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Agglomeration Externalities vs. Network Externalities: Impact on Green Technology Innovation in 283 Chinese Cities

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Abstract: The prominence of agglomeration externalities (*AEs*) and network externalities (*NEs*) in urban sustainable development has intensified in recent times, with advances in transportation infrastructure and information technology acting as key accelerators. Despite the scholarly attention they receive, the specific spillover effects that these externalities exert on green technology innovation (*GTI*) remain under-explored. In an effort to bridge this knowledge gap, the present study employs a spatial Durbin model to scrutinize, spanning a decade from 2011 to 2021, the impact and spatial spillover of *AEs* and *NEs* on *GTI* across 283 Chinese cities of prefecture level and above. The findings reveal the following: (1) *AEs* exert a U-shaped influence on *GTI*, initially inhibiting it, before ultimately fostering its growth. (2) *NEs* are found to consistently promote *GTI*. (3) The spatial spillover effects of *AEs* on *GTI* are significantly positive, while those from *NEs* are not statistically significant. (4) The influences of *AEs* and *NEs* on *GTI* exhibit marked regional variations. This study extends the research scope on the factors influencing *GTI* by examining the role of *AEs* and *NEs*, thereby aiming to offer valuable insights for enhancing the level of *GTI*.

Keywords: agglomeration externalities; network externalities; green technology innovation; spatial Durbin model; Chinese cities

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1. Introduction

Economic agglomeration, representing the concentration of economic activities within a defined geographic space, fundamentally arises from the existence of agglomeration externalities (*AEs*) [1,2]. As characterized by Rosenthal and Strange [3], *AEs* refer to the incremental benefits economic agents can derive by their co-location in a shared area. Extensive discussions and contributions concerning *AEs* have resulted in two divergent perspectives: Marshallian and Jacobian externalities. Marshallian externalities propose that knowledge spillovers are exclusive to a specific industry, implying that regions with high degrees of specialization foster agglomeration economies [4]. Contrarily, Jacobian externalities account for diversification, positing that knowledge spillovers transpire between varied industries [5]. The existing literature often frames industrial agglomeration as the subject of investigation, with cities serving as the operational units, thereby probing the effects of *AEs* on economic growth, innovation, and environmental pollution. Concerning economic growth, Tang et al. [6], Jiang et al. [7], and Peng et al. [8] have independently scrutinized the influence of *AEs* on urban economies within various Chinese provinces, the Yangtze River Delta region, and in diverse city clusters. Their research collectively affirmed that *AEs* considerably advance economic growth. Contrarily, Liu et al. [9] found that *AEs*' impact on high-quality development unfolds as a U-shaped relationship, thereby implying that such externalities initially impede, but subsequently enhance, high-quality development. Regarding innovation, studies conducted by Yang et al. [10], Yao and Wu [11], and Li and Song [12], using spatial econometric models, underscored that *AEs* can notably foster innovation development in Chinese cities. In the context of environmental pollution, scholarly opinions diverge. Liu et al. [13] discovered that the urban spatial structure exerts a pivotal influence on augmenting the mitigating impact of technological innovation on haze, while *AEs* notably diminish the haze-reducing effect of regional technological innovation. Conversely, Shen and Peng [14] suggested a U-shaped relationship between *AEs* and environmental efficiency, emphasizing that different regions exist at various points along this curve. Wang et al. [15] contend that the association between *AEs* and environmental pollution is not simply linear- or U-shaped but exhibits an N-shaped relationship.

In the context of modern transportation and information technology advancements, cross-regional interactions between enterprises and cities have been invigorated to an unprecedented degree. This has triggered a shift from *AEs* to network externalities (*NEs*), which transcend geographical confines. Traditional theories on *AEs*, which are bound by the law of distance decay and restricting externalities within cities or administrative borders, falter in elucidating the external economy generated by spatially discontinuous elements. Katz and Shapiro [16], Camagni and Salone [17], and Capello [18] progressively refined the theory of urban *NEs*, whereby they highlighted the benefits accruing from inter-city connections. Predominantly, the existing literature, employing inter-city transportation or population migration data [2,19], embodies the urban network from a "flow" perspective. Compared with *AEs*, the research that has delved into the spillover effects of *NEs* remains scarce, and a comprehensive theoretical framework is yet to materialize. Tang et al. [6] and Huang et al. [2] investigated the relationship between *NEs* and urban development, discovering that such externalities significantly advance urban development with varying effects across different cities. Zhou et al. [19] studied the interplay between *NEs* and urban population, uncovering not only a positive local spillover effect of *NEs*, but also a negative cross-regional spillover effect. Yao and Wu [11] evaluated the impact of *NEs* on the innovative development of Chinese cities, determining that these externalities considerably foster urban innovation.

Green technology innovation (*GTI*), which is a fusion of technological innovation activities imbued with green principles, simultaneously fuels economic growth and environmental protection [20,21]. In reference to the "Green Technology Patent Classification System" issued by the State Intellectual Property Office, green patents encompass a wide range of technologies that contribute to sustainable development. These patents cover areas such as the clean utilization of traditional energy, utilization of new energy sources, energy conservation and efficiency, greenhouse gas reduction, capture and storage, recycling, environmental protection materials, pollution control, green transportation, green agriculture and forestry, green buildings, and other technologies that promote sustainable development. Since 2011, China's green patents, which are represented by *GTI* activities, have been highly active; moreover, they have demonstrated continuous improvement in *GTI* capabilities, and we have witnessed a gradual increase in the number of green patents granted. Globally, from 2016 to 2021, a total of 471,000 green technology patents were granted, with 160,000 patents granted by the State Intellectual Property Office of China, accounting for 33.97% of the total. China has emerged as a significant driving force behind *GTI*. The innovative aspects of these green technology patents contribute to the promotion of sustainable development, reduction in reliance on traditional energy sources, improvement of environmental quality, and fostering the coordinated development of the economy and the environment. The determinants of *GTI* have been a recurring theme in academic discourse, and investigating this issue possesses significant value for enhancing *GTI* levels and achieving sustainable development goals [22]. Qiu et al. [23] found that upgrading industrial structures substantially propels *GTI* [23]. Lin and Ma [24] revealed that digital finance augments the quantity and quality of *GTI*. Various other scholars have studied the impacts of environmental regulation, economic scale, social culture, and other factors on *GTI* [25]. However, the impact of *AEs* and *NEs* on *GTI* remains to be studied. Undertaking such research holds not only scientific value and pioneering importance for investigating the determinants of *GTI* from the perspectives of spatial relations and element flow, but it also bears crucial theoretical significance for enriching the empirical cases and research scope of the spillover effects of *AEs* and *NEs*. What impacts do *AEs* and *NEs* exert on *GTI*? Will the influence of *NEs* on *GTI* amplify or diminish compared to that of *AEs*? Do the two externalities have spatial spillover effects on *GTI*? These are pressing questions that warrant further exploration.

To summarize, this study focuses on 283 Chinese cities of prefecture level and above during the period of 2011 to 2021. It utilizes economic density as a proxy for *AEs*, the degree centrality of the asset flow of sizable enterprises within the social association network to represent *NEs*, and the number of green patents as an indicator of *GTI*. A spatial Durbin model (SDM) is employed to examine the impact of *AEs* and *NEs* on *GTI*. The incremental contributions of this paper relative to the existing literature are as follows: Firstly, by examining the influence of *AEs* and *NEs* on *GTI*, this study contributes innovative perspectives and content to the understanding of the determinants of *GTI*. Secondly, by concurrently investigating the spillover effects of *AEs* and *NEs* on *GTI*, this study not only allows for a comparative analysis of the results, but it also broadens the research content on the spillover effects of these externalities. Thirdly, through modeling and computing *NEs* based on the current assets of enterprise above a designated size (CA of EADS), this study complements previous research that has utilized transportation or population flow data to depict *NEs*.

The rest of this paper is structured as follows: Section 2 outlines the theoretical hypotheses, introducing the *AEs* and *GTI*, the *NEs* and *GTI*, and the spatial spillover effects of both types of externalities on *GTI*. Section 3 describes the data and research methods, including the sources and calculation methods for the data used and the SDM employed in this study. Section 4 presents the results and discussion, wherein the findings regarding the influence of *AEs* and *NEs* on *GTI*, as well as the results of robustness tests and heterogeneity tests, are displayed and discussed. In Section 5, the discussion is centered around the effects of *AEs* and *NEs* on *GTI* and the spillover effects of both. The final section concludes the study and provides policy implications, thereby proffering research conclusions based on the results and formulating corresponding policy suggestions in line with the study's conclusions.

2. Hypotheses

2.1. *AEs and GTI*

The Marshallian externality theory posits that geographical proximity, which is facilitated by agglomeration, enhances the dissemination of knowledge, skills, and information, and that such knowledge spillover can bolster the level of innovation within an agglomeration area. Concurrently, agglomeration can effectively increase the speed of information exchange, decrease uncertainty for businesses in the innovation process, and thereby diminish the risk of innovation [26,27]. Magrini and Galliano [28] established that *AEs* can positively influence urban innovation based on an investigation of French industrial enterprises. Hervas-Oliver et al. [29] found that *AEs* can enhance the innovative performance of enterprises, albeit to varying degrees across different businesses. It is apparent that *AEs* can stimulate innovation. Further investigating the impact of *AEs* on *GTI* reveals that, in an imperfect system, the broad geographical agglomeration of economic activities could inadvertently cause environmental pollution and a decline in the quality of development due to economic scale expansions [30], and unfair competition among enterprises might lead to improper resource allocation, thereby inhibiting *GTI* [31,32]. However, as sharing, matching, and learning mechanisms continually improve [33], the positive externalities of agglomeration have emerged gradually, thus fostering green technology exchange and cooperation through knowledge and technology spillover. And the agglomeration process itself attracts innovative talent, technology, and enterprises [34], thereby promoting the advancement of *GTI*. Thus, *AEs* can both impede and foster *GTI*. Given this, this study proposes the following hypothesis:

H1. *AEs have a nonlinear U-shaped impact on GTI.*

2.2. NEs and GTI

The formation of an urban network enhances inter-city connections and the flow of elements, thereby fostering the diffusion of knowledge and innovation, as well as improving the level and capability of urban innovation [35,36]. Alonso [37] introduced the concept of "borrowed size", by which *NEs* can facilitate positive spillovers to *GTI*. Urban networks offer advantages in industrial collaboration, specialized divisions of labor, and market integration, which will further stimulate the spillover of *GTI* and eliminate obsolete technologies [11]. Moreover, compared to *AEs*, *NEs* can achieve innovation effects over a larger spatial range [38], thus promoting a more expansive development range for *GTI*. Additionally, *NEs* are a significant supplement and extension to *AEs*. Once *AEs* reach a certain threshold, *NEs* gradually come into effect, meaning that *NEs* emerge after the impact of *AEs* on *GTI* crosses the inflection point, thereby facilitating an improved level of *GTI*. Based on these insights, this study proposes the following second hypothesis:

H2. *NEs can enhance the level of GTI.*

2.3. Spatial Spillover of AEs and NEs on GTI

AEs underscore the benefits accrued from geographical proximity, which leads to nearby cities influencing one another. On the basis of Tobler's first law of geography [39], the spatial spillover of *AEs* on *GTI* in other cities diminishes as distance increases. With the acceleration of element flow and the growing significance of "flow" space, traditional *AEs* gradually break free from the constraints of geographical space and distance decay, and urban *NEs* with cross-border, mobile, multi-scale, and shared characteristics begin to surface [40,41]. Cities that exhibit network characteristics will generate spillover effects that transcend geographical boundaries, thereby broadening the spatial spillover of traditional *AEs*. The impact on *GTI* can achieve leapfrog spatial network spillover through network associations, and it can also help cities break free from the innovation lock in that may be caused by their inherent knowledge system, thereby enabling technological breakthroughs across levels. In light of these observations, this study proposes the third hypothesis:

H3. *Both AEs and NEs exert spatial spillover effects on GTI, and the spatial spillover effect of NEs is more pronounced.*

3. Data and Methods

3.1. Selection and Description of Variables

3.1.1. Dependent Variable

The dependent variable in this study is *GTI*. Guided by the extant literature [42–44], this study utilizes the number of green patents as a proxy variable for *GTI*. Green patents offer a focused and accurate reflection of the level of *GTI*. By incorporating this variable, we eliminate the potential interference of indicators with minimal correlation to *GTI* in the index system. Moreover, taking such an approach overcomes the limitations of establishing an indicator system to capture *GTI*, which would impede the utilization of spatial econometric models in studying the factors influencing and spillover effects of *GTI*.

3.1.2. Core Explanatory Variables

The core explanatory variables of this study are *AEs* and *NEs*. *AEs* are expressed by economic density [45]. Economic density is a crucial indicator reflecting the density of economic output and the state of economic development. It denotes the level of economic concentration and the scale effect within a region, and it can foster knowledge sharing, technological exchange, talent mobility, and supply chain effects, thus enabling the association and subsequent release of *AEs* with other cities. A higher economic density implies a greater level of *AEs* in the city [46]. The specific equation for its calculation is as follows:

$$Density_{i,t} = G_{i,t} / A_{i,t}. \quad (1)$$

In Equation (1), $Density_{i,t}$ denotes the economic density of the city; $G_{i,t}$ is the city's gross domestic product (GDP); and $A_{i,t}$ signifies the built-up area of the city.

NEs are computed using degree centrality in social network analysis. By adjusting the gravity model to accommodate the flow of assets of enterprise above a designated size, the inter-city association gravity is determined. Relying on the 0–1 relationship matrix, the degree centrality of different cities is computed using UCINET 6.0 software, which is a software specifically designed for social network analysis, and it provides various features such as visual analysis, network analysis, and subgroup analysis. A higher degree of centrality indicates more frequent economic activity associations between enterprises in various cities, which enhance the city's *NEs* [47,48]. The specific equations for this are as follows:

$$R_{ij} = \frac{\sqrt{C_i}\sqrt{C_j}}{\left(D_{ij}\right)^2}, \quad (2)$$

$$S_{ij} = \begin{cases} 1, & R_{ij} > x^* \\ 0, & R_{ij} \le x^* \end{cases}, \quad (3)$$

$$RD_i = \sum_{j \in N}^{N} X_{ij} / (N-1). \quad (4)$$

In Equation (2), R_{ij} denotes the spatial association strength of the CA of EADS between cities; C represents the CA of EADS in each city; and D_{ij} is the inter-city distance calculated using ArcGIS 10.8. In Equation (3), if R_{ij} exceeds the average value x^* for each row of data, then S_{ij} is set to 1, thus signifying an association between City i and City j; otherwise, S_{ij} equals 0, which indicates a lack of association between the cities. This forms a spatial binary matrix of Chinese cities and serves as data for spatial network structure analysis. In Equation (4), RD_i represents the degree centrality of the city's spatial association network and N stands for the number of city nodes under research. If there is a spatial association between City i and j, then X_{ij} equals 1; otherwise, it is set to 0.

3.1.3. Control Variables

Given that *GTI* is subject to various influences, this study incorporates a set of control variables that are guided by the pertinent literature [23,24,49]. These include the following: (1) The economic base. This is represented by per capita GDP (Pgdp) and the proportion of the tertiary industry (Tertiary). The enhancement of economic development levels and the upgrading of industrial structure will encourage the effective amalgamation of production factors such as labor and capital, thus providing foundational conditions for the advancement of urban green transformation and *GTI* [50]. (2) Technological input. This is represented by the full-time equivalent of R&D personnel (RD) and the expenditure on science and technology (Tech). As *GTI* is a novel form of technological innovation activity, it necessitates significant human and financial investments. Incremental technological input can significantly foster the advancement of *GTI* levels [51]. (3) Ecological and environmental policy. This is represented by environmental regulation (Environ) and the green coverage rate of built-up areas (Green). According to Porter and Linde (1995), escalating the level of environmental regulation can compel enterprises to augment R&D investments, thereby promoting *GTI* [52]. The green coverage rate of built-up areas not only indicates the governmental prioritization of environmental governance, but it also reflects the attractiveness of the city's environment. A high index implies a greater capacity to attract green technology talents [53].

In the aforementioned dataset, the data pertaining to green patents were sourced, utilizing web crawler technology, from the China National Intellectual Property Administration. Environmental regulation data, which are indicated by the frequency proportion of terms such as "environmental protection" and "ecological civilization" within city government work reports, were also obtained via web crawler technology [54]. All other data were retrieved from the "China City Statistical Yearbook" (http://www.stats.gov.cn/, accessed on 5 June 2023). Table 1 presents the descriptive statistics for the data employed in this study.

Table 1. Descriptive statistics of the data.

Name	Units	Size	Mean	Std. Dev.	Max.	Min.
Green patent (X)	PCS	3113	596.09	1703.47	26,056.00	0
AEs (Y1)	100 million CNY/square kilometer	3113	19.16	9.47	70.58	1.39
Nes (Y2)	—	3113	73.71	45.59	275.00	17.00
Pgdp (Z1)	CNY 10,000	3113	54,641.85	33,492.33	256,877.00	6457.00
Tertiary (Z2)	%	3113	42.86	10.42	84.64	10.15
RD (Z3)	Person/year	3113	14,333.58	27,472.02	345,858.93	496.52
Tech (Z4)	CNY 10,000	3113	124,423.29	404,010.16	6,118,019.15	771.00
Environ (Z5)	%	3113	0.27	1.33	35.10	0.000001
Green (Z6)	%	3113	40.13	5.80	82.32	6.75

3.2. Methods

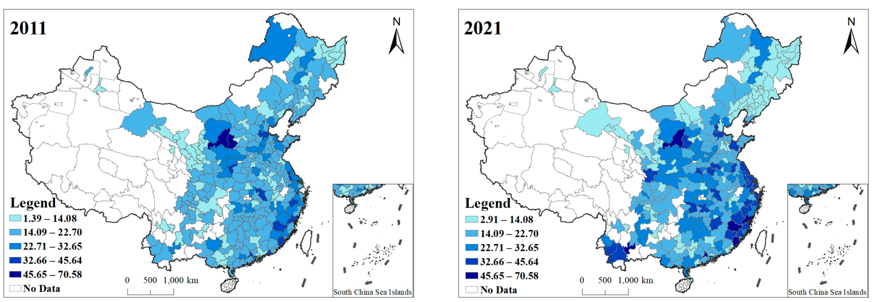
Following spatial autocorrelation, Lagrange multiplier, Wald, and likelihood ratio tests (the results of which are presented in the Supplementary Material), this study employed SDM to examine the influence, as well as their respective spatial spillover effects, of both *AEs* and *NEs* on *GTI* [55]. The model is expressed as follows:

$$lnGTI_{it} = \alpha + \rho\sum_{j\neq i}^{n} W_{ij}lnGTI_{it} + \beta lnX_{it} + \lambda\sum_{j\neq i}^{n} W_{ij}lnX_{it} + \gamma lnZ_{it} + \eta\sum_{j\neq i}^{n} W_{ij}lnZ_{it} + \varphi_i + \phi_t + \varepsilon_{it}. \quad (5)$$

In Equation (5), GTI_{it} signifies the dependent variable, *GTI*, with $W_{ij}lnGTI_{it}$, which represents its spatial lag term; X_{it} is the core explanatory variable, and it encompasses *AEs* and *NEs*; $W_{ij}lnX_{it}$ is the spatial lag term of the core explanatory variable, signifying the *GTI* in neighboring regions influenced by *AEs* and *NEs*; lnZ_{it} is a vector consisting of the control variables in this study, with $W_{ij}lnZ_{it}$ standing as its spatial lag term; and W_{ij} is the spatial weight matrix. Additionally, α represents a constant term; φ_i and ϕ_t denote spatial and temporal fixed effects, respectively; while ε_{it} is a normally distributed random disturbance term.

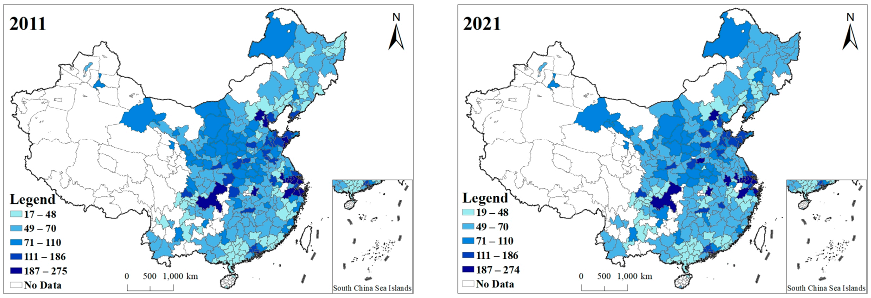
4. Results

Figures 1–3 depict the spatial expressions of *AEs*, *NEs*, and *GTI* in Chinese cities in 2011 and 2021, respectively. Building upon these findings, an in-depth analysis is conducted to examine the impact of *AEs* and *NEs* on the advancement of *GTI*.



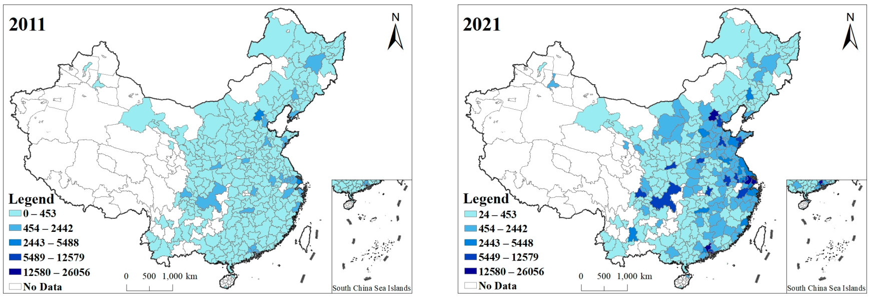
(**a**) (**b**)

Figure 1. The spatial expression of *AEs* in Chinese cities in 2011 and 2021.



(**a**) (**b**)

Figure 2. The spatial expression of *NEs* in Chinese cities in 2011 and 2021.



(**a**) (**b**)

Figure 3. The spatial expression of *GTI* in Chinese cities in 2011 and 2021.

4.1. Regression Results

Through utilizing the aforementioned variables and models, we conducted an analysis using Stata16.0 to examine the impact of both agglomeration and network externalities on *GTI*. The results of the regression are presented in Table 2.

Table 2. The results of the regression.

Variable	Coef.	Std. Err.	z	$p > \|z\|$	[95% Conf. Interval]	
Ln Y1	−0.6141272 ***	0.1898513	−3.23	0.01	−0.9862289	−0.2420255
sq Ln Y1	0.060033 *	0.0338073	1.78	0.076	−0.0062281	0.126294
Ln Y2	0.2217026 ***	0.0657502	3.37	0.01	0.0928346	0.3505707
sq Ln Y2	0.077561 ***	0.0099858	7.77	0.000	0.0579892	0.0971329
Ln Z1	0.2019515 ***	0.0554718	3.64	0.000	0.0932288	0.3106741
Ln Z2	0.8195157 ***	0.0711606	11.52	0.000	0.6800436	0.9589879
Ln Z3	0.9905141 ***	0.0468609	21.14	0.000	0.8986685	1.08236
Ln Z4	0.0765685 ***	0.0188129	4.07	0.000	0.0396958	0.1134412
Z5	0.0108684 *	0.0058804	1.85	0.065	−0.000657	0.0223938
Ln Z6	0.1656033 ***	0.0560202	2.96	0.003	0.0558057	0.2754009
W* Ln Y1	1.540577 ***	0.2923329	5.27	0.000	0.9676154	2.113539
W* Ln Y2	0.0383755	0.0993834	0.39	0.699	−0.1564144	0.2331613
_cons	−11.38657	0.8140973	−13.99	0.000	−12.98217	−9.790967

Note: *, **, and *** represent $p < 0.1$, $p < 0.05$, and $p < 0.01$, respectively. The same also applies below.

Focusing on the results related to *AEs*, it was observed that the coefficient for the first rank was negative while the coefficient for the second rank was positive, and both coefficients passed the significance test. This implied that the influence of *AEs* on *GTI* had transitioned from a negative to a positive effect, thereby suggesting that it initially inhibits then promotes *GTI*. This lends credence to Hypothesis 1.

Turning our attention to the results pertaining to *NEs*, we observed that both the first-order and second-order coefficients associated with an impact on the *GTI* were statistically significant. This suggests that *NEs* exert a positive influence on *GTI*, and they can foster the advancement of *GTI*, thereby confirming Hypothesis 2.

Considering the findings pertaining to spatial spillover effects, we observed that the coefficient representing the *AEs'* spillover effect on the *GTI* of neighboring cities was positive and statistically significant. However, the spatial spillover of *NEs* did not meet the significance threshold. This indicates that *AEs* foster *GTI* in neighboring cities, whereas no such spatial spillover effect was observed for *NEs*.

4.2. Robustness Test

Taking into account the potential endogeneity concerns in the model, this study executed a robustness test for the findings. Adhering to the method of variable substitution as suggested by Qiao and Huang [56], the ratio of a city's GDP to the area of its built-up land was employed as an indicator of *AEs*, while the closeness centrality of the interconnection network of movable assets among enterprises above a designated size was utilized to denote Nes. Table 3 delineates the results of the robustness test. As discernible from Table 3, the effect of *AEs* on *GTI* persisted in its original pattern—first positive, then negative. The coefficient for the impact of *NEs* on *GTI* retained its positive value, and the spatial spillover effect of *AEs* remained positive. All of these findings are statistically significant. These test results are in harmony with the initial results, which attests to the robustness of the research findings.

Table 3. The results of the robustness test.

Variable	Coef.	Std. Err.	Z	$p > \|Z\|$	[95% Conf. Interval]	
Ln Y1	−0.5526026 ***	0.1386982	−3.98	0.000	−0.8244461	−0.280759
sq Ln Y1	0.0652718 ***	0.0244637	2.67	0.008	0.0173239	0.1132198
Ln Y2	0.4701083 *	0.2694453	1.74	0.081	−0.0579947	0.9982113
sq Ln Y2	0.321144 ***	0.0435038	7.38	0.000	0.2358718	0.4064099
Ln Z1	0.216237 ***	0.0558513	3.87	0.000	0.1067706	0.3257035
Ln Z2	0.859301 ***	0.0715998	12.00	0.000	0.718968	0.999634
Ln Z3	0.9960589 ***	0.0463767	21.48	0.000	0.9051623	1.086956
Ln Z4	0.0805032 ***	0.0188731	4.27	0.000	0.0435127	0.1174938
Z5	0.0095607	0.0059127	1.62	0.106	−0.002028	0.0211494
Ln Z6	0.1426199 **	0.0561135	2.54	0.011	0.0326395	0.2526002
W* Ln Y1	1.023703 ***	0.2220545	4.61	0.000	0.5884837	1.458921
W* Ln Y2	0.2834411	0.4238008	0.67	0.504	−0.5471932	1.114075
_cons	−12.55287	1.754625	−7.15	0.000	−15.99188	−9.11387

4.3. Heterogeneity Test

Considering the disparities in the geographical location, resource endowment, and economic foundations among Chinese cities, this study, informed by the related literature [53,57], segmented China into the following four regions to specifically scrutinize the heterogeneity of the influences of *AEs* and *NEs* on *GTI*: eastern, central, western, and northeastern. The results of the heterogeneity test are displayed in Table 4, and the numbers in brackets correspond to the standard errors of the coefficients.

For the eastern region, the first- and second-order coefficients of *AEs* were −0.704 and 0.103, respectively, where both achieved statistical significance at the 5% and 10% levels. This illustrated a U-shaped relationship between the *AEs* and *GTI* in the eastern region, which is consistent with the results acquired for cities nationwide. The first- and second-order coefficients of *NEs* were 2.234 and −0.200, respectively, both passing the 1% significance test. This indicated an inverted U-shaped relationship between the *NEs* and *GTI* in the eastern region—an initial promotion followed by inhibition.

In the central region, the first- and second-order coefficients of *AEs* were −1.458 and 0.190, respectively, while the first- and second-order coefficients of *NEs* were 0.312 and 0.086, respectively. All of these results passed the 1% or 5% significance tests. The influence of *AEs* and *NEs* on the *GTI* in the central region aligned with the results from the nationwide sample.

Table 4. The results of the heterogeneity test.

Variable	Eastern Region	Central Region	Western Region	Northeastern Region
Ln Y1	−0.704 (0.345) **	−1.458 (0.504) ***	−1.006 (0.458) **	0.155 (0.354)
sq Ln Y1	0.103 (0.056) *	0.190 (0.085) **	0.133 (0.084)	0.104 (0.076)
Ln Y2	2.234 (0.356) ***	0.312 (0.107) ***	1.042 (0.246) ***	0.695 (0.300) *
sq Ln Y2	−0.200 (0.039) ***	0.086 (0.015) ***	0.190 (0.031) ***	0.138 (0.041) ***
Ln Z1	0.090 (0.058)	0.289 (0.081) ***	0.167 (0.121)	−0.396 (0.173) **
Ln Z2	1.051 (0.137) ***	−0.010 (0.070)	0.118 (0.074)	0.113 (0.112)
Ln Z3	0.706 (0.039) ***	0.834 (0.084) ***	0.665 (0.138) ***	1.101 (0.144) ***
Ln Z4	0.185 (0.031) ***	0.102 (0.035) **	0.035 (0.044)	0.131 (0.038) ***
Z5	0.050 (0.025) **	0.003 (0.007)	0.008 (0.012)	0.016 (0.027)
Ln Z6	0.453 (0.108) ***	0.085 (0.099)	−0.051 (0.108)	0.405 (0.171) **
W* Ln Y1	1.653 (0.585) ***	5.077 (3.176)	15.988 (3.44) ***	3.032 (2.271)
W* Ln Y2	1.400 (0.629) **	0.164 (0.763)	−0.763 (1.109)	3.829 (1.868) **
_cons	−16.420	−11.113	−25.456	−30.352

In the western region, the first-order coefficient of *AEs* was −1.006, which is significant at the 5% level, while the second-order coefficient failed the significance test. This suggests a need for western cities to further enhance the quality and efficiency of agglomeration, thereby facilitating the positive influence of *AEs* on *GTI*. The first- and second-order coefficients of *NEs* were 1.042 and 0.190, respectively, with both passing the 1% significance test, thereby echoing the results from the cities nationwide.

In northeast China, both the first- and second-order coefficients of *AEs* failed the significance test, thus indicating that *AEs* in this region have not been effectively harnessed. Conversely, the first- and second-order coefficients of *NEs* passed the significance test at 0.695 and 0.138, respectively, thus mirroring the national results and indicating that *NEs* in northeast China have fostered the enhancement of *GTI*.

Examining the spatial spillover effects within each region revealed that *AEs* and *NEs* in the eastern region have spatial spillover effects on *GTI*, with coefficients of 1.653 and 1.400, respectively. The western region's *AEs* and the northeastern region's *NEs* exhibited spatial spillover effects on *GTI*, with coefficients of 15.988 and 3.829, respectively. However, the central region's *AEs* and *NEs* displayed no spatial spillover effect on *GTI*.

5. Discussion

5.1. The Impact of AEs on GTI

This study revealed that the *AEs* in the study area in China exhibited a U-shaped impact on *GTI*, i.e., they initially impede it and then subsequently foster it. Furthermore, this pattern was observed in both the eastern and central regions of China. This result may be attributable to the aftermath of China's reform and opening up policy, which engendered a phase of extensive development characterized by high speed and a large scale. This led to a variety of issues such as diminished development quality, irrational competition, and environmental pollution, which was primarily due to an excessive focus on scale over quality during the process of factor agglomeration in urban environments [58,59]. However, with the recent rollout of a range of strategies such as the high-quality development and ecological civilization construction proposed by China [60], cities have gradually begun to prioritize development quality, guide rational factor agglomeration, and foster the dissemination and spillover of technological knowledge and achievements, thus bolstering the advancement of *GTI*. The relationship between urban spatial structures and *GTI* has garnered significant attention in academic circles. Some scholars argue that a monocentric structure is more favorable for the development of *GTI* [61], while others propose an inverted U-shaped relationship between the compactness of spatial structure and *GTI* [62,63]. This study expanded from a single city to a large sample of Chinese cities to study the impact of *AEs* on *GTI*, thus forming a beneficial extension and supplement to the impact of urban spatial structures on *GTI*.

5.2. The Impact of NEs on GTI

In this article, it was found that *NEs* exert a sustained promotion effect on *GTI*, and the same impact was observed in the central, western, and northeastern regions of China. A plausible explanation for this result may lie in the context of the ongoing improvement in transportation routes and information and communication technology, which have significantly augmented the *NEs* in Chinese cities. Cities have enhanced the robustness of their *GTI* networks through strategies such as scale borrowing, industrial collaboration, and technological cooperation, thereby enhancing the level of *GTI*. Notably, compared to the positive influence on *GTI* that was observed once *AEs* crossed the inflection point, the promotional effect of *NEs* on *GTI* was found to be markedly stronger. This demonstrates that urban *NEs* not only exert a significant impact on economic development [7,64], but also emerge as a vital pathway to bolster *GTI*. The existing research on the impacts of urban networks on *GTI* has primarily concentrated on the structural characteristics of urban networks. By developing an associated network model and analyzing factors such as network size, network density, and structural holes in the network, the effects on *GTI* can be investigated [25,65]. This study investigates the impact of *NEs* on *GTI* based on the dynamic perspective of inter-city scale enterprise liquid asset data. It provides innovative and supplementary insights to relevant studies by establishing a correlation network model.

5.3. Spatial Spillover Effects of AEs and NEs on GTI

This study reveals that *AEs* exert a significantly positive spatial spillover effect on *GTI*, while the spatial spillover effect of *NEs* was not found to be significant. Possible explanations for these results warrant further discussion. The spatial spillover effect of *AEs* is a pervasive phenomenon in contemporary Chinese cities. The Beijing–Tianjin–Hebei and Pearl River Delta regions provide illustrative examples as these two areas have attracted a considerable number of listed companies (386 in the Beijing–Tianjin–Hebei region and 415 in the Pearl River Delta area). The innovative prowess of these leading firms has not only been advantageous in its own right, but, due to the spatial proximity of these companies, the innovation performance of other firms in the vicinity has also witnessed substantial improvement [66]. As such, at the current stage, there is a positive spatial spillover effect from *AEs* on *GTI* in China. However, impacted by factors such as policy, location, and infrastructure, there exists a significant digital divide between cities in China [67]. A considerable disparity in the digital economy could be discerned between the provincial capital cities and their surrounding counterparts, and likewise between the eastern and central–western regions. This digital divide reinforces the connections between cities of similar stature, yet it weakens the ties between cities of different levels due to the effect of asymmetric factors, thereby curtailing the potential for further spatial spillover effects of urban *NEs* on *GTI*.

5.4. Strengths and Limitations

This research contributes to the scholarly discourse on the spillover effects of *AEs* and *NEs*, as well as to the factors impacting *GTI*. It provides a theoretical foundation for crafting policies geared toward *GTI*, thereby offering valuable insights for the high-quality development of China's economy and society. Theoretically, this paper contributes to the existing literature on the spillover effects of *AEs* and *NEs*, as well as to the determinants of *GTI*. It expands our understanding and provides valuable insights into these research areas. Moreover, it serves as a reference for other researchers interested in investigating the impact of urban spatial structures on *GTI*. From a practical perspective, the findings of this study offer valuable guidance for governmental decision-making processes. They assist in the precise identification of *GTI* clusters and facilitate their development through financial support and the establishment of collaborative platforms. Ultimately, these efforts contribute to the enhancement of urban *GTI* levels.

GTI encompasses different types, including product innovation, technology innovation, and process innovation. However, due to constraints in data acquisition, this study has not further explored the influence of *AEs* and *NEs* on these different types of *GTI*, which marks a limitation of the research. Future research should aim to resolve this gap by examining the effects of *AEs* and *NEs* on different forms of *GTI*. Simultaneously, further exploration is needed to address the variations in externalities across different regional contexts and to maximize the potential of *AEs* and *NEs*.

6. Conclusions and Policy Implications

6.1. Conclusions

This study focused on 283 prefecture-level and above cities in China; it utilized economic density as a proxy for *AEs*, the degree centrality of the CA of EADS to represent *NEs*, and the number of green patents as an indicator for *GTI*. Through SDM, we analyzed the impact of *AEs* and *NEs* on *GTI*, and we arrived at the following conclusions: Firstly, the impact of *AEs* on *GTI* follows a nonlinear U-shaped trajectory, initially inhibiting but later promoting *GTI*. Secondly, *NEs* consistently encourage *GTI*, with the positive promotional effect surpassing that of *AEs*. Thirdly, *AEs* exhibit significant positive spatial spillover effects, meaning they substantially boost *GTI* in neighboring cities; meanwhile, the spatial spillover effects of *NEs* do not meet the significance test. Lastly, the influence of *AEs* and *NEs* on *GTI* have exhibited pronounced heterogeneity across the eastern, central, western, and northeastern regions of China.

6.2. Policy Implications

Firstly, a U-shaped relationship was found to characterize the influence of *AEs* on *GTI*. It is incumbent upon all governmental departments to maximize and enhance the positive spillover effects of *AEs* to counteract their initial inhibitory effect. This can be achieved in two ways: Firstly, by promoting integrated city development based on improved infrastructure by reinforcing the interconnections and collaboration among enterprises, thus refining the scale and quality of agglomeration economies. Secondly, by introducing appropriate measures to guide rational enterprise clustering according to urban development positioning, thereby preventing the inhibition of *GTI* due to factors such as unfair competition.

Secondly, considering that the spatial spillover effect of *NEs* on *GTI* did not pass the significance test, it is essential for all governmental departments to actively implement measures to foster the spatial spillover effect of *NEs*. Initial steps would involve enhancing information connectivity and technical exchanges between cities and enterprises under the banner of informatization and digitalization, thereby expanding the extent of urban networks and transforming more cities into network nodes. Additionally, efforts should be made to bridge the digital divide between cities, as well as enhance the digital economy and industrial digitalization levels, thereby avoiding issues such as weakened intercity connections and cooperation due to asymmetry.

Lastly, given the regional heterogeneity of the effects of *AEs* and *NEs* on *GTI*, several strategies should be considered. Firstly, the negative impact of *NEs* on *GTI* in the eastern region should be mitigated through technological upgrading, international cooperation, and regional integration. Secondly, the spatial spillover effects of the central region's *AEs* and *NEs* on *GTI* should be enhanced by leveraging scale effects and technological advancements. Lastly, rational factor clustering in the northeastern region should be guided to harness the positive impact of *AEs* on its *GTI*.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16093540/s1, Figure S1. The global Moran's *I*; Figure S2. The local Moran's *I* of green technology innovation; Figure S3. The local Moran's *I* of agglomeration externalities; Figure S4. The local Moran's *I* of network externalities; Table S1. The LM test results; Table S2. The Wald and LR test results.

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