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Producer Services Agglomeration and Carbon Emission Reduction—An Empirical Test Based on Panel Data from China

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Abstract: Although China has a high rate of economic development, it still faces the problems of unstable industrial structure, low industrial level, and large carbon emissions, which pose huge challenges to China's sustainable development. China is working hard to develop producer services to achieve industrial transformation and reduce carbon emissions. In this context, there is an extremely urgent need to conduct academic research on changes in producer service agglomeration and carbon emissions. Whether the producer service industry has agglomeration characteristics, and whether the producer service industry affects carbon emissions through multiple paths, are issues worthy of attention. Therefore, this paper takes China as the research area, selects the provincial administrative unit as the research sample, and conducts research on these issues by using exploratory spatial data analysis methods and various spatial econometric models under the guidance of the relevant theories of new economic geography. Our research finds that producer services have significant spatial agglomeration characteristics, and they also have significant spatial differentiation patterns. In addition, the agglomeration of producer services can significantly promote the reduction of carbon emissions and can show obvious spillover effects. Finally, in response to the research conclusions of this paper, we also put forward countermeasures and suggestions from the perspective of the common development of producer service industry and manufacturing industry, hoping to promote China's transformation from industrial economy to service economy, to maximize the use of producer service industry accumulated dividends.

Keywords: producer services; manufacturing; agglomeration; carbon emissions; China

Citation: Mi, K.; Zhuang, R. Producer Services Agglomeration and Carbon Emission Reduction—An Empirical Test Based on Panel Data from China. *Sustainability* **2022**, *14*, 3618. https://doi.org/10.3390/su14063618

Academic Editors: Elena Cristina Rada and Lucian-Ionel Cioca

Received: 23 January 2022
Accepted: 17 March 2022
Published: 19 March 2022

1. Introduction

Currently, the total economic output of China has leaped to second place in the world, and the manufacturing industry has steadily ranked first. However, China has also paid a serious environmental price for this. In addition, there are also practical problems such as unstable industrial structure, demanding production methods, and being at a lower link in the global value chain [1]. To promote the transformation from a large manufacturing country to a strong one, and to realize the green development, the producer service industry is an effective starting point [2–5].

In China, the central government attaches great importance to the development of the producer service industry, with particular attention to the role of carbon emission reduction. In 2013, it issued several policies to support the development of the producer service industry. It is worth noting that the situation about carbon emission constraints in China is still severe, and the producer service industry still has a lot of potential in alleviating the environmental pressure and reducing carbon emissions [6,7]. In the above case, it is necessary to analyze the overall development of the producer service industry and seek possible paths for the agglomeration to promote carbon emission reduction, to promote the upgrading of industrial structure, transform the economic development mode, and provide strong support to achieve green and sustainable development.

In summary, based on the agglomeration economy and new economic geography, this article tries to analyze the overall development of China's producer service industry. Afterwards, using the panel data of 30 provincial-level units from 2010 to 2019, this article tries to explore the mechanism and spatial effects of the agglomeration of producer services on carbon emission reduction by use of spatial econometric models. Finally, this article provides strong empirical evidence for promoting the coordinated development of producer services and manufacturing industry, ensuring steady economic growth, and reducing carbon emissions.

The remainder of this study is structured as follows. Section 2 presents the relevant literature on this research topic and formulates research hypotheses. Section 3 constructs an econometric model and provides methods and data sources. Temporal and spatial characteristics of the producer service industry are presented in Section 4. Both estimation steps and results are reported in Section 5. Finally, Section 6 concludes the study and provides policy implications of further directions.

2. Literature Review and Theoretical Analysis

A systematic review of current research shows that the relevant research results of producer service agglomeration are mainly manifested in the level of agglomeration, agglomeration characteristics, influencing factors, and the economic and social effects of agglomeration [8]. The research in these areas has achieved relatively rich research results. The impact of industrial agglomeration on environmental pollution is derived from the research on the relationship between economic development and environmental pollution [9]. Economic development is one of the core issues of economic research. Therefore, academia has produced a lot of theoretical and empirical research on the relationship between economic development and environmental pollution. Grossman and Krueger produced the famous environmental Kuznets curve in 1992, which has become a classic theory to study the relationship between economic development and environmental pollution [10]. Environmental Kuznets reflects economic development through income, studies the relationship between income and environmental pollution, and finds that this relationship shows the characteristics of an inverted U shape [11]. With the increase in income, environmental pollution will gradually become worse and more serious, but when it reaches a certain inflection point, environmental pollution will decrease with the continuous increase in income [12]. This lays an important foundation for studying the impact of industrial agglomeration in economic development on environmental pollution. Since then, many experts and scholars have conducted in-depth and extended research on the Kuznets curve [13]. They have obtained real experimental data and proposed theoretical hypotheses for analysis and verification.

Based on the above research, some scholars have begun to pay attention to the relationship between industry and environmental pollution, especially the impact of industrial agglomeration on environmental pollution, which is an extension and expansion of the research on the relationship between economic development and environmental pollution [14]. Due to the differences in the methods, data, and research areas used, scholars' research conclusions are not the same. The impact of industrial agglomeration on environmental pollution can be roughly divided into three conclusions, which are described as follows.

One conclusion is that industrial agglomeration will have an impact on environmental pollution and may lead to environmental degradation. For example, based on data from different countries, scholars have found that industrial agglomeration has a significant positive impact on environmental pollution. The increase in the degree of industrial agglomeration will bring about an increase in the level of environmental pollution, resulting in a decline in environmental quality [15]. Some scholars conduct research from different cities or regions within a country and find that industrial agglomeration may indeed bring about environmental pollution [16]. Moreover, this influence relationship may show a linear or nonlinear relationship. In addition, some scholars have begun to explore the path and mechanism of industrial agglomeration affecting environmental pollution, further improving the level of academic research [17]. The second conclusion is that industrial agglomeration will not bring about environmental pollution, and even improve environmental quality through industrial competition, technological progress, and innovation spillovers, etc., thus having a negative inhibitory effect on environmental pollution. For example, some scholars have selected specific industries and analyzed that industrial agglomeration will reduce the level of environmental pollution, and even improve environmental quality by affecting industrial structure, production efficiency, and technological spillovers [18]. In this regard, domestic and foreign scholars have conducted extensive and in-depth research. The last conclusion is the uncertainty of the relationship between industrial agglomeration and environmental pollution. Scholars have found that the impact of industrial agglomeration on environmental pollution has an uncertain relationship [19]. This relationship has the characteristics of stages, regions, variability, and alternation.

In the study of the relationship between industrial agglomeration and environmental pollution, some of them began to focus on the service industry, especially the producer service industry, which is closely related to our research. In 2003, the United Kingdom first proposed the concept of low-carbon economy in the energy white paper, and domestic and foreign academic circles began to focus on the development of low-carbon economy based on paying attention to energy economy, environmental economy, and ecological economy, and focused on the service industry [20]. The service industry, especially the producer service industry, plays a crucial role in the adjustment and optimization of the industrial structure in the process of transition from an extensive economy to a low-carbon economy. In addition, the producer service industry is an important channel for realizing a low-carbon economy and promoting sustainable economic development due to its large employment population, high technology content, strong innovation ability, and high industrial relevance [21]. Therefore, the current research on the relationship between producer service agglomeration and carbon emissions has become an important hot issue in this field.

According to the Classification of National Economic Industries (GB/T 4754-2017) and the Classification of Producer Services (2015), producer services mainly include transportation, warehousing and postal services, information transmission, computer services and software industries, financial industry, leasing, and business services, as well as scientific research and technical services, etc. Compared with other industries, these industries have lower energy consumption and pollutant emissions, so they have the characteristics of energy saving and low carbon [22]. Therefore, the agglomeration of producer services may not cause serious environmental pollution, but the research results in this area are not rich and profound. Some scholars discuss the impact of producer services on environmental quality from their own energy-saving advantages and agglomeration economies of scale [23]. More scholars pay attention to the impact of producer services on environmental pollution through the characteristics of industrial associations [24]. For example, producer services can function through technology externalities and market externalities. In addition, the producer service industry can influence the manufacturing industry in various ways such as promoting industrial upgrading, improving production efficiency, and exerting technological spillover effects, which will ultimately promote the green transformation and low-carbon development of the manufacturing industry. In addition, there are also studies focusing on the degree of synergistic agglomeration of producer services and manufacturing industries, promoting the integration and development of the two industries through the basis of inter-industry knowledge and technology, and ultimately reducing carbon emissions by improving production efficiency and management level, which are good effects [25]. Of course, some scholars believe that the impact of producer service agglomeration on environmental pollution is affected by various factors, so different conclusions may be obtained in the specific verification process [26].

By systematically sorting the existing research results, it is found that the existing research results have achieved some research results on the agglomeration of producer services and carbon emissions, and these results have a good basic role for this research [27]. However, the literature on carbon emission reduction mainly examines from the perspective of manufacturing agglomeration, especially from the perspective of industrial structure transformation and upgrading. However, there are few research results on the in-depth study of the relationship between producer service agglomeration and carbon emission reduction, and most of them are based on experience summarization and qualitative analysis. Especially for the carbon emission reduction mechanism of producer service industry agglomeration, a scientific and reasonable explanation has not yet been formed, especially the lack of an analysis of the spatial agglomeration characteristics of various producer service industries under the carbon emission reduction target and the empirical analysis and spatial effects of the resulting spatial effects test. Therefore, this paper attempts to expand and deepen the current research from the following aspects: First, under the guidance of agglomeration externality theory, new economic geography theory, endogenous growth theory, and environmental Kuznets theory, etc., this paper innovatively builds a theoretical analysis framework for the impact of producer services on carbon emissions and expands industrial agglomeration and environmental pollution. The theoretical research system has laid a theoretical foundation for subsequent related research. Second, on the basis of the previous research results, this paper forms a more scientific and reasonable analysis idea through on-the-spot investigation and research, which is used to explain the specific path of the agglomeration of producer services affecting carbon emissions and provides a way to promote low-carbon development ideas and perspectives. Third, before studying the relationship between producer service industry agglomeration and carbon emissions, this paper systematically analyzes and discusses the spatial and temporal characteristics of producer service industry agglomeration levels in China's provincial administrative units, which will help readers gain an in-depth understanding of China's producer service industry development. It also provides a factual background for analyzing the effect of producer services on carbon emissions.

A systematic review of existing research shows that the agglomeration of producer services can affect carbon emissions in many ways, but the comprehensive impact path has not yet reached a consistent conclusion and judgment. Therefore, based on the analysis and investigation, this paper summarizes and analyzes the mechanism by which producer services affect carbon emissions, and clarifies the possible impact path.

First, with the diversification of consumption types and the rapid growth of specialized demands, the type of industry has become more refined. The productive services sector is gradually separated from the manufacturing sector and forms the characteristics of agglomeration distribution, thus producing economies of scale effects. In the process of continuous separation, the manufacturing industry gradually transferred non-core businesses to the producer service industry, and the proportion of the producer service industry continued to increase [28]. Producer service industry has the characteristics of low resource consumption and low environmental pollution. When outsourcing business is completed, the impact of producer services on environmental pollution is less than that of manufacturing, thereby reducing the carbon emissions of traditional manufacturing.

At the same time, with the continuous development of the producer service industry, the manufacturing industry can obtain the richer and more professional intermediate service products provided by the producer service industry. This not only optimizes its own factor input structure, but also reduces the cost of production, thereby promoting the extension of production and operation activities to the high end of the value chain, which can effectively improve production efficiency and reduce carbon emissions.

In addition, in manufacturing-intensive areas, producer services are also very likely to form agglomeration. Manufacturing and producer services can form synergistic development through input-output correlation effects. The participation of producer services in all aspects of manufacturing will effectively exert economies of scale, and reduce production and transaction costs. The investment of high-polluting and energy-consuming resources promotes production and manufacturing to move towards a green, low-carbon, and environmentally friendly direction, thereby reducing environmental pollution, improving resource utilization efficiency, and reducing carbon emissions.

Secondly, whether it is diversified agglomeration or specialized agglomeration, the agglomeration of productive service industries can play a sharing effect, a learning effect, and a matching effect, enhance the technical cooperation and knowledge diffusion of enterprises in the agglomeration area, and produce knowledge spillover effects. Producer service industry is a typical knowledge- and technology-intensive industry. In the process of agglomeration, it is very easy to infiltrate advanced production technology, ideas, experience, and methods into traditional manufacturing industry through formal and informal channels, and subtly improve enterprise technology levels and productivity [29]. In addition, the agglomeration of producer services will also create a good environment for collective learning and innovation through close cooperation with the upstream and downstream of the manufacturing industry and promote the overall improvement of factor productivity under the effect of technology spillover effects, so as to achieve the goal of reducing carbon emissions.

In China, the overall technological innovation capability of the manufacturing industry is low, and the efficiency of resource utilization is not high. As an independent industry characterized by technology-intensive and knowledge-intensive characteristics, the spatial agglomeration of the producer service industry will attract various types of high-tech enterprises. In addition, the specialized agglomeration of the producer service industry, especially financial institutions, and scientific research institutes, can provide necessary financial and technical support for the improvement of manufacturing innovation capabilities, and its diversified agglomeration can provide a good external environment for technological innovation.

It is worth noting that the agglomeration of producer services not only has an impact on environmental pollution in the region but may also have obvious spatial spillover effects. With the rapid development of the economy, the agglomeration of producer services can easily break through the limitations of geographical space and traditional industries, which may increase the speed of the optimization of the industrial structure in adjacent regions. It also can promote the separation of producer services in adjacent regions from the manufacturing industry. It is embedded in the value chain of the manufacturing industry, which optimizes the internal organizational structure of the manufacturing industry and gradually develops towards an environmentally friendly direction [30]. In this process, the reduction of the proportion of production and manufacturing will be accompanied by the reduction of energy consumption, which will promote the effective improvement of environmental pollution in adjacent areas. It can be seen that the agglomeration of producer services can have spillover effects on environmental improvement through the optimization of industrial structure.

The mechanism by which the productive service industry affects carbon emissions is shown in Figure 1.

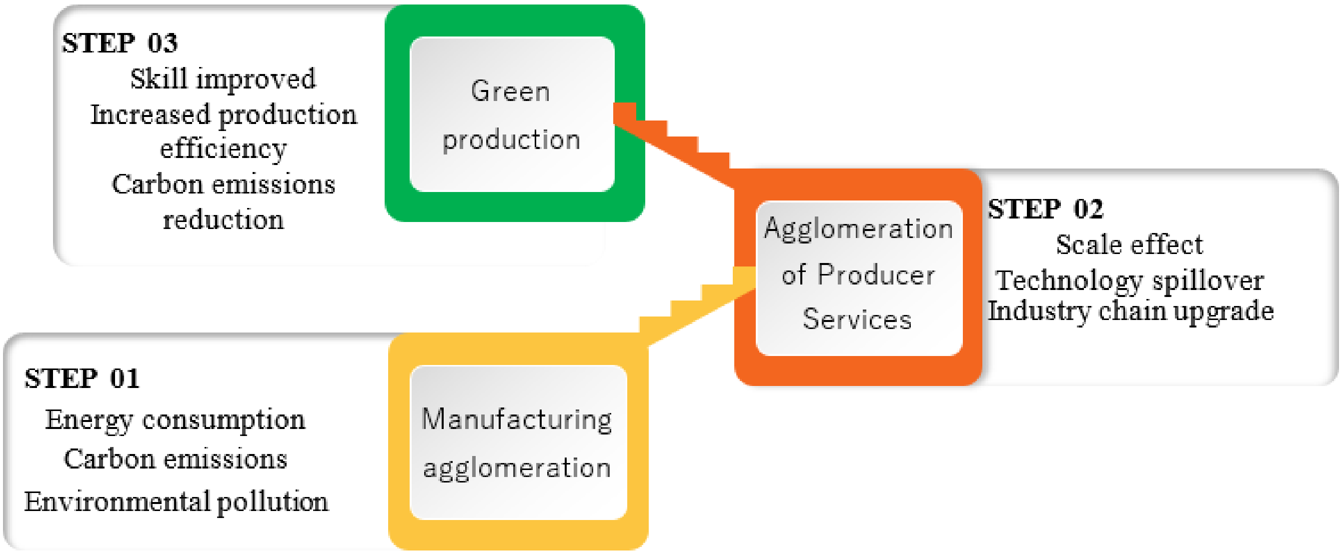

Figure 1. Flowchart of the mechanism by which the productive services sector affects carbon emissions.

3. Methods and Data Sources

3.1. Producer Service Industry Agglomeration Index

The producer service industry agglomeration index is calculated based on location entropy [31,32]. It can not only eliminate the difference in size and truly reflect the geographic distribution characteristics, but also because of its good measurement advantages for the relative concentration and specialization of the industry, it is widely used in domestic and foreign research industry agglomeration. Therefore, the producer service industry agglomeration index is constructed as follows:

$$ser_{ij} = {}^{q_{ij}}/_{q_j} / {}^{q_i}/_{q} \quad (1)$$

In the above formula, ser_{ij} is the agglomeration index of i industry in province j, i represents the producer service industry, and j is 30 provincial-level units. q_{ij} represents the number of employees in the i industry in province j; q_j is the number of employees in the i industry in province j; q_i is the number of employees in the i industry in the country; q is the number of employees in the country. It should be noted that according to the Classification of National Economic Industries (GB/T 4754-2017) and Classification of Producer Service Industries (2015), and with reference to relevant research results, the transportation, storage, and postal industry, information transmission, computer service and software industry, financial industry, leasing and business service industry, scientific research, and technical service industry are the representatives of the producer service industry.

3.2. K-means Cluster Analysis

Cluster Analysis is a method of classifying individuals based on their own characteristics. The principle of cluster analysis is that individuals in the same class have greater similarity, and individuals in different classes have greater differences. Among many clustering methods, K-means has become a widely used clustering algorithm because of its fast clustering speed and clear cluster structure [33,34].

Specifically, K-means is based on the principle of the minimum distance to the cluster center under a given number of clusters and objective function, and the observation values are allocated to the clusters where the centers are located to form the first iteration. K category is formed. Calculate the mean value of each variable based on the observations that comprise each category. The n means values in each class form k points in the n-dimensional space, which is the class center of the second iteration. Through multiple iterations, when the objective function converges to the threshold, the clustering scheme is completed [35,36]. The specific process is as follows:

(1) The system randomly selects k cluster centroid points as $u_1, u_2, \ldots, u_k \in R^n$;
(2) For each observation value i, calculate the distance from the center of mass and classify it:

$$c^{(i)} = \text{argmin}_j ||x^{(i)} - u_j||^2 \tag{2}$$

(3) For each type j, recalculate the centroid:

$$u_j = \frac{\sum_{i=1}^{m} 1\left\{x^{(i)} = j\right\} x^{(i)}}{\sum_{i=1}^{m} 1\{c^{(i)} = j\}} \tag{3}$$

In the above formula, k is the number of clusters. After many calculations, it is found that 5 categories of k have good characteristic distribution directivity; c is the clustering unit i and the closest category among the k categories; u_j represents the centroid point.

3.3. Spatial Correlation Analysis

Global Moran's Index is one of the commonly used global indexes to measure spatial correlations [37–39]. The formula is as follows: The value range is (−1, 1), less than 0 means negative correlation, equal to 0 means irrelevant, and greater than 0 means positive correlation.

$$I = \frac{n \sum_{i=1}^{n} \sum_{j=1}^{n} wij(xi - \overline{x})(xj - \overline{x})}{\sum_{i=1}^{n} \sum_{j=1}^{n} wij(xi - \overline{x})^2} = \frac{\sum_{i=1}^{n} \sum_{j \neq i}^{n} wij(xi - \overline{x})(xj - \overline{x})}{S^2 \sum_{i=1}^{n} \sum_{j \neq i}^{n} wij} \tag{4}$$

In the above formula, I is the Global Moran's I, x_i is the observation value of i, w_{ij} is the spatial weight matrix. When Global Moran's I is significantly positive, it indicates that the research index has a positive spatial correlation, and the research unit with high or low value of the index shows a spatial agglomeration trend; conversely, it shows a spatial dispersion trend; when Global Moran's I is zero, the research unit shows space random distribution trend. Another commonly used index is the Geary's C. Unlike Global Moran's I, the core component is $(x_i - x_j)^2$. The value of Geary's C is generally between 0–2, greater than 1 means negative correlation, equal to 1 means no correlation, and less than 1 means positive correlation. The formula is as follows:

$$C = \frac{(n-1) \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} (x_i - x_j)^2}{2(\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij})[\sum_{i=1}^{n} (x_i - \overline{x})^2]} \tag{5}$$

3.4. Construction of the Spatial Econometric Model

3.4.1. Model Specification

IPAT (I = Human Impact, P = Population, A = Affluence, T = Technology) is the original model used to study the effects of economic and social activities on environmental changes [40]. Since then, Dietz and Rosa proposed an extensible random environmental effect assessment model STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology), and revealed that the number of people, economic development, and technological level are the main variables of environmental effects [41,42]. It has become an empirical model widely used by academia. The formula is as follows: In the formula, P represents the population. A represents the economic development. T represents the technical level. b, c, and d are the exponential terms. a is a constant term, and e is a random error term. Formula (2) is obtained by taking the natural logarithm of both sides on the basis of Formula (1).

$$I = aP^b A^c T^d e \tag{6}$$

$$\ln I = \ln a + b(\ln P) + c(\ln A) + d(\ln T) + e \tag{7}$$

Considering the spatial correlation between variables, this article chooses the most general SDM (Spatial Durbin Model) [43,44]. The model is as follows: In the above formula, ce represents carbon emissions, and ser represents the agglomeration index of producer service industry, which is calculated by location entropy. W represents the spatial weight matrix, which is used to reflect the spatial relationship between 30 units. In order to improve the accuracy and robustness of the results, this paper sets up four kinds of spatial weight matrices, namely the contiguity weight (IW), the inverse distance weight (IW1), the economic distance weight (IW2), and the minimum proximity weight (IW3) [45–47]. X'_{it} represents the control variable matrix, ϕ represents the coefficient vector, and the subscripts i and t represent the provincial unit and year, respectively. In addition, a_i and λ_t represent individual fixed effects and time fixed effects, and u_{it} represents a random disturbance term.

$$\ln ce_{it} = \rho W \ln ce_{it} + \gamma \ln ser_{it} + \xi W \ln ser_{it} + \phi X'_{it} + \zeta W X'_{it} + a_i + \lambda_t + u_{it} \tag{8}$$

In the analysis of regional heterogeneity, it is necessary to systematically study the regional differences about the effect of the agglomeration of the producer service industry on carbon emissions [48,49]. The model settings are as follows: In the above formula, geoi represents the geographic location, which does not change with time. β indicates the coefficient of the interaction term, and the remaining variables are consistent with model (1). This article sets the dummy variable east, which means that the unit in the eastern region is set to 1, and the unit in the remaining regions is set to 0. In addition, this article sets the dummy variable as ns, which means that the unit in the northern region is set to 1, and the unit in the remaining regions is set to 0. Further, the dummy variable is *hhy*, which means that the unit in southeast area is set to 0, and the unit in the northwest is set to 0.

$$\ln ce_{it} = \rho W \ln ce_{it} + \beta geo_i \times \ln ser_{it} + \xi W geo_i \times \ln ser_{it} + \phi X'_{it} + \zeta W X'_{it} + a_i + \lambda_t + u_{it} \tag{9}$$

3.4.2. Variable Descriptions

(1) Dependent variable: Carbon emissions (CE). After the industrial revolution, human society began to use fossil fuels in large quantities, and greenhouse gas emissions increased dramatically [50]. The burning of fossil energy has become a major source of carbon emissions. Currently, there is still a lack of official statistics for the estimation of carbon emissions, and it mainly relies on the existing fossil energy consumption to estimate the possible carbon emissions [51,52]. Therefore, on the basis of referring to related research results, three types of energy such as coal, oil, and natural gas are selected. The calculation formula is as follows: Since the existing energy is counted in physical quantity and has different units, it needs to be uniformly converted into standard coal and calculated based on the carbon emission coefficient. In the above formula, ce_j represents the carbon emissions of province j, and e_{ij} represents the physical amount of energy consumed by province j in a certain period of time for the i. f_i represents the conversion coefficient of standard coal, and ci represents the type of energy.

$$ce_j = \sum_{i=1}^{3} e_{ij} \times f_i \times c_i (i = 1, 2, 3) \tag{10}$$

The carbon emission factor of energy. Among them, the standard coal conversion coefficient refers to the China Energy Statistical Yearbook (2019). The carbon emission coefficient refers to the existing research results, combined with the General Principles for Comprehensive Energy Consumption Calculation (GB/T2589-2008) and Provincial Greenhouse Documents such as Guide to Compilation of Gas Inventory to be determined. Standard coal conversion coefficient and carbon emission coefficient are shown in Table 1.

Table 1. Standard coal conversion coefficient and carbon emission coefficient.

Project	Coal	Oil	Natural Gas
Standard coal conversion coefficient	0.7143	1.4286	1.2722
Carbon emission coefficient	0.7329	0.5574	0.4226

(2) Independent variable: Producer service industry agglomeration index (ser). The producer service industry is an emerging industry that arises and develops independently, and does not provide services directly to consumers. It is a guarantee service industry for the sustainable development of the manufacturing industry, promoting technological progress and industrial upgrading, and improving production efficiency. Due to the rapid development, the academic community has not yet reached a consensus on its connotation and extension. This paper systematically sorts relevant research and refers to current policies. The calculation of the agglomeration index has been explained in the research method part.

(3) Control variables: There are many factors that affect carbon emissions [53,54]. In order to avoid estimation bias due to missing variables, the following variables are selected as control variable:

1. Industrial structure (ecbz). It is said that whether the industrial structure is advanced or not affects carbon emissions directly. Generally speaking, advanced industrial structure can effectively reduce carbon emissions. This article uses the proportion of secondary industry output value to represent it [55].
2. The level of economic development (pgdp). According to the STIRPAT model, the level of economic development is another important factor that affects carbon emissions. Here, PGDP is selected to measure [56].
3. Traffic conditions (glmd). Transportation is an important channel for consuming a large amount of fossil energy in addition to industrial production. It will bring a lot of carbon emissions and cause serious pollution to the environment. The road density is used here to measure [17].
4. The population size (rkgm). The increase in the number of people will lead to an increase in the demand for production and consumption, which will expand the scale of energy consumption to a certain extent, which will lead directly to an increase in carbon emissions. Here we choose the population at the end of the year to be measured [57].
5. Environmental regulations (rdry). Many studies have shown that the improvement of environmental regulations will promote the transformation of enterprises to green development and reduce the emission of greenhouse gases and various toxic and harmful substances. Therefore, the number of R&D personnel is selected to measure the level of environmental regulation [58,59].

3.5. Data Sources

The consumption of coal, oil, and natural gas comes from the regional energy balance sheet (physical volume) in the China Energy Statistical Yearbook in each year [60]. The relevant data of the producer service industry come from the China Labor Statistics Yearbook and China Population and Employment Statistics Yearbook in each year. The rest of the data come from the China Statistical Yearbook, China City Statistical Yearbook, and so on. Depending on the availability of data and the operability of calculations, this article uses 30 provincial-level units as the research sample, excluding China's Hong Kong, Macau, and Taiwan. Finally, in order to ensure the continuity of data statistics, while considering the availability of data, the period is determined to be 2010–2019.

4. Temporal and Spatial Characteristics

4.1. General Characteristic Analysis

The results are shown in Figure 2. The results show that the number of employees in the producer service industry showed a gradual growth trend and achieved leap-forward growth in 2012–2013 and 2018–2019. Specifically, in 2010, the number of employees was 18.86 million, accounting for 13.78%. By 2019, the number of employed people in the producer service industry had increased to 31.83 million, accounting for 18.60%, which is close to one-fifth of the national total. Among them, in 2012–2013 and 2018–2019, the number of employees increased by 4.79 and 3.04 million, respectively, and the growth rate reached 23.52% and 10.57%, which exceeded other historical growth levels.

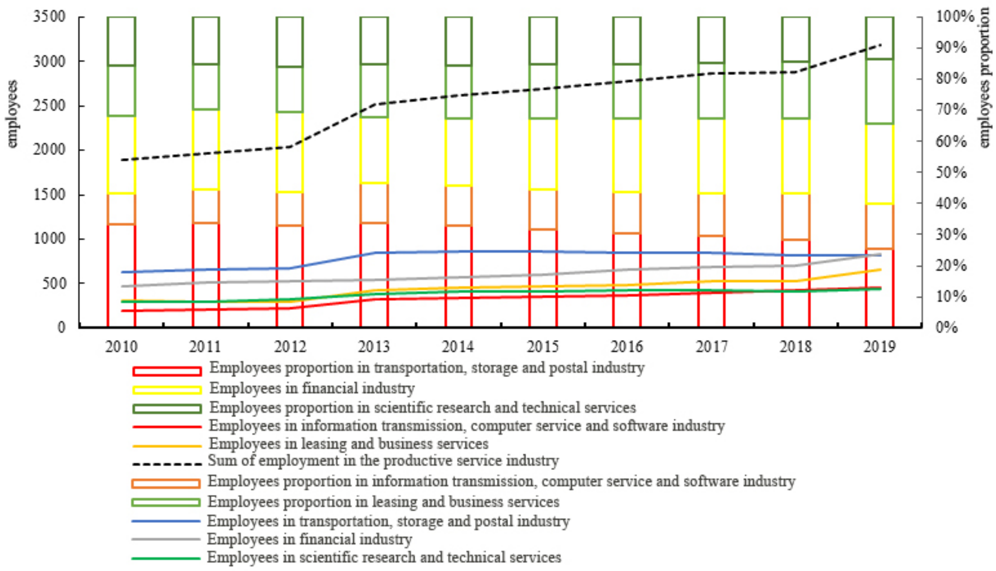

Figure 2. The structure of the producer service industry and its sub-industry.

In terms of industries, the transportation-related industry has the highest employment share, with an average value of 31.19% over the years. The average employment proportions of the rest of the industries were 23.99%, 17.16%, 15.04%, and 12.62%, respectively. From the perspective of the changing trend, the employment share of the transportation-related industry dropped significantly. In contrast, the proportion of employees of information and service industries continued to increase, rising from 8.93% to 14.27% and 16.43% to 20.69%, respectively [10].

With the help of ArcGIS 10.6, a comparative analysis of the 30 provincial units in the producer service industry was performed to systematically analyze the evolution characteristics of the pattern. The number of employees in the producer service industry is divided into five levels from low to high, namely the first level (0, 40), the second level (40, 80), the third level (80, 130), the fourth level (130, 240), and the fifth level (240, 400). The results are shown in Figure 3. The inter-provincial differences are obvious and continue to expand. Further, the pattern presents high in the east and low in the central and western regions. Moreover, the number of employees in each provincial unit has increased to varying degrees over time, among which, the eastern part increased significantly and accounted for a relatively high proportion, and the central and western regions increased slowly and accounted for a relatively low proportion.

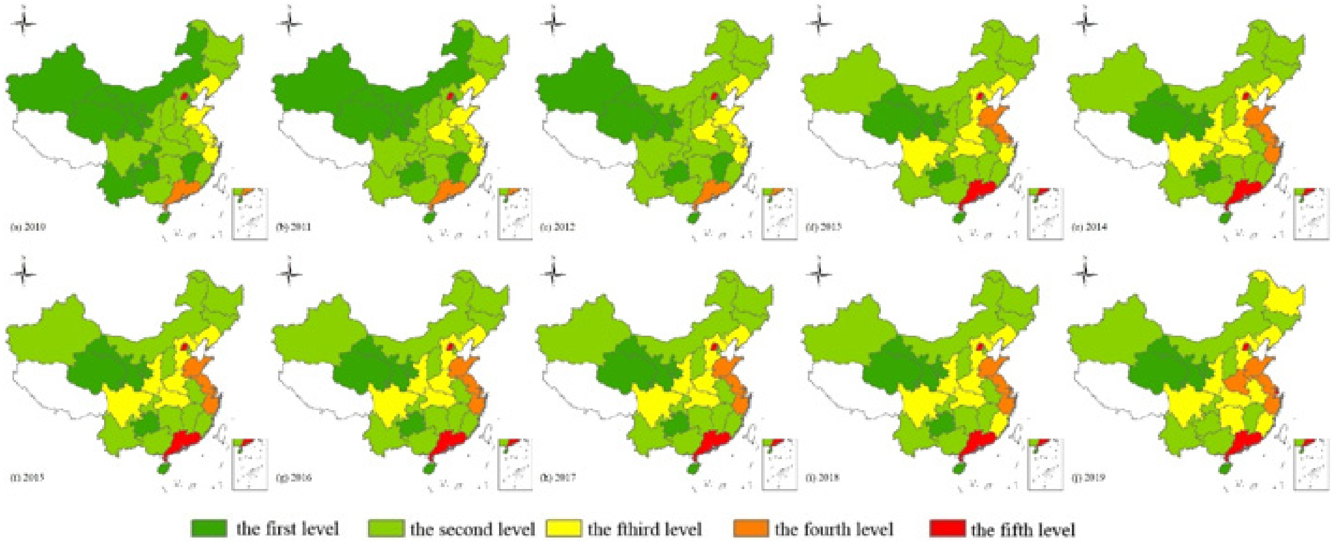

Figure 3. Temporal and spatial differentiation of the number of employees in the producer service industry.

Furthermore, the producer service industry agglomeration index is also divided into five levels, which are low agglomeration level (0, 0.8), lower agglomeration level (0.8, 1), general agglomeration level (1, 1.2), higher agglomeration level (1.2, 1.5), and high agglomeration levels (1.5, 2.8), and the results are shown in Figure 4. It also shows significant inter-provincial differences, but the overall difference is shrinking. It presents a pattern of high in the east and low in the central and western regions. However, compared with the number of employments in the producer service industry, the first feature of the agglomeration index is more obvious, as it fell to a lower level of agglomeration. Heilongjiang in the central part and Hainan in the east showed a gradual rise, reaching a higher level of agglomeration and a general level of agglomeration.

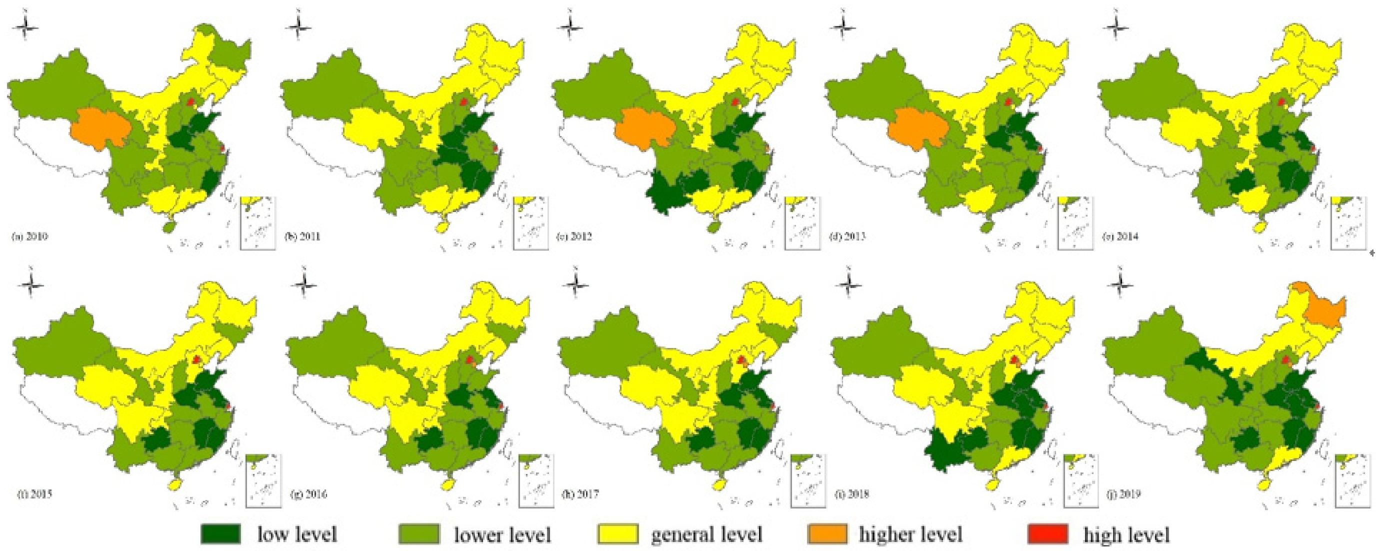

Figure 4. Spatio-temporal differentiation of the agglomeration index of producer service industry.

4.2. Spatial Correlation Analysis

The results are shown in Table 2. From 2010 to 2019, both the producer service industry agglomeration index and carbon emissions showed a continuous spatial agglomeration trend. Global Moran's I and Geary's C are both positive, and both have passed different degrees of significance tests, indicating that there is a positive spatial correlation within 30 provinces. The preliminary test of this spatial effect lays the foundation for the subsequent construction of spatial economic models [61,62]. Table 2 shows Global Moran's *I* of the co-agglomeration index of 30 provinces.

Table 2. Spatial correlations of producer service industry and carbon emissions.

	Producer Service Industry Index			Carbon Emissions	
	Moran's I	**Geary's C**		**Moran's I**	**Geary's C**
2010	0.073	0.440	2010	0.334	0.670
2011	0.032	0.523	2011	0.335	0.707
2012	0.060	0.519	2012	0.323	0.716
2013	0.050	0.478	2013	0.340	0.694
2014	0.058	0.467	2014	0.320	0.707
2015	0.086	0.446	2015	0.313	0.703
2016	0.107	0.430	2016	0.286	0.721
2017	0.161	0.379	2017	0.287	0.724
2018	0.168	0.376	2018	0.300	0.749 *
2019	0.179	0.376	2019	0.276	0.799

5. Empirical Results of Producer Services Agglomeration on Carbon Emission Reduction

5.1. Model Testing and Selection

The model selection test results are shown in Table 3. First, the Hausman statistical value is 26.68 and passed the 1% significance test. This means the null hypothesis of random effects is clearly rejected, and fixed effects should be used. Furthermore, Lagrange Multiplier Test and Robust Lagrange Multiplier Test are used to select spatial lag and spatial error models [63,64]. The results show two models passed the 1% significance test, but the lag model failed the robust Lagrange test. In contrast, the spatial error model is better. On this basis, using the Likelihood-ratio tests, the applicability of the Spatial Durbin model was assessed. It was found that the results all passed the 1% significance test, indicating that the Spatial Durbin model cannot be reduced to a spatial lag or spatial error model. Therefore, the Spatial Durbin model is more suitable than others. Finally, through the test of individual effect and time effect, it was found that the dual fixed effects of individual and time meet the needs. Finally, this paper chooses the Spatial Durbin model under double fixed effects.

Table 3. Space metering model selection test results.

Methods	Statistics	*p*
Hausman	52.18	0.000
LM-Spatial error	14.787	0.000
Robust LM-Spatial error	82.993	0.000
LM-Spatial lag	120.703	0.000
Robust LM-Spatial lag	188.909	0.000
LR-Spatial error	66.39	0.000
LR-Spatial lag	64.81	0.000
LR-SDM-ind	51.53	0.000
LR-SDM-time	303.52	0.000

5.2. The Baseline Regression Result

The estimated results of the effect of the agglomeration of producer service industry on carbon emissions are shown in Table 4. The (1) column is the ordinary panel estimation result, and the (2)–(5) columns are the Spatial Durbin model estimation results under different spatial weight matrices. The results show that the agglomeration of the producer service industry has a significant negative impact on carbon emissions, which means that the agglomeration of the producer service industry can bring about carbon emissions reduction.

Specifically, the estimated coefficient of the ordinary panel is −0.180, and the estimated coefficient of the Spatial Durbin model under different spatial weight matrices fluctuates around 0.2, and all models have passed different degrees of significance level tests.

Table 4. The empirical results of the baseline model.

	(1)	(2)	(3)	(4)	(5)
	(OLS)	**(SDM-IW)**	**(SDM-IW1)**	**(SDM-IW2)**	**(SDM-IW3)**
ln*ser*	−0.180 **	−0.248 ***	−0.247 ***	−0.190 **	−0.212 ***
	(0.091)	(0.075)	(0.085)	(0.080)	(0.075)
ecbz	0.432 **	0.757 ***	0.483	0.539 *	0.501 *
	(0.184)	(0.263)	(0.308)	(0.280)	(0.289)
ln*rkgm*	1.472 ***	2.742 ***	1.930 ***	1.975 ***	1.365 ***
	(0.378)	(0.398)	(0.357)	(0.400)	(0.337)
ln*glmd*	0.552 ***	0.356 ***	0.427 ***	0.372 ***	0.557 ***
	(0.126)	(0.106)	(0.132)	(0.111)	(0.113)
ln*rdry*	−0.031	−0.047 *	−0.073 **	−0.043	−0.005
	(0.030)	(0.028)	(0.030)	(0.028)	(0.029)
ln*pgdp*	−0.006	−0.069	−0.140	−0.151 *	−0.109
	(0.054)	(0.086)	(0.090)	(0.084)	(0.093)
W × ln*ser*		−0.276 **	−1.122 *	−0.261 **	−0.294 **
		(0.129)	(0.608)	(0.108)	(0.133)
W × *Y*		0.258 ***	−0.118	0.227 ***	0.307 ***
		(0.079)	(0.254)	(0.066)	(0.078)
W × *X′*		Yes	Yes	Yes	Yes
Ind-fixed effect	Yes	Yes	Yes	Yes	Yes
Time-fixed effect	Yes	Yes	Yes	Yes	Yes
N	300	300	300	300	300
r2_a	0.4148	0.5020	0.4710	0.4073	0.3212

Robust standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The following tables are the same.

Taking the contiguity weight as an example, the estimated coefficient is −0.248, which means that every 1% increase in the agglomeration level of the producer service industry will reduce carbon emissions by 0.248%. From the perspective of spatial lag terms, the estimated coefficients are also significantly negative, indicating that the agglomeration of the producer service industry can have a significant spatial spillover effect. The agglomeration of the producer service industry can not only produce a significant reduction in carbon emissions in the region, but also achieve reductions in the surrounding areas through various spillover effects. In addition, the spatial lag term of carbon emissions is significantly positive, which is consistent with the positive spatial correlation found in the foregoing calculations. Table 4 shows the baseline regression results.

5.3. Analysis of Regional Heterogeneity

Due to the obvious differences in the industrial structure, resource endowments, and economic foundations of different regions, the effect of the agglomeration of the producer service industry on carbon emissions may have regional heterogeneity [65]. The analysis is performed and the results are shown in Table 5.

From the perspective of the difference between the east and the west, the effect of the agglomeration of producer service industry on carbon emissions is consistent with the results of the baseline regression, showing a significant negative effect. At the same time, this effect is more pronounced in the eastern region than in the central and western regions. The possible reason is that industrial manufacturing in the eastern region is more developed and carbon emissions are greater. The agglomeration of the producer service industry can reduce carbon emissions more significantly. From the perspective of the difference between the north and the south, the agglomeration of the producer service industry also shows the effect of carbon emission reduction, but it has not passed the significance test. It may be that the difference between the north and the south is not enough to cause the difference in results, or it may be caused by sample selection. From both sides of the Heihe–Tengchong Line, the carbon emission reduction effect of the agglomeration of the producer service industry is more obvious on the southeast side than on the northwest side. This is mainly because the southeast side belongs to the economically developed area, and industrial production and manufacturing occupy a large proportion of the country. Increasing the level of agglomeration of the producer service industry will help to achieve carbon emission reduction in multiple ways [66].

Table 5. The empirical results of regional heterogeneity.

	(1)	**(2)**	**(3)**
	ln*ce*	**ln*ce***	**ln*ce***
ln*ser_east*	−0.302 *** (0.114)		
ln*ser_ns*		−0.157 (0.111)	
ln*ser_hhy*			−0.293 *** (0.082)
$W \times Y$	0.252 *** (0.080)	0.224 *** (0.081)	0.274 *** (0.078)
X'	Yes	Yes	Yes
$W \times X'$	Yes	Yes	Yes
Ind-fixed effect	Yes	Yes	Yes
Time-fixed effect	Yes	Yes	Yes
N	300	300	300
r2_a	0.4986	0.5076	0.5009

Note: *** $p < 0.01$.

5.4. Robustness and Endogeneity Test

For the robustness tests, this paper adopts two methods to approach it. One is to replace the variables, and the other is to replace the model [67,68]. The results are shown in Table 6.

Table 6. The empirical results of the robust test of the effects.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
	ln*cc*	**ln*oc***	**ln*gc***	**(SEM-IW)**	**(SEM-IW1)**	**(SEM-IW2)**	**(SEM-IW3)**
ln*ser*	−0.289 * (0.153)	−0.180 (0.117)	−0.576 *** (0.196)	−0.170 ** (0.076)	−0.237 *** (0.082)	−0.178 ** (0.082)	−0.151 ** (0.077)
X'	Yes	Yes	Yes	Yes	Yes	Yes	Yes
$W \times X'$	Yes	Yes	Yes	Yes	Yes	Yes	Yes
$W \times Y$	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	300	300	300	300	300	300	300
r2_a	0.3211	0.4275	0.3301	0.4590	0.4153	0.4296	0.4177

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

First, this paper calculated the carbon emissions of coal (cc), oil (oc), and natural gas (gc) separately, and incorporated them into the model for estimation. Columns (1)–(3) show that the agglomeration of the producer service industry has a significant effect on reducing carbon emissions from coal and natural gas, indicating that the above baseline estimation results have a certain degree of robustness. In addition, the estimated coefficients are −0.289 and −0.576, respectively, indicating that the agglomeration of the producer service industry has differences in the reduction of carbon emissions from different energy sources, and the effect on natural gas is more obvious. The possible reason for this conclusion is that natural gas is an environmentally friendly fuel, and the total amount of carbon dioxide released by the combustion of coal and oil far exceeds that of natural gas. With the same standard amount of energy, natural gas has the least carbon emissions. In addition, the agglomeration of the producer service industry also has a negative impact on oil carbon emissions, but it has not yet passed the significance test. Then, according to the model selection and test results, compared with the spatial lag model, the spatial error model also shows good adaptability to this research. Therefore, the spatial error model is used to re-regress. Columns (4)–(6) show that under different spatial weight matrices, the spatial error model can still get basically the same conclusions, confirming the robustness of the results.

This paper deals with the possible endogenous problems caused by missing variables and measurement errors, etc., by lagging the core explanatory variables and control variables. At the same time, considering that the fixed-effects model can alleviate the endogenous problems that may be caused by the omission of variables, the Spatial Durbin model and the spatial error model under the dual fixed-effects are still used for model estimation. The results are shown in Table 7. No matter what type of spatial weight matrix is used, both models show that the agglomeration of the producer service industry has a significant effect on carbon emission reduction. It shows that in the case of considering the endogenous problem, the significant causality still holds.

Table 7. Endogenous treatment results.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
	(SDM-IW)	**(SDM-IW1)**	**(SDM-IW2)**	**(SDM-IW3)**	**(SEM-IW)**	**(SEM-IW1)**	**(SEM-IW2)**	**(SEM-IW3)**
ln*ser_1*	−0.246 *** (0.077)	−0.229 *** (0.088)	−0.187 ** (0.079)	−0.167 ** (0.075)	−0.169 ** (0.080)	−0.212 *** (0.080)	−0.187 ** (0.081)	−0.147 * (0.077)
X'	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
$W \times X'$	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
$W \times Y$	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ind-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	270	270	270	270	270	270	270	270
r2_a	0.4604	0.4102	0.3222	0.3020	0.4030	0.3688	0.3790	0.3749

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

6. Conclusions and Future Directions

(1) The number of employees in the producer service industry has shown a trend of gradual growth and achieved leapfrog growth in 2012–2013 and 2018–2019. There are obvious differences in the number of employees in the producer service industry across provinces and the differences continue to expand, showing a pattern of high in the east and low in the central and western regions. (2) The producer service industry agglomeration index also shows significant inter-provincial differences, but the overall difference is shrinking. (3) The agglomeration of the producer service industry has a significant negative impact on carbon emissions, which means that the agglomeration of the producer service industry can bring about carbon emission reduction. In addition, the estimated coefficients are also significantly negative, indicating that the agglomeration of the producer service industry can have a significant spatial spillover effect on surrounding areas. In addition, there is significant regional heterogeneity in the impact of the agglomeration of the producer service industry on carbon emissions.

The producer service industry, also known as the manufacturer service industry, is a kind of service industry that provides guarantee services for maintaining the continuity of industrial production processes, promoting industrial technological progress, industrial upgrading, and improving production efficiency. It is a service industry that directly or indirectly provides intermediate services for the industrial production process and is an important part of the modern service industry.

To accelerate the development of the producer service industry and realize the transition from an industrial economy to a service economy, it is necessary to realize the joint interaction between the producer service industry and the manufacturing industry, and maximize the agglomeration dividends of it. According to these main conclusions, this study provides the following suggestions. On the one hand, developing producer service industries that are in line with local manufacturing conditions can lead to the development of the manufacturing industry in accordance with local conditions, and strengthen the complementary advantages, industrial linkages, technical cooperation, and upstream and downstream integration with the manufacturing industry. On the other hand, considering the significant spatial spillover effects, the producer service industry clusters such as Beijing, Shanghai, and Guangdong should fully release the spillover dividends, and drive the technological progress of the surrounding areas and the provincial level of industry, thereby driving the overall carbon emission reduction. In addition, it is necessary to strengthen regional linkage, increase policy support, train and absorb senior technical and managerial talents, and accelerate the improvement of enterprises' independent innovation mechanism, so as to promote the rapid development of the producer service industry.

Future research can be further deepened and expanded from the following aspects.

First, for the manufacturing industry, the amount of carbon emissions mainly depends on innovation capabilities and technological progress, which is the core factor that determines carbon emissions. Therefore, the agglomeration of the productive service industries will help and contribute to the manufacturing industry in terms of innovation ability and technological progress, which requires further in-depth study. In addition, due to the wide variety of industries, the agglomeration of productive services has the greatest impact on which type of manufacturing industry has the greatest carbon emissions and which type of manufacturing industry has the least carbon emission impact. For this problem, it is necessary to further analyze and study from the perspective of industrial characteristics.

Second, due to the limitation of data, this paper mainly uses panel data at the provincial level for empirical verification, and this type of data is relatively rough. In the future, it is necessary to obtain enterprise-level data in academic research to provide a more detailed analysis and accurately judge the impact of productive service agglomeration on carbon emissions of different types of manufacturing enterprises. For such studies, data can be collected and analyzed with the help of a variety of well-known data.

Third, in future research, we can try to use a variety of econometric models for empirical analysis and testing. For the impact paths obtained through theoretical analysis and screening, the mediation model can be further used to test and discover the main paths of the agglomeration of productive services on carbon emissions. Such research can help to grasp the impact of agglomeration of the productive services on carbon emissions in more detail, and help to make corresponding policy recommendations in more detail.

Author Contributions: Conceptualization, R.Z. and K.M.; methodology, K.M.; software, R.Z. and K.M.; validation, R.Z. and K.M.; formal analysis, R.Z.; writing—original draft preparation, R.Z. and K.M.; investigation, R.Z. and K.M.; resources, R.Z. and K.M.; data curation, R.Z.; writing—review and editing, R.Z. and K.M.; supervision, R.Z.; project administration, K.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Zhejiang Philosophy and Social Science Planning Project (21NDQN287YB).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Acknowledgments: The authors would like to thank the editors and anonymous reviewers for their thoughtful and constructive comments.

Conflicts of Interest: The authors declare no conflict of interest.

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