints; the first one holds that the MAR externality is conductive to the growth of TFP (Hashiguchi and Tanaka, 2015), the second, that the Jacobs externality is beneficial for the growth of TFP (Ehrl, 2013; Cieslik et al., 2018), the third viewpoint is that both the MAR externality and the Jacobs externality are beneficial for the growth of TFP but they differ in the degrees to which they exert an effect (Fazio and Maltese, 2015; Hu et al., 2015; Wetwitoo and Kato, 2017). These differences in the results are partially caused by the differences in, among other things, sample selection, analysis period, variable selection and empirical methods.

The problem is, the above studies all employ TFP for their analyses but do not consider energy inputs and undesirable outputs, which may be a contributing factor to the disparities in their results. The traditional TFP takes input and output constraints into account but ignores energy and environmental constraints. GTFP can better deal with the shortcomings of traditional TFP by incorporating energy and environmental constraints into traditional TFP measurement. Actually, GTFP and TFP have different connotations. The main difference centers on the standards used for measuring efficiency. Generally speaking, GTFP requires both high desirable output and low pollution and obtains a comprehensive trade-off between the two but TFP only considers maximum output. Therefore, under the same inputs, the outcomes of the two methods are dramatically different after calculation; this may lead to different conclusions. used the Malmquist-Luenberger productivity index to estimate GTFP and TFP and found that GTFP, which considers environmental constraints, was much lower than TFP when environmental factors were ignored. More importantly, the effects of agglomeration externalities on urban economic development are reflected not only in TFP but are also reflected in energy and the environment. Drut and Mahieux (2017) studied the effects of externalities on productivity when considering air contamination; they found that when air pollution was taken into consideration, the elasticity of the promoting effect of agglomeration externalities on productivity decreased by 13%. As a result, using GTFP to measure the effect of agglomeration externalities is more reasonable and suitable than just using TFP by itself.

In terms of research methods, the above studies have mostly ignored the spatial effects of GTFP in the regression process. In fact, because of the existence of economic trade, technological cooperation, pollutant diffusion and the development of network information technology, the spatial spillover of knowledge and technology has gradually become an important factor affecting GTFP. The spatial spillover effect decreases with increases in geographical distance (Puskarova and Piribauer, 2016). Consequently, some scholars incorporate geographical distance into their analyses of variations in spatial spillover effects with the most representative research being that of Keller (2002). His research found that technology spillover was local, decreased as geographical distance increased and decreased by half at about 1200 km. Fischer et al. (2009) analyzed the spillover effect of TFP and found that the spillover effect between European regions was significant within 300 km. It is our opinion that, when analyzing the effects of agglomeration externalities on GTFP, we should consider this spillover effect.

In terms of research focus, almost all studies on China have used provincial data to perform analyses; city-level data has been scarce. However, provincial-level analysis cannot meet the requirements necessary for optimal calculations. First, the areas and populations of many provinces in China are even larger than those of some countries, so using provincial data to analyze the effect of agglomeration externalities is a bit rough. Moreover, due to significant differences in industrialization and urbanization between cities, there are certain differences in GTFP between cities. Analysis at the provincial level ignores the differences in GTFP between cities; this will probably bring about estimation and analysis bias (Ke and Yu, 2014).

This paper tries to expand and perfect the previous research in the following two aspects: first, we use GTFP to measure the agglomeration effect; this makes the measurements more accurate and reliable. This aspect can be regarded as an expansion of the current literature. Second, based on data from 285 Chinese cities, we empirically analyze the effects of three kinds of externalities on urban GTFP, as well as the associated spatial spillover effects. We also conduct further research into whether these effects have heterogeneities of economic development stage and urban scale. This aspect can be seen as an improvement on the literature to date.

3. Conceptual framework

3.1. Overall analyses

The mechanisms by which the various agglomeration externalities exert an effect on GTFP differ considerably; this section analyzes the theoretical mechanisms of three different kinds of agglomeration externalities that promote GTFP growth. The MAR externality can boost GTFP growth through the following three channels: First, the knowledge and technology spillover effect. The spread and sharing of knowledge, information and technology within the industry is facilitated by a specialized agglomeration of the same industry in a specific region (Duranton and Puga, 2000; de Lucio et al., 2002). This promotes the growth of GTFP. Second, the scale economy effect. Specialized agglomeration can provide both labor market sharing and specialized intermediate inputs and outputs as well as contribute to the formation of both specialized production and a scale economy (Marshall, 1890; Caragliu et al., 2016). This effectively reduces production costs and improves energy efficiency, both of which are beneficial to GTFP growth. Third, the energy conservation and emissions reduction effect. Specialized agglomeration is also conducive to the centralized treatment of pollutants and wastes, forming both a specialized economy and a scale economy for pollutant control. This can effectively minimize pollution emissions while also promoting GTFP growth.

The Jacobs externality can boost GTFP growth through the following three channels: First, the knowledge and technology spillover effect. The spread and sharing of knowledge, information, and technology between industries is facilitated by a diversified industrial agglomeration in the same region (Jacobs, 1969; Graham, 2009), thus promoting the growth of GTFP. Second, the industrial correlation effect. Diversified agglomeration can significantly strengthen the forward and backward linkages between upstream and downstream industries, effectively lower production costs and greatly improve resource allocation efficiency (Thabet, 2015), all of which are beneficial to GTFP growth. Third, the energy conservation and emissions reduction effect. Cross-industry knowledge and technology spillovers can better assist businesses in adopting advanced environmental production technologies and achieving a circular economy. This can effectively reduce energy usage and pollutant emissions while also promoting GTFP growth.

In the following three ways, the Porter externality can boost GTFP growth: First, the technical progress effect. Market competition under specialization agglomeration can promote or push enterprises to change, upgrade and update their original equipment and technologies (Cainelli et al., 2015). GTFP growth can also be aided by facilitating the diffusion and spillover of information and technology within the same industry (Porter, 1990). Second, the resource allocation effect. Competition can stimulate enterprises to optimize resource allocation, reduce inefficient behavior and enhance both production efficiency and energy efficiency (Cieslik et al., 2018), all of which are favorable to GTFP growth. Third, the energy conservation and emissions reduction effect. Competition between similar enterprises can reduce production costs and energy consumption by inducing price and quality competition, thus forming an effective energy conservation incentive mechanism which promotes the growth of GTFP.

3.2. Analyses of urban economic development stage

The effects of agglomeration externalities on urban GTFP are closely related to urban economic development stage. Levels of industrialization and urbanization are relatively low for cities in a lower economic development stage, their industrial structure and employment structure are relatively simple, and urban industrial structure is thus more inclined to specialized development (Meliciani and Savona, 2015). At this time, the development of urban industrial structure is relatively specialized and the growth of urban GTFP may benefit more from the MAR externality. For cities in a higher economic development stage, levels of industrialization and urbanization are relatively high, industrial chains are relatively perfect and all these factors make the cities more capable of meeting and realizing the diversified development of urban industry. At this time, the development of urban industrial structure is relatively diversified and the growth of urban GTFP may benefit more from the Jacobs externality. Meanwhile, in contrast to the early and late stages of industrialization, urban market competition in the middle stage of industrialization may be fiercer and is thus more conducive to the growth of urban GTFP.

3.3. Analyses of urban scale

The effects of agglomeration externalities on urban GTFP are also closely related to urban size. For cities with lower urban scale, their industrial and employment structures are relatively simple, their diversified labor is comparatively small and their total market demands are relatively low; urban industrial structure is thus more inclined to specialized development (Meliciani and Savona, 2015). At this time, the development of urban industrial structure is relatively specialized and the growth of urban GTFP may benefit more from the MAR externality. For cities with higher urban scale, industrial chains are more or less perfect, diversified labor is relatively abundant and total market demands are relatively high; these cities are more capable of meeting and realizing the diversified development of urban industry. At this time, the development of urban industrial structure is relatively diversified and the growth of urban GTFP may benefit more from the Jacobs externality. Meanwhile, with the improvement of urban scale, urban market competition may become ever fiercer, which is better for urban GTFP growth.

4. Econometric model, variable and data

4.1. Econometric model

The theory of agglomeration externalities indicates that the output of a city is not only a function of production factors but also a function of agglomeration degree, urban economic activities and agglomeration economic types (Wetwitoo and Kato, 2017). In the actual production process, input can produce desirable and undesirable outputs simultaneously. Therefore, based on the principle of endogenous growth, we incorporate agglomeration externality factors to construct the following urban production function:

$$Y/C = A(Agglo, Edu, t)\bullet F(K, L, E) \tag{1}$$

where Y represents desirable output and C represents undesirable output, $Agglo$ represents agglomeration externalities, Edu represents human capital level, K represents capital input, L represents labor input, E represent energy input, and F denotes production function. We always want more desirable output, but less undesirable output; that is why the production function is set in the form of Y/C. In Formula (1), human capital mainly promotes output growth through both the technological progress effect and the knowledge and technology spillover effects; agglomeration externalities mainly promote output growth through the knowledge and technology spillover effect and the competitive effect. All these effects are reflected in the $A(Agglo, Edu, t)$. $A(\bullet)$ represents the Hicks-neutral technical change efficiency function. Because $A(\bullet)$ can keep the marginal substitution rate of factors unchanged, it can make the factor production function move outward or inward.

Assuming that the input in the competitive market is effectively used and that the returns to scale remain unchanged, the contribution of each input to the output is equal to the share of the input cost in the total cost. The production function is expressed in logarithmic form (lowercase letters represent differentiation), and the production function is assumed to be Cobb-Douglas function form. Thus, after taking the logarithm and derivative of Model (1), it can be further changed into:

$$y - c = a + s_l l + s_k k + s_e e \tag{2}$$

where, the parameter “s” represents the share of each input variable. According to the definition and measurement of GTFP (Cheng et al., 2017a), GTFP is defined as the difference between the utilization rate of output and input. Then, based on Eq. (2), we obtain:

$$GTFP = y - c - s_l l - s_k k - s_e e = a \tag{3}$$

where, the technical parameter “a” denotes a region's level of technical progress. According to both endogenous growth theory and industrial agglomeration theory (Hulten et al., 2006), $A(Agglo, Edu, t)$ can be set as follows:

$$A(Agglo, Edu, t) = A_{i,0} e^{\alpha_i t} Agglo_{it}^{\delta} Edu_{it}^{\varphi} \tag{4}$$

where i represents city and t represents year. $A_{i,0}$ denotes the initial productivity level of city i, α_i is the exogenous productivity change, δ and φ represent the effect coefficients of agglomeration externalities and human capital on the technical level, respectively.

According to Eq. (4), we first assume that technical parameter “a” can be expressed as a linear function of agglomeration externality “Agglo” and human capital level “Edu”. Following this we perform the nonlinear test. It can be specifically expressed as follows:

$$a = \delta Agglo_{it} + \varphi Edu_{it} + \varepsilon_{it} \tag{5}$$

In addition, this study establishes the following ordinary static panel model, which takes into account the influence of other factors on GTFP:

$$GTFP_{it} = \alpha + \delta Agglo_{it} + \varphi Edu_{it} + \phi X_{it} + \varepsilon_{it} \tag{6}$$

where α denotes the constant term, ε_{it} denotes the random error and X denotes the other key factors that affect urban GTFP. Combining the research of Cheng et al. (2017a) and Otsuka (2017), we choose the following control variables: informatization level (*Infor*), foreign direct investment (*Fdi*), transportation infrastructure (*Infra*), environmental regulation intensity (Reg) and degree of government intervention (Gov). Some studies show that GTFP may exert both a spatial effect (Long et al., 2016) and a dynamic effect (Cheng et al., 2017a). As a result, by adding the spatial effect and the dynamic effects of GTFP into Model (6), we set up the following dynamic spatial panel model:

$$\begin{aligned} GTFP_{it} = {} & \tau GTFP_{i(t-1)} + \rho \sum_{j=1, j\neq i}^{N} W_{ij} GTFP_{jt} + \alpha + \delta Agglo_{it} \\ & + \varphi Edu_{it} + \phi X_{it} + \eta_i + \upsilon_t + \varepsilon_{it} \\ \varepsilon_{it} = {} & \lambda \sum_{j=1, j\neq i}^{N} W_{ij} \varepsilon_{jt} + \mu_{it} \end{aligned} \tag{7}$$

where τ represents the dynamic regression coefficient, ρ and λ represent the spatial lag and spatial error regression coefficients, respectively. W_{ij} represents the urban distance spatial weight matrix. η_i , υ_t and ε_{it} represent the stochastic disturbances from different dimensions affecting urban GTFP, respectively (Elhorst, 2003).

4.2. Variable description

4.2.1. Explained variable: GTFP

We use the GML productivity index proposed by Oh (2010) to measure urban GTFP. If $GML > (<)1$, it indicates that there is productivity gain (loss). The more the GML is greater than 1, the better the GML. We use MATLAB 2016 software to calculate the GML index. The following are the instructions for relevant indicators and data: To calculate capital stock, we adopt the perpetual inventory method and use it as a proxy variable of capital input. To quantify labor and energy inputs, we use as a measure the number of employees in each city and the total electricity consumption of each city throughout the whole year. We evaluate desirable output using the GDP of each city deflated by the 2003 price indices in each province. We measure undesirable output using industrial wastewater discharge, sulfur dioxide emissions and soot emissions.

4.2.2. Core explanatory variable: agglomeration externalities (Agglo)

Based on the methods of Duranton and Puga (2000), and Martin et al. (2011), we adopt the relative-specialization index, the relative-diversification index and the competition index to measure the MAR externality (*MAR*), the Jacobs externality (*Jacobs*) and the Porter externality (*Porter*), respectively. We define the MAR externality as follows: $MAR_i = \max_j (s_{ij}/s_j)$, where s_{ij} denotes the ratio of the employment within industry *j* at city *i* to total employment at city *i*, and s_j denotes the ratio of the employment within industry *j* at all sample cites to total employment at all sample cites. We define the Jacobs externality as follows: $Jacobs_i = 1/\sum_j |s_{ij} - s_j|$, where $\mathrm{s_{ij}}$ and $\mathrm{s_j}$ are same as above. We define the Porter externality as follows: $Porter_i = \frac{N_i / G_i}{\sum_i N_i / \sum_i G_i}$, where N_i denotes the number of industrial enterprises at city *i*, G_i denotes the industrial GDP at city *i*. We calculate these indexes for each city in 2003–2018 according to the classification of 19 industries by the National Economic Industry Classification.

4.2.3. Control variables

1. Human capital (*Edu*): According to New Economic Growth Theory, human capital can promote technological progress because it is conducive to the dissemination of knowledge and the acquisition of innovative ideas. It can also help enterprises improve energy efficiency, thus boosting GTFP growth. Furthermore, we consider that people's health status may also affect GTFP. The level of healthy human capital is used as the proxy variable. It can be calculated as follows: Edu = (number of primary school students / total population * 6 + number of middle school students / total population * 12 + number of college students / total population * 16) * life expectancy / mortality.
2. Foreign direct investment (*Fdi*): International trade theory holds that FDI has mixed effects on GTFP. For one thing, FDI can both increase a city's capital stock and promote enterprise technological innovation through industrial transfers, technological association and knowledge spillovers, all of which promote GTFP growth. FDI may also induce the “pollution heaven” effect, thereby inhibiting the growth of GTFP. We use the proportion of actual annual foreign investment to GDP as a measure.
3. Informatization level (*Infor*): Knowledge and technology spillovers can be sped up and transaction costs can be reduced by improving information levels. Informatization levels can also significantly reduce energy consumption per unit, so improving manufacturing capacity and efficiency and promoting GTFP growth. We use Per capita telecom traffic to measure informatization levels.
4. Transportation infrastructure (*Infra*): Improvements in transportation infrastructure have mixed effects on GTFP. On the one hand, improvements can significantly reduce transport and transaction costs of production factors and contribute to the formation of urban scale economies and industrial agglomeration; this leads to the growth of GTFP. On the other hand, infrastructure improvements may bring more motor cars which consume more energy and induce more emissions (Cheng et al., 2017b). This probably inhibits the growth of GTFP. Therefore, the effect of transportation infrastructure on GTFP needs further empirical testing. We use per capita area of roads to measure *Infra*.
5. Environmental regulation intensity (*Reg*): According to the Porter hypothesis, environmental regulations can boost business innovation, improve both enterprise productivity and competitiveness, and realize the "win-win" of obtaining both environmental and economic development (Cheng et al., 2017a). These are all conducive to the growth of GTFP. We use the sum of sulfur dioxide removal and industrial dust removal rates to measure Environmental regulation intensity.

Table 1
Descriptive statistics.

Variables	Number of samples	Mean	Standard deviation	Minimum	Maximum
GTFP	4275	1.036	0.328	0.906	1.458
ln*MAR*	4275	1.057	0.787	4.797	1.349
ln*Jacobs*	4275	0.807	0.455	-0.276	2.685
ln*Porter*	4275	0.045	0.665	-2.864	1.754
ln*Edu*	4275	9.561	0.298	8.520	10.957
ln*FDI*	4275	-4.540	1.918	-10.372	-1.367
ln*Infor*	4275	9.867	1.735	4.486	12.925
ln*Infra*	4275	2.079	1.672	-1.171	4.736
ln*Reg*	4275	-1.042	0.273	-2.679	-0.163
ln*Gov*	4275	-2.598	0.565	-4.648	-1.054

Table 2
Correlation and multicollinearity tests.

	VIF	*GTFP*	ln*MAR*	ln*Jacobs*	ln*Porter*	ln*Edu*	ln*FDI*	ln*infor*	ln*infra*	ln*Reg*	ln*Gov*
GTFP		1.000									
ln*MAR*	3.45	0.076	1.000								
ln*Jacobs*	2.67	0.161	-0.305	1.000							
ln*Porter*	2.73	0.242	0.147	-0.079	1.000						
ln*Edu*	1.56	0.187	-0.175	0.254	-0.106	1.000					
ln*FDI*	1.23	-0.143	-0.137	0.075	0.169	0.132	1.000				
ln*infor*	1.08	0.306	-0.053	0.212	0.108	0.256	0.142	1.000			
ln*Infra*	4.21	0.175	-0.175	0.151	0.244	0.139	0.064	0.351	1.000		
ln*Reg*	1.65	0.183	0.064	-0.145	0.192	0.212	-0.176	0.089	0.127	1.000	
ln*Gov*	1.34	-0.281	0.102	-0.121	0.413	0.207	0.060	-0.132	0.273	0.252	1.000

6. Degree of government intervention (*Gov*): Government intervention can limit the market's ability to allocate resources; this may do harm to the transformation of economic development and technological progress (Wang and Shen, 2016), likely inhibiting the growth of GTFP. We use the proportion of fiscal revenue to GDP to measure *Gov*.

4.3. Data source

According to the availability and validity of data, we chose the panel data of 285 Chinese cities from 2003 to 2018 but did not include Chao Hu, Bi Jie, Tong Ren, San Sha, Hai Dong, Danzhou (administrative planning adjustment) and Lhasa (serious data loss). The data come from *The China City Statistical Yearbook* (2004–2019) and the official website of National Bureau of Statistics. In order to avoid heteroscedasticity as much as possible, we take the logarithm of each variable. Tables 1 and 2 show descriptive statistics as well as correlation and multicollinearity tests, respectively.

5. Empirical results and analyses

5.1. Dynamic evolution of GTFP in Chinese cities

The GTFP considering energy input and environmental pollution and the traditional TFP without considering energy input and environmental pollution are calculated using the GML index. Table 3 shows their results.

Table 3 shows that, from 2003 to 2018, the average annual GTFP and the average annual TFP were 1.012 and 1.027 respectively, indicating that GTFP was lower than TFP. By calculating the contributions of GTFP and TFP, we find that throughout the inspection period, the average annual contribution of GTFP was 17.23%, but the average annual contribution of TFP was 28.87%. This indicates that ignoring environmental factors will lead to an overestimation of TFP and its contribution to economic growth, thus giving an overly optimistic evaluation.

5.2. Analysis of regression results of all cities taken together

This research conducts a nonlinear test before regression analysis because there may be a nonlinear link between green total factor productivity (GTFP) and the agglomeration externality (Agglo). Referring to Lind and Mehlum (2010), we use the Sasabuchi-Lind-

Table 3
The results of GTFP and TFP.

Period	TFP	GTFP	Contribution of TFP	Contribution of GTFP
2003–2004	1.027	1.012	27.29	12.85
2004–2005	1.036	1.024	35.21	23.74
2005–2006	1.038	1.026	33.51	22.90
2006–2007	1.030	1.014	23.19	10.61
2007–2008	1.041	1.024	28.74	16.94
2008–2009	1.037	1.022	38.76	22.28
2009–2010	1.024	1.012	25.32	12.45
2010–2011	1.010	0.947	9.02	-0.05
2011–2012	1.021	1.009	22.12	10.06
2012–2013	1.025	1.017	32.32	22.14
2013–2014	1.029	1.022	37.63	28.09
2014–2015	1.022	1.016	29.32	21.37
2015–2016	1.018	1.013	26.52	18.70
2016–2017	1.024	1.014	34.53	20.14
2017–2018	1.020	1.011	29.63	16.30
Average	1.027	1.012	28.87	17.23

Table 4
U-shaped test results.

ln*MAR*	Slope at (ln*MAR*) min	0.398
	Slope at (ln*MAR*) max	-0.014
	Extreme point	35.361
		[0.159 , 32.296]
ln*Jacob*	Slope at (ln*Jacob*) min	0.420
	Slope at (ln*Jacob*) max	-0.023
	Extreme point	35.926
		[0.113 , 31.349]
ln*Porter*	Slope at (ln*Porter*) min	0.453
	Slope at (ln*Porter*) max	-0.027
	Extreme point	38.885
		[0.190 , 35.496]

Table 5
The estimation results of all cities as a whole.

	Ordinary dynamic panel model (1)		Static spatial panel model (2)		Dynamic spatial panel model (3)	
	TFP	GTFP	TFP	GTFP	TFP	GTFP
τ	0.506***	0.487***			0.327***	0.289***
	[0.083]	[0.076]			[0.065]	[0.061]
ρ			0.227***	0.253***	0.027***	0.023***
			[0.010]	[0.009]	[0.006]	[0.005]
ln*MAR*	0.037	0.046	0.033	0.024	0.027	0.031
	[0.031]	[0.032]	[0.027]	[0.025]	[0.024]	[0.022]
ln*Jacobs*	0.076	0.057***	0.071	0.092***	0.065	0.076***
	[0.045]	[0.041]	[0.059]	[0.051]	[0.043]	[0.039]
ln*Porter*	0.134***	0.154***	0.102***	0.097***	0.131***	0.128***
	[0.027]	[0.021]	[0.023]	[0.021]	[0.018]	[0.015]
ln*Edu*	0.127**	0.194***	0.130***	0.214***	0.135***	0.253***
	[0.020]	[0.027]	[0.021]	[0.029]	[0.025]	[0.031]
ln*Fdi*	-0.014	-0.011	-0.015*	-0.012*	-0.009**	-0.008**
	[0.018]	[0.015]	[0.027]	[0.025]	[0.011]	[0.010]
ln*Infor*	0.215***	0.232***	0.296***	0.274***	0.302***	0.293***
	[0.017]	[0.019]	[0.015]	[0.013]	[0.010]	[0.009]
ln*Infra*	0.049***	0.043***	0.029***	0.022***	0.025***	0.024***
	[0.040]	[0.032]	[0.025]	[0.024]	[0.023]	[0.019]
ln*Reg*	0.013*	0.011**	0.009**	0.013***	0.006**	0.008***
	[0.012]	[0.010]	[0.008]	[0.007]	[0.005]	[0.006]
ln*Gov*	-0.032	-0.027	-0.015	-0.012	-0.028	-0.021
	[0.036]	[0.032]	[0.031]	[0.027]	[0.037]	[0.035]
Cons	-0.810***	-0.827***	-0.524***	-0.503***	-0.745**	-0.769***
	[0.239]	[0.282]	[0.218]	[0.196]	[0.208]	[0.213]
LM-Lag test			(0.027)	(0.021)	(0.029)	(0.022)
Robust LM-Lag test			(0.039)	(0.030)	(0.045)	(0.031)
LM-Error test			(0.049)	(0.042)	(0.056)	(0.040)
Robust LM-Error test			(0.187)	(0.173)	(0.191)	(0.163)
AR(1) test	(0.037)	(0.029)			(0.032)	(0.023)
AR(2) test	(0.257)	(0.238)			(0.247)	(0.225)
Hansen over-identification test	(0.197)	(0.213)			(0.206)	(0.217)
Sargan test	(0.248)	(0.259)			(0.269)	(0.283)
Obs	3990	3990	4275	4275	3990	3990

Notes: Standard errors are provided in brackets, and p-values are included in parentheses. ***,**,* denote statistical significance levels at 1%, 5% and 10%, respectively.

Mehlum test (SLM U test) for inspection. The results show that the slopes of the upper and lower bounds of the three kinds of agglomeration externalities are not significant and that the extreme points are not within the data range. It indicates that there is no U-shaped relationship, which further proves that the calculation of GTFP should follow a linear path (Table 4).

Three panel models are adopted to perform a comparative analysis. The GMM method, the QML method and the spatial system GMM method are used to estimate the ordinary dynamic panel model, the static spatial panel model and the dynamic spatial panel model respectively (Jacobs et al., 2009; Lee and Yu, 2010).

The results in Table 5 show that the LM_LAG statistic is more extreme and that the Robust LM_LAG statistic is significant. The Robust LM_ERR statistic is, however, not significant. In view of the foregoing, we select the SAR model to estimate the spatial panel model. Since the Hansen test is not informative in the case, we reduce the number of GMM-style instruments and get their robust results.

Table 6
Estimation results of instrumental variables.

Variables	First	2SLS
IV	-0.059*** [0.007]	
ln*MAR*		0.179 [0.080]
ln*Jacobs*		0.251*** [0.116]
ln*Porter*		0.298*** [0.131]
Controls	YES	YES
Year fixed effects	YES	YES
City fixed effects	YES	YES
Cragg-Donald Wald F-statistic	63.75	
N	4275	4275

Comparing the regression results of TFP and GTFP, we find that, no matter what model we use for regression, the results are quite different in terms of significance and coefficients. This indicates that using TFP and GTFP as independent variables can lead to different conclusions. TFP can overestimate total-factor productivity and its contribution to economic growth because it ignores both energy consumption and pollutant emissions. Since using TFP as an independent variable may bring biased results and conclusions, we adopt GTFP.

Comparing regression results of the three models, we find that Model (3) is superior to Models (1) and (2) in terms of estimated parameter significance. This is due to the fact that Model (3) considers both the spatial spillover effect and the dynamic effect of GTFP simultaneously, resulting in more precise and dependable results. In conclusion, the dynamic spatial panel model is selected as our final interpretation model.

The results show that the MAR externality has no significant effect on urban GTFP. This is mainly because the MAR externality places more emphasis on the knowledge and technology spillover effect brought on by monopolies in the specialized agglomeration environment. With specialized monopolies, a lot of enterprises in China are able to increase profits by virtue of their monopoly position, so the impetus to improve technology and management levels will be weakened. This is more prominent in state-owned enterprises, meaning that external influences on the technical progress of monopolized enterprises are weak. The Jacobs externality is conducive to urban green growth, not only because there will be a greater number of intermediate products in a more diversified industrial structure, but also because the relationship between the upstream and the downstream industry chains will provide information, funds and production factors for urban green development. Inter-industrial knowledge and technology spillover effects can then be used to promote urban green growth. The Porter externality is also beneficial for urban green growth mainly because effective competition among businesses in the same industry will force businesses to transform their production processes, improve the technical levels of their equipment, improve service and increase production efficiency. It is only then that urban green growth can be promoted through the spillover of knowledge and technology within the industry. Comparing the coefficients of these externalities, the coefficient of the Porter externality is the greatest, showing that, in a city, the effective competition of many enterprises is more favorable for the promotion of urban green growth.

As for the control variables, human capital is conducive to urban green growth because not only does it lead to an accumulation of knowledge and technological innovation, but it also accelerates the spread of that knowledge and technology. Improvements in informatization and transport infrastructure are beneficial for urban green growth because they can significantly reduce the transportation and transaction costs of production factors and accelerate spillovers of knowledge and technology. Environmental regulation can significantly promote urban green growth, thus verifying the Porter hypothesis. This shows that environmental regulation can achieve the win-win situation of both economic growth and energy conservation and emissions reduction. The effect of government intervention on urban GTFP is not significant because this effect has two sides. On the one hand, government intervention may restrain the role of the market in allocating resources. On the other hand, government intervention can correct information errors in the market, effectively compensate for defects in the market economy and achieve an optimized configuration of resources. Under the interaction of these two effects, the significance of the effect of government intervention on urban GTFP disappears. The effect of FDI on urban GTFP is significantly negative and the “pollution haven” hypothesis is verified. This is mainly because the foreign investors in China prefer to invest in industries at the middle and low ends of the global industrial value chain; examples are production processing and brand foundries.

5.3. Endogenous problem

Considering that there may be endogenous problems in the model, this paper uses the instrumental variable method for endogenous treatment. This method is also a robustness test of the benchmark regression results. Specifically, the topography relief of each city is chosen as the tool variable, and it is dealt with using the two-stage least square method (Cai et al., 2016). For one thing, there is a certain correlation between topographic relief and agglomeration externality. The flatter the topographic relief is, the better the externality of industrial agglomeration is, which is more conducive to urban development. For another thing, topographic relief is

Table 7
The estimation results of different urban economic development stages.

	Initial stage of industrialization Model (4)	Middle stage of industrialization Model (5)	Late stage of industrialization Model (6)
τ	0.227***	0.281***	0.327***
	[0.095]	[0.081]	[0.083]
ρ	0.025***	0.029***	0.021***
	[0.011]	[0.009]	[0.008]
ln*MAR*	0.068*	0.032	0.021
	[0.041]	[0.030]	[0.024]
ln*Jacobs*	0.043	0.068***	0.096***
	[0.057]	[0.035]	[0.042]
ln*Porter*	0.038***	0.189***	0.086***
	[0.021]	[0.024]	[0.020]
LM-Lag test	(0.025)	(0.021)	(0.019)
Robust LM-Lag test	(0.038)	(0.027)	(0.035)
LM-Error test	(0.056)	(0.033)	(0.047)
Robust LM-Error test	(0.187)	(0.156)	(0.165)
AR(1) test	(0.027)	(0.023)	(0.029)
AR(2) test	(0.234)	(0.227)	(0.231)
Hansen over-identification test	(0.227)	(0.242)	(0.226)
Sargan test	(0.213)	(0.436)	(0.284)
Obs	686	2170	1134

determined by the objective geographical factors of a city. This has no direct relationship with other control variables in the model, and has a certain exogeneity. In addition, since topographic relief is section data and cannot be directly used for the econometric analysis of panel data, we introduce the multiplication term of instrumental variables and time to construct panel data (Nunn and Nancy, 2014). The first stage results demonstrate that topographic relief and the agglomeration externality have a significantly negative connection, which is in line with expectations. At the same time, the value of the F-statistic is significantly higher than 10, showing that not only are weak instrumental variables not a problem, but that the instrumental variables are, indeed, appropriate. The second stage results show that, after solving the possible endogenous problems, the positive impact of the *Jacobs* externality and the *Porter* externality on urban green development still exists, indicating that the benchmark regression results are robust.

5.4. Analysis of regression results in different economic development stages

Because the agglomeration externalities may have different effects on urban GTFP due to different stages of economic development, we have divided urban economic development stages into three types: initial stage, middle stage and late stage of industrialization. In the urban samples, there were 49, 155 and 81 cities in the initial, middle and late stages of industrialization, respectively. This indicates that, as a whole, the industrial structure of China's cities was still in the middle stage of industrialization. We demonstrate these three types of urban stages using dynamic spatial panel data.

The results of Table 7 show that, from the perspective of agglomeration externalities, the MAR externality has a considerable positive influence on urban GTFP in the initial stages of industrialization but exerts an insignificant effect in the middle and late stages. This shows that the MAR externality is more beneficial for urban green growth in the initial stage of industrialization. The Jacobs externality is beneficial for urban green growth in middle and late stages of industrialization; the promotion effect in the late stage is strong but insignificant in the initial stage. This means that the Jacobs externality is more beneficial for urban green growth in the late stage. The Porter externality is beneficial for urban green growth in the three developmental stages; the promoting effect in the middle stage the strongest, the late stage is second and the initial stage the weakest. This means that the Porter externality is more beneficial for urban green growth in the middle stage of industrialization.

From the perspective of economic development stage, for a city in the initial stages of industrialization, both the MAR externality and the Porter externality are beneficial for green growth, although the promoting effect of the MAR externality is stronger; the Jacobs externality has no significant effect. This indicates that urban green growth in the initial stage of industrialization benefits more from the MAR externality. For a city in the middle stage, the Jacobs externality and the Porter externality are both beneficial for green growth, albeit, with the Porter externality exerting a stronger effect. The effect of the MAR externality is not significant. This means that urban green growth in the middle stage of industrialization benefits more from the Porter externality. For a city in the late stage, the Jacobs externality and the Porter externality are both beneficial for green growth with the promoting effect of the Jacobs externality the stronger. The MAR externality has an insignificant effect, indicating that urban green growth in the late stage of industrialization benefits more from the Jacobs externality.

5.5. Analysis of regression results in different urban scales

To investigate the effects of externalities on urban GTFP in cities of different sizes, we selected the 2016 urban district population data and divided urban scale into four categories: megacity, big city, medium-sized city and small city. We also selected the dynamic spatial panel model for the four types of urban data. Table 8.

Table 8
The estimation results of different urban scales.

	Megacities Model (7)	Big cities Model (8)	Medium-sized cities Model (9)	Small cities Model (10)
τ	0.326***	0.297***	0.258***	0.237***
	[0.113]	[0.086]	[0.098]	[0.093]
ρ	0.033***	0.025***	0.017***	0.013***
	[0.014]	[0.012]	[0.011]	[0.015]
ln*MAR*	0.018	0.023	0.030**	0.037***
	[0.035]	[0.020]	[0.021]	[0.029]
ln*Jacobs*	0.116***	0.097**	0.084	0.068
	[0.051]	[0.043]	[0.045]	[0.041]
ln*Porter*	0.108***	0.156***	0.137***	0.096
	[0.026]	[0.025]	[0.019]	[0.013]
LM-Lag test	(0.024)	(0.016)	(0.019)	(0.028)
Robust LM-Lag test	(0.037)	(0.028)	(0.034)	(0.045)
LM-Error test	(0.048)	(0.037)	(0.040)	(0.049)
Robust LM-Error test	(0.175)	(0.134)	(0.173)	(0.187)
AR(1) test	(0.028)	(0.021)	(0.033)	(0.031)
AR(2) test	(0.247)	(0.225)	(0.230)	(0.257)
Hansen over-identification test	(0.204)	(0.236)	(0.247)	(0.239)
Sargan test	(0.257)	(0.416)	(0.331)	(0.213)
Obs	840	1316	1260	574

The results of Table 6 show that, from the perspective of agglomeration externalities, the effect of the MAR externality on the GTFP of medium and small-sized cities is significant, the effect is stronger for small cities. The effect of the MAR externality on megacities and big cities is not significant. This suggests that in small cities, the MAR externality is more favorable to green growth. The Jacobs externality has a significant positive effect on the GTFP of megacities and big cities, with megacities showing the stronger effect; the effect of the Jacobs externality on either medium-sized or small cities is not significant. This indicates that the Jacobs externality is more beneficial for green growth in megacities. The effect of the Porter externality on small city GTFP is not significant, although it is beneficial for green growth in megacities, big cities and medium-sized cities. The promoting effect in big cities is the strongest, in medium-sized cities the second strongest and in megacities the weakest. This means that the Porter externality is more conducive to green growth in big cities.

From the perspective of urban scale, for a megacity, both the Jacobs externality and the Porter externality are beneficial for green growth. The effect of the Jacobs externality is strong but the effect of the MAR externality is not significant. This indicates that green growth in megacities benefits more from the Jacobs externality. For a big city, both the Jacobs externality and the Porter externality are beneficial to green growth; the effect of the Porter externality is stronger. The MAR externality has an insignificant effect, which means that green growth in big cities benefits more from the Porter externality. For a medium-sized city, both the MAR externality and the Porter externality are beneficial for green growth. The effect of the Porter externality is strong, but the effect of the Jacobs externality is not significant, meaning that green growth in medium-sized cities benefits more from the Porter externality. For a small city, although the MAR externality is conducive to green growth, both the Jacobs externality and the Porter externality have insignificant effects, indicating that green growth in small cities benefits more from the MAR externality.

5.6. Robustness test

The GTFP is calculated using the ML index proposed by Chung et al. (1997) and the robustness tests are conducted using the dynamic spatial panel model. As can be seen from Table 9, we find only the coefficients and significance of some control variables have changed; the coefficients and significance of aggregation externalities have not changed significantly. This indicates that the conclusions above are robust and reliable.

6. Conclusions

The impacts of agglomeration externalities on urban GTFP are empirically analyzed in this research, with the findings showing that, in terms of all cities taken together, both the Jacobs externality and the Porter externality are beneficial for urban green growth, although the effect of the MAR externality is insignificant. Meanwhile, the impacts of agglomeration externalities on GTFP depend on economic development stage and urban population scale. As regards the stage of economic development, the green growth of a city in the initial stage of industrialization benefits more from the MAR externality, while cities in the middle stage and in the late stage could obtain stronger green growth from the Porter externality and the Jacobs externality, respectively. In terms of urban scale, green growth in big and medium-sized cities benefits more from the Porter externality, while megacities and small cities obtain stronger green growth from the Jacobs externality and the MAR externality, respectively. Therefore, this paper puts forward the following suggestions.

(1) China should raise the level of competition. Because intra-industry competition has significant positive effects on urban green growth it is necessary to both perfect competition policy and market competition rules and to implement fair competition. China

Table 9
The estimation results of robustness test.

	Overall city	Initial stage of industrialization	Middle stage of industrialization	Late stage of industrialization	Megacities	Big cities	Medium-sized cities	Small cities
τ	0.290***	0.235***	0.283***	0.331***	0.329***	0.306***	0.260***	0.241***
	[0.068]	[0.089]	[0.078]	[0.096]	[0.097]	[0.092]	[0.090]	[0.093]
ρ	0.026***	0.019***	0.030***	0.024***	0.036***	0.028***	0.021***	0.016**
	[0.008]	[0.013]	[0.009]	[0.007]	[0.012]	[0.014]	[0.013]	[0.010]
ln*MAR*	0.059	0.069**	0.051	0.036	0.039	0.049	0.032**	0.038***
	[0.021]	[0.041]	[0.032]	[0.025]	[0.027]	[0.037]	[0.023]	[0.035]
ln*Jacobs*	0.079***	0.052	0.075***	0.105***	0.117***	0.098***	0.087	0.077
	[0.036]	[0.044]	[0.037]	[0.045]	[0.042]	[0.041]	[0.043]	[0.040]
ln*Porter*	0.135***	0.041***	0.182***	0.088***	0.112***	0.174***	0.138***	0.103
	[0.016]	[0.013]	[0.021]	[0.023]	[0.020]	[0.026]	[0.017]	[0.015]
LM-Lag test	(0.027)	(0.029)	(0.023)	(0.021)	(0.028)	(0.022)	(0.025)	(0.032)
Robust LM-Lag test	(0.042)	(0.045)	(0.037)	(0.039)	(0.043)	(0.035)	(0.038)	(0.056)
LM-Error test	(0.051)	(0.062)	(0.040)	(0.054)	(0.059)	(0.041)	(0.058)	(0.075)
Robust LM-Error test	(0.179)	(0.188)	(0.167)	(0.172)	(0.180)	(0.143)	(0.179)	(0.230)
AR(1) test	(0.029)	(0.028)	(0.025)	(0.031)	(0.029)	(0.023)	(0.035)	(0.037)
AR(2) test	(0.231)	(0.240)	(0.229)	(0.237)	(0.241)	(0.227)	(0.231)	(0.281)
Hansen over-identification test	(0.218)	(0.221)	(0.247)	(0.235)	(0.228)	(0.239)	(0.245)	(0.242)
Sargan test	(0.302)	(0.215)	(0.447)	(0.297)	(0.259)	(0.446)	(0.334)	(0.229)
Obs	3990	686	2170	1134	840	1316	1260	574

should relax market access, perfect the market exit mechanism and improve a market supervision and anti-monopoly law enforcement system that is unified and standardized, clearly defined in terms of rights and responsibilities, fair and efficient and guaranteed by the rule of law. Meanwhile, China should also speed up the integration of its internal markets, gradually diminish market segmentation, constantly improve the marketization level of central and western cities and continuously promote urban green growth through enterprise competition between cities.

(2) The research conclusions of this paper show that urban green growth in cities of different economic development stages and different scales will benefit from different agglomeration externalities. Therefore, China's urban industrial structure should be adjusted in accordance with economic development stage and city size. Cities in the initial stage of industrialization and small cities ought to pay more attention to the MAR externality; cities in the middle stage of industrialization and big and medium-sized cities should focus more on the Porter externality and cities in late stage of industrialization and megacities ought to pay more attention to the Jacobs externality.

(3) China should continue to improve its environmental regulation policies and tools. China ought to set barriers for resource-based industries, encourage each city to formulate stricter pollutant emission standards, and increase efforts to eliminate backward capacity and reduce surplus capacity. China should also encourage enterprises to pursue both green R&D and green production by strengthening its support for economic policy and tax policy. As a further step, China ought to improve the market-oriented operation mechanism of energy prices, as well as accelerate the development and application of technologies that can save energy and reduce emissions.

Funding

The work in this paper was supported by the Major Project of the National Social Science Foundation (grant no. 16ZDA047), the National Natural Science Foundation of China (grant no. 71803087).

CRediT authorship contribution statement

Zhonghua Cheng: Conceptualization, Formal analysis, Methodology, Writing – original draft. **Xiang Li**: Methodology, Writing – review & editing, Software. **Yeman Zhu**: Formal analysis, Writing – review & editing. **Meixiao Wang**: Data curation, Software.

Conflicts of Interest

The authors declare no conflict of interest.

References

Beaudry, C., Schiffauerova, A., 2009. Who's right, Marshall or Jacobs? The localization versus urbanization debate. Res. Policy 38, 318–337.

Cai, X.Q., Lu, Y., Wu, M.Q., Yu, L.H., 2016. Does environmental regulation drive away inbound foreign direct investment? Evidence from a quasi-natural experiment in China. J. Dev. Econ. 123, 73–85.

Cainelli, G., Ganau, R., 2018. Distance-based agglomeration externalities and neighbouring firm's characteristics. Reg. Stud. 52 (7), 922–933.

Cainelli, G., Fracasso, A., Marzetti, G.V., 2015. Spatial agglomeration and productivity in Italy: a panel smooth transition regression approach. Pap. Reg. Sci. 94 (1), 39–67.

Caragliu, A., de Dominicis, L., de Groot, H.L.F., 2016. Both Marshall and Jacobs were right. Econ. Geogr. 92, 87–111.

Cheng, Z.H., Li, L.S., Liu, J., 2017a. The emissions reduction effect and technical progress effect of environmental regulation policy tools. J. Clean. Prod. 149, 191–205.

Cheng, Z.H., Li, L.S., Liu, J., 2017b. Identifying the spatial effects and driving factors of urban PM2.5 pollution in China. Ecol. Indic. 82, 61–75.

Cheng, Z.H., Li, L.S., Liu, J., Gu, X.B., 2020. Research on meta-frontier total-factor energy efficiency and its spatial convergence in Chinese provinces. Energy Econ. 86, 104702.

Chung, Y.H., Fare, R., Grosskopf, S., 1997. Productivity and undesirable outputs: a directional distance function approach. J. Environ. Manag. 51 (3), 229–240.

Cieslik, A., Gauger, I., Michalek, J.J., 2018. Agglomeration externalities, competition and productivity: empirical evidence from firms located in Ukraine. Ann. Reg. Sci. 60, 213–233.

Drut, M., Mahieux, A., 2017. Correcting agglomeration economies: how air pollution matters. Pap. Reg. Sci. 96 (2), 381–400.

Duranton, G., Puga, D., 2000. Diversity and specialization in cities: why, where and when does it matter? Urban Stud. 37 (3), 533–555.

Ehrl, P., 2013. Agglomeration economies with consistent productivity estimates. Reg. Sci. Urban Econ. 43, 751–763.

Elhorst, J.P., 2003. Specification and estimation of spatial panel data models. Int. Reg. Sci. Rev. 26 (3), 244–268.

Fazio, G., Maltese, E., 2015. Agglomeration externalities and the productivity of Italian firms. Growth Change 46 (3), 354–378.

Fischer, M.M., Scherngell, T., Reismann, M., 2009. Knowledge spillovers and total factor productivity: evidence using a spatial panel data model. Geogr. Anal. 41 (2), 204–220.

Graham, D.J., 2009. Identifying urbanization and localization externalities in manufacturing and service industries. Pap. Reg. Sci. 88, 63–84.

de Groot, H.L.F., Poot, J., Smit, M.J., 2016. Which agglomeration externalities matter most and why? J. Econ. Surv. 30 (4), 756–782.

Hashiguchi, Y., Tanaka, K., 2015. Agglomeration and firm-level productivity: a Bayesian spatial approach. Pap. Reg. Sci. 94 (1), 95–114.

Hu, C., Xu, Z.Y., Yashiro, N., 2015. Agglomeration and productivity in China: firm level evidence. China Econ. Rev. 33, 50–66.

Hulten, C.R., Bennathan, E., Srinivasan, S., 2006. Infrastructure, Externalities and Economic Development: a study of the India Manufacturing Industry. World Bank Econ. Rev. 20 (2), 291–308.

Jacobs, J., 1969. The Economy of Cities. Random House, New York.

Jacobs, J.P.A.M., Ligthart, J.E., Vrijburg, H., 2009. Dynamic Panel Data Models Featuring Endogenous Interaction and Spatially Correlated Errors; International Center for Public Policy Working Paper Series 0915; Georgia State University: Atlanta, GA, USA.

Ke, S.Z., Yu, Y.F., 2014. The pathways from industrial agglomeration to TFP growth-the experience of Chinese cities for 2001-2010. J. Asia Pac. Econ. 19 (2), 310–332.

Keller, W., 2002. Geographic localization of international technology diffusion. Am. Econ. Rev. 92 (1), 120–142.

Lee, L.F., Yu, J.H., 2010. Estimation of spatial autoregressive panel data models with fixed effects. J. Econ. 154 (2), 165–185.

Li, K., Lin, B.Q., 2017. Economic growth model, structural transformation, and green productivity in China. Appl. Energy 187, 489–500.

Lind, J.T., Mehlum, H., 2010. With or without U?: The appropriate test for a U-shaped relationship. Oxf. Bull. Econ. Stat. 72, 109–118.

Long, R.Y., Shao, T.X., Chen, H., 2016. Spatial econometric analysis of China's province-level industrial carbon productivity and its influencing factors. Appl. Energy 166, 210–219.

de Lucio, J.J., Herce, J.A., Goicolea, A., 2002. The effects of externalities on productivity growth in Spanish industry. Reg. Sci. Urban Econ. 32, 241–258.

Marshall, A., 1890. Principles of Economics. MacMillan, London.

Martin, P., Mayer, T., Mayneris, F., 2011. Spatial concentration and plant-level productivity in France. J. Urban Econ. 69, 182–195.

Meliciani, V., Savona, M., 2015. The determinants of regional specialization in business services: agglomeration economics, vertical linkages and innovation. J. Econ. Geogr. 15, 387–416.

Nunn, N., Nancy, Q., 2014. US food aid and civil conflict. Am. Econ. Rev. 104 (6), 1630–1666.

Oh, D.H., 2010. A global Malmquist-Luenberger productivity index. J. Product. Anal. 34 (3), 183–197.

Otsuka, A., 2017. Regional determinants of total factor productivity in Japan: stochastic frontier analysis. Ann. Reg. Sci. 58, 579–596.

Porter, M.E., 1990. The Competitive Advantage of Nations. Free Press, New York.

Puskarova, P., Piribauer, P., 2016. The impact of knowledge spillovers on total factor productivity revisited: new evidence from selected European capital regions. Econ. Syst. 40 (3), 335–344.

Romer, P.M., 1986. Increasing returns and long-run growth. J. Political Econ. 94 (5), 1002–1037.

Thabet, K., 2015. *Industrial* structure and total factor productivity: the Tunisian manufacturing sector between 1998 and 2004. Ann. Reg. Sci. 54, 639–662.

Wang, Y., Shen, N., 2016. Environmental regulation and environmental productivity: the case of China. Renew. Sustain. Energy Rev. 62, 758–766.

Wetwitoo, J., Kato, H., 2017. Inter-regional transportation and economic productivity: a case study of regional agglomeration economics in Japan. Ann. Reg. Sci. 59, 321–344.