Journal of Infrastructure, Policy and Development 2024, 8(13), 8947.
https://doi.org/10.24294/jipd.v8i13.8947

Article

The impact of urban soccer events on carbon emissions: Panel threshold analysis for Chinese cities

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CITATION

Jin J, Chen J, Pan L. (2024). The impact of urban soccer events on carbon emissions: Panel threshold analysis for Chinese cities. Journal of Infrastructure, Policy and Development. 8(13): 8947.
https://doi.org/10.24294/jipd.v8i13.8947

ARTICLE INFO

Received: 2 September 2024
Accepted: 29 September 2024
Available online: 6 November 2024

Abstract: The holding of soccer events has an important impact on modern urban activities, which is conducive to the economic development, social harmony, cultural integration and regional integration of cities. However, massive energy is consumed during the event preparation and infrastructure construction, resulting in an increase in the city's carbon emissions. For the sustainable development of cities, it is important to explore the theoretical mechanism and practical effectiveness of the relationship between soccer events and urban carbon emissions, and to adopt appropriate policy management measures to control carbon emissions of soccer events. With the development of green technology, digitalization, and public transportation, the preparation and management methods of soccer events are diversified, and the possibility of carbon reduction of the event is further increased. This paper selects 17 cities in China from 2011 to 2019 and explores the complex impact of soccer events on urban carbon emissions by using green technology innovation, digitalization level and public transportation as threshold variables. The results show that: (1) Hosting soccer events increases carbon emissions with an impact coefficient of 0.021; (2) There is a negative single-threshold effect of green innovation technology, digitalization level and public transportation on the impact of soccer events on carbon emissions, with the impact coefficients of soccer events decreasing by 0.008, 0.01 and 0.06, respectively, when the threshold variable crosses the threshold. These findings will enhance the attention of city managers to the management of carbon emissions from soccer events and provide guidance for reducing carbon emissions from soccer events through green technology innovation, digital means and optimization of public transportation.

Keywords: soccer events; carbon emissions; green technology innovation; digitalization level; public transportation

1. Introduction

The sports industry is gradually becoming a new engine for China's economy as the residents' spending power rises and consumption attitudes change (Wang et al., 2019). Data from China's National Bureau of Statistics shows that the total output of the sports industry grew at an average annual rate of 13.2% between 2012 and 2022, far outpacing the growth rate of GDP over the same period. The 14th Five-Year Plan for Sports specifies the future development goals, and it is expected that by 2025, the output scale of the sports industry will reach 5 trillion yuan, and by 2035, the sports industry will become a pillar industry for economic development. However, data from the International Energy Agency show that China became the world's top carbon emitter in 2005, with carbon emissions rising from 5.407 billion tons in 2005 to 9.809

billion tons in 2019, indicating tremendous pressure that China is facing with in CO_2 emission mitigation. It is important to note that the sports industry, as a composite industry, is closely related to high-carbon industries such as textiles, construction, transportation and electricity (Hu et al., 2023). While injecting new growth momentum into China's economy, the sports industry potentially has an increasing impact on carbon emissions, which requires more attention to the low-carbon management of the sports industry.

With its high exposure and far-reaching social influence, sports events are the core of the sports industry which promote the development of the entire sports industry (Fernandez-Martinez et al., 2021). It not only affects related sports industries such as sporting goods and sports venues, but also has an impact on the development of other industries such as catering and accommodation, transportation, tourism and construction. Among them, soccer events are one of the largest events in the market due to their high spectator nature and usually require larger venues. Correspondingly, the scale of carbon emissions resulting from organizing soccer events is considerable. For example, according to the Qatar World Cup Greenhouse Gas Accounting Report published by the International Federation of Association Football Associations, a total of 3.63 million tons of carbon dioxide equivalent was emitted during the entire process of hosting the 2018 World Cup, which is equivalent to the carbon emissions of 830,000 people for one year. It is clear that hosting a soccer event results in non-negligible carbon emissions.

In the process of promoting the low-carbon transformation of sports events, green technology innovation and digital development are two important directions that cannot be ignored (Gupta and Rhyner, 2022; Jie and Lv, 2023; Lutfi et al., 2023; Valero-Gil et al., 2024). We believe that green technology innovation will help in carbon emission mitigation of urban soccer events by: 1) Sustainable venue construction: use of green building materials and design (Wang, 2020). For example, the Lucerne Stadium for the World Cup in Qatar uses recycled materials and has been certified with a five-star rating by the Global Sustainability Rating System. 2) Energy management at event venues: use renewable energy sources, such as solar and wind to reduce reliance on fossil fuels (Katsaprakakis et al., 2023). 3) Transportation Optimization: Encourage the use of electric vehicles and public transportation during events (Collins et al., 2009; Stavros Triantafyllidis, 2018). 4) Waste Management: Reduce garbage generation and environmental pollution during events through efficient recycling and waste management measures (McCullough et al., 2016). Meanwhile, the digitalization level has impacts on reducing carbon emissions from urban soccer events by: 1) Optimization of energy management: digital technologies such as smart grids and energy efficiency management systems can optimize the use of energy during soccer events (Chard and Mallen, 2013). Through real-time data analysis, the operation of lighting, air conditioning and other power systems in venues can be precisely controlled to reduce energy wastage (Xu and Liu, 2024). 2) Enhancement of operational efficiency: digital tools used for event organizations can reduce unnecessary consumption of materials and energy (Gerke et al., 2024). For example, the use of digital platforms for event promotion and ticket sales can reduce the use of paper materials. 3) Traffic Management and Optimization: Digital applications can optimize traffic flow management and reduce traffic-related carbon emissions by reducing vehicle congestion and idling through intelligent transportation systems (Triantafyllidis et al., 2018). In addition, digital incentives effect in promoting electric vehicles and encouraging public transportation, which also help reduce emissions (Li et al., 2024). 4) Enhanced Spectator Engagement: spectators can be encouraged to take part in green initiatives, such as watching matches through digital channels to reduce the carbon footprint of on-site spectatorship (Tan et al., 2024). 5) Carbon Emissions Monitoring and Reporting: Digital technologies can improve the accuracy of carbon emissions monitoring and reporting. Sensors and data analysis tools can be used to accurately measure carbon emissions associated with the event, providing a basis for formulating mitigation strategies (Wicker, 2019). 6) Green Technology Integration: Digitization can facilitate the integration and application of green technologies which can be operated more efficiently under the monitoring of the digital system (Belhadi et al., 2024; Liu and Chiu, 2021). 7) Supply Chain Management: Digitization tools can optimize the supply chain management of the event, reducing the waste of materials and unnecessary transportation, and thus reducing the carbon footprint of on-site viewing. material waste and unnecessary transportation, thus reducing carbon emissions. 8) Carbon Trading and Offsetting: The digital platform can support the trading of carbon credits and carbon offsetting projects, helping event organizers to compensate for unavoidable carbon emissions by purchasing carbon credits (Cooper, 2020).In addition, travel by public transportation modes is more low-carbon compared to the use of private cars, and the level of public transportation development in a city affects the preferences of event participants in terms of travel, which in turn affects the city's carbon emissions. Therefore, we selected 17 cities in China between 2011 and 2019 as research objects to explore the impacts of soccer events on urban carbon emissions by combining the threshold effects of green technological innovations, digitalization levels, and public transportation, in order to better propose tournament management suggestions. The main reason we chose this sample time is that the Chinese Football Association (CFA) established the CFA Super League in 2011, marking the advancement of the professionalization of soccer in China. During this period, the organization of soccer events requires more investment and equipment support, and also enhances the spectacle of the matches, attracting more spectators to the venue, promoting the expansion of the scale of the events and, in turn, leading to more carbon emissions. In addition, the emergence of the COVID-19 pandemic has led to the suspension of some football events after 2020. To ensure the consistency and comparability of the study, this paper determines the study period to be 2011–2019. We selected such cities because they hosted most of the soccer events, for example, the CFA Super League accounted for 92.36% of the sample cities.

The marginal contributions of this paper are: (1) Unlike the past, which only focused on the carbon emissions increased by the event itself, this paper considers soccer events as a complex systematic process, and comprehensively analyzes the mechanism of its impact on urban carbon emissions from the production and consumption side. (2) This study theoretically describes the impact of soccer events on urban carbon emissions, considers the threshold effects of green technology innovation, digitalization level, and public transportation, and empirically tests this impact using a threshold model to provide a theoretical basis and empirical evidence for enhancing low-carbon management of soccer events.

2. Literature review

2.1. Sporting events and carbon reduction

As a multidisciplinary and multiagency activity, the carbon emission of sports events has attracted much attention. Current research mainly focuses on accounting for the carbon footprint of sports events and proposing corresponding emission reduction measures. Some scholars point out specific management measures while studying the carbon footprint of the event from the event participants' activities. For example, Dolf and Teehan (2015) explored the carbon emissions of spectators and travel in events held at Columbia University. Herold et al. (2024) used Sportklub Rapid Wien as an example to measure and analyze the carbon emissions generated during the event, focusing on the carbon emissions caused by spectators' transportation. They both identified transportation travel as a significant source of carbon emissions and advocated for low-carbon travel for their participants. Ito et al. (2022) measured the carbon emissions of the 2020 Tokyo Olympics based on the seven major participants of the event, pointing out that the number of participants largely affects carbon emissions and the use of virtual media instead of offline on-site communication is effective in reducing carbon emissions from the event. Other scholars focus on measuring the overall carbon emissions of large sport events. Zhang et al. (2022) estimated the carbon emissions of the Nanjing Youth Olympic Games from the whole process of "preparation, organization and follow-up" of the sports event, pointing out that the preparation and follow-up phases are the key phases of the low-carbon management of the event as well as the measures that should be taken to take into account the continuity of the event after the event. To summarize, decarbonization measures for sports events are not limited to a single stage and subject, and need to take into account a combination of factors in order to develop emission reduction strategies.

2.2. Soccer events and carbon reduction

Soccer, as a large-scale type of sports events in China, numbers of scholars have explored the relationship between soccer events and carbon emissions, focusing on emission reduction measures for event organizing. Some scholars explore the emission reduction measures of events as a whole. For example, Liu and Guo (2023) constructed a neural network model to calculate the least-cost low-carbon strategy for soccer events. Some scholars propose carbon reduction measures for the carbon sources of specific events. For example, Al-Hamrani et al. (2021) explored the different stadium construction technologies affecting carbon emissions, and the study showed that using low-carbon technology to build stadiums can reduce 32% carbon emissions. Manni et al. (2018) point out that the use of new energy sources can effectively reduce carbon emissions from stadium operations. Crabb (2018) used the 2014 World Cup event as a study, noting that planting trees effectively offsets the carbon emissions emitted by hosting the event.

From the above literature review shows that researchers recognize that the event is a complex activity involving multiple industries and subjects, and more from different dimensions of the event itself to measure or predict the trend of carbon emissions, and put forward measures for emission mitigation of the event. At the same time, because the data of events are different from other macro data, scholars mostly account for carbon emissions of a single sports event, but the general applicability of the research results may be low, and it is difficult to provide sufficient support for extensive theory building. Zhou et al. (2023) portrayed the sports industry in terms of the number of sports programs to explore how sports industry effects on carbon emissions. This study provides an important idea for the management of decarbonization. Therefore, this paper measures soccer events by the number of soccer events, combines theoretical analysis and econometric methods to empirically explore the impact of soccer events on urban carbon emissions, and further proposes measures to reduce emissions from soccer events.

3. Mechanism and hypothesis

3.1. Soccer events affect carbon emissions

Soccer events require a large amount of energy supply during their organization, and an increase in their size and frequency will affect urban carbon emissions. In addition, organizing soccer events also affect urban carbon emissions through the industrial linkage effect at the production end and the guiding effect at the consumption end.

3.1.1. Industry linkage effects

In the 1930s, Wassily Leontief first put forward the theory of industrial linkage, which reveals that economic sectors establish relationships with each other through the inputs and outputs of factor resources, thus exploring in depth the linkage effect and economic association between industries (Beck, 2021). As the core of the soccer industry chain, soccer events form a close connection with upstream and downstream industries. The upstream demand for sportswear, equipment and other products from soccer events directly affects the sports equipment manufacturing industry. As a platform for advertising and sponsorship, soccer events attract corporate investment and are closely linked to the advertising and sponsorship industry. The construction of venues and infrastructure for soccer events is closely related to the construction industry. In terms of the downstream industries of soccer events, the events enhance regional sports attractiveness and positively affect the development of sports tourism. As soccer events are usually held across multiple regions and attract national audiences, this will affect the size of the transportation industry. Therefore, the organization of soccer events indirectly increases carbon emissions from upstream and downstream industries. If the organizer adopts the concept of low carbon management to hold sports events, it will help to transfer the low carbon concept to the whole industry chain, and inversely promote the upstream industry and lead the downstream industry to adopt the optimization of the management mode, enhance the low carbon technologies, and improve resource utilization efficiency. At the same time, enterprises in the soccer industry chain are also in the other industry chain, and will lead the related industry chain towards emission mitigation. Also, enterprises in the football industry chain are also in other industry chains, which will lead the relevant industries to adopt optimized management modes, so as to reduce the carbon emissions of the region comprehensively.

3.1.2. Consumption-led effects

Sports consumption is regarded as an important driving force for economic growth and the promotion of high-quality and healthy development of the sports industry (Caiazza and Audretsch, 2015; Zhou et al., 2023). China's soccer fan base is huge in size and has huge consumption potential. According to the data in the White Paper on Insights into the Behavior of Chinese Football Fans, as of 2022, the number of soccer fans in China is close to 200 million, of which the proportion of the group aged less than 34 years old accounts for 74.3%, while the proportion of fans with bachelor's degree or above reaches 66.0%. As large-scale public events, soccer events attract a wide range of online and offline audiences. The exciting experience of the event stimulates the audience's interest in sporting goods, which in turn prompts their desire to consume. In addition, the setting of the advertising space of the event provides viewers with product information, which in turn builds awareness and interest in the viewers' mind, prompting them to be more willing to buy the relevant products, thus stimulating consumption behavior. The fan base has a higher education level and stronger plasticity of consumption concepts, and is more likely to accept green and low-carbon consumption concepts. If a low-carbon management model is adopted for soccer matches, it will help cultivate the environmental awareness of the sports crowd and push consumers to choose green and low-carbon products. This will prompt relevant industries to accelerate the research and development of low-carbon technologies to meet consumer demand for low-carbon products.

Based on the above analysis, this paper proposes research hypothesis 1: soccer events promote urban carbon emissions.

3.2. Threshold effects of green innovation technologies on soccer events and carbon emissions

Green technological innovation refers to technologies and processes characterized by low emissions and good efficiency, which can effectively improve energy efficiency and productivity (Ning et al., 2022). The use of green technological innovation or the use of products containing green technological innovation in the process of organizing soccer events will directly reduce carbon emissions. At the same time, the industrial linkage and high exposure characteristics of soccer events will respectively prompt enterprises in the relevant industry chain and consumers to pay attention to the use and application of green technological innovation, promote enterprises to invest more resources in the research and development and application of green technological innovation, and increase consumers' understanding of products with green technological innovation, which will lead to a greater preference for low-carbon products when choosing products. In addition, innovative technology to improve production efficiency may promote the industry to carry out large-scale production, extrusion of efficiency improvement brought about by the carbon reduction effect. And green technology innovation research and development and utilization are more capable of inhibiting the enhancing effect of soccer events on carbon emissions.

Therefore, this paper proposes the hypothesis 2: Negative threshold effects of green innovation technology on the impact of carbon emissions from soccer events.

3.3. Threshold effects of digitization level on soccer events and carbon emissions

The improvement of digitalization level can reduce soccer events to promote carbon emissions. On the one hand, the level of digitization is crucial for the low-carbon management of all links in the soccer chain. Digital technology can alleviate the problem of information asymmetry and strengthen the linkage between industries (Liu et al., 2024). The close linkage between industries enables enterprises in each link to receive and understand each other's demand information in a more timely manner, which reduces the situation in which products do not meet market demand, promotes the efficient use of raw materials and energy resources, and reduces carbon emissions. At the same time, digitization also helps enterprises to reduce the time and cost of technological innovation, so that they can invest more in the practice of innovative technologies and further reduce carbon emissions (Jia et al., 2022; Li et al., 2023). On the other hand, the level of digitization has increased the speed and quality of information dissemination (Chen et al., 2024). This reduces the need for people to travel to watch soccer events, thereby reducing carbon emissions from activities such as off-site transportation and accommodation, and reduces the additional environmental burden on spectators while guaranteeing them consumer benefits through live online streaming and interactive experiences. Taken together, improving the level of digitization can help to ensure the good development of soccer matches and reduce carbon emissions at the same time.

Therefore, this paper proposes the hypothesis 3: Negative threshold effects of digitization level on the impact of carbon emissions from soccer events.

3.4. Threshold effects of public transportation on soccer events and carbon emissions

Transportation modes are an important contributor to urban carbon emissions. Public transportation development can reduce the use of private cars. Firstly, it can directly reduce the carbon emissions of vehicles, and secondly, it can reduce the carbon emissions generated by the stagnation of vehicles caused by traffic congestion. In addition, for example, electric buses, hybrid vehicles and other modern public transportation can effectively improve the efficiency of energy use. According to research data from the World Resources Institute, China's transportation sector will have as much as carbon emissions in 2019, reaching 11% of the global transportation sector. Soccer events, as large-scale public events, are characterized by high audience participation and large organizational scale. For example, the CFA Super League, CFA China League, which will be held in Beijing in 2019, has an audience of up to 816,600 people. Low-carbon and green public transportation travel modes can effectively reduce the increase in urban carbon emissions from soccer events.

Therefore, this paper proposes the hypothesis 3: Negative threshold effects of public transportation on the impact of carbon emissions from soccer events.

4. Models, variables and data sources

4.1. Models

In this paper, the two-way fixed effects model of time and city is chosen to examine the impact of soccer events on carbon emissions, as shown below:

$$\text{LN }CI_{i,t}=\alpha_0+\alpha_1\text{LN }SE_{i,t}+\alpha_{2\text{-}5}\text{LN }Controls_{i,t}+u_{i,t}+\phi_{i,t}+\varepsilon_{i,t} \quad (1)$$

In the above equation, CI is the explanatory variable; SE is the core explanatory variable; Controls are a series of control variables, which are trade openness, financial scale, government intervention, industrial structure and population density. α_0 is the constant term, α_1–α_5 are the regression coefficients of the variables, and u and φ are the fixed effects with fixed city and time, respectively. ε denotes the random perturbation term. i and t denote the city and time.

Referring to the threshold model proposed by Hansen (1999), the formula constructed in this paper is shown below:

$$\text{LN }CI_{i,t}=\alpha_0+\beta_1\text{LN }SE_{i,t}\times I(GTI\leq\phi)+\beta_1\text{LN }SE_{i,t}\times I(GTI>\phi)+\alpha_{2\text{-}5}\text{LN }Controls_{i,t}+u_{i,t}+\varphi_{i,t}+\varepsilon_{i,t} \quad (2)$$

$$\text{LN }CI_{i,t}=\alpha_0+\beta_3\text{LN }SE_{i,t}\times I(DI\leq\phi)+\beta_4\text{LN }SE_{i,t}\times I(DI>\phi)+\alpha_{2\text{-}5}\text{LN }Controls_{i,t}+u_{i,t}+\varphi_{i,t}+\varepsilon_{i,t} \quad (3)$$

$$\text{LN }CI_{i,t}=\alpha_0+\beta_3\text{LN }SE_{i,t}\times I(PT\leq\phi)+\beta_4\text{LN }SE_{i,t}\times I(PT>\phi)+\alpha_{2\text{-}5}\text{LN }Controls_{i,t}+u_{i,t}+\varphi_{i,t}+\varepsilon_{i,t} \quad (4)$$

In the above equation, GTI, DI and PT are threshold variables, denoting green technological innovation, digitization level, and public transportation, respectively. I( ) is the assignment function, when the condition of ( ) is satisfied, I( ) takes the value of 1, otherwise it takes the value of 0. ϕ is the threshold value of the variable to be estimated, β_1–β_4 denote the regression coefficients of the soccer events under the condition of satisfying the different ranges of the threshold variables, and the rest of the symbols are consistent with Equation (1).

4.2. Variables

4.2.1. Explanatory variables: Carbon intensity

In this paper, carbon intensity is chosen to measure the level of urban carbon emissions, specifically calculated from the ratio of urban carbon emissions to GDP.

4.2.2. Core explanatory variables: Soccer events

This paper uses the sum of the number of matches played in the CFA Super League, CFA China League, CFA Division Two League, and CFA Cup to measure the number of soccer matches.

4.2.3. Control variables

Trade openness: measured by actual foreign capital utilization. Trade promotes the exposure of developing regions to the excellent enterprise management and advanced production technology of developed regions, improves the energy utilization efficiency of developing regions to a certain extent, and suppresses regional carbon emissions. (Derindag et al., 2023).

Financial scale: expressed as the ratio of the sum of deposit and loan balances of financial institutions to GDP at the end of the year. Currently, scholars have not reached a consensus on the impact of financial scale on carbon emissions (Ren et al., 2023). It mainly depends on the characteristics of the enterprises that financial institutions lend to, such as the size of the enterprise and the production mode. If the enterprise is in the stage of rapid expansion, the enterprise will use more funds to purchase production equipment to establish new production lines, which will lead to more energy consumption and carbon emissions (Shahbaz et al., 2016; Yao and Zhang, 2021). On the contrary, if the enterprise is in the stage of technological upgrading and low-carbon transformation, it will use the funds to increase technological research and development and low-carbon management in order to improve the efficiency of energy utilization (Tao et al., 2023).

Government intervention: We choose the ratio of government budget revenues and expenditures to GDP to measure the intensity and effectiveness of government intervention. (Xiang et al., 2023). The Chinese government is committed to reducing carbon emissions and supporting decarbonization through fiscal policies. (Cheng et al., 2022). For example, the Chinese government used feed-in tariff subsidies, tax incentives and other policies to promote the development and growth of clean energy in 2005. Therefore, the Chinese government's intervention in the market will contribute to the reduction of carbon emissions.

Industrial structure: We choose the ratio of the value added of the tertiary industry to that of the secondary industry to measure the industrial structure. In the process of optimizing the industrial structure, resources will flow from high-energy-consumption and low-efficiency industries to low-energy-consumption and high-efficiency industries, which reduces the structural waste of energy and improves the efficiency of energy use, thus reducing carbon emissions. (Chen et al., 2022; Hu et al., 2023). Population density: We choose the number of people per unit of urban area. Increased population density means increased demand for energy for production, housing, transportation, etc., which in turn will lead to increased carbon emissions. (Zhou et al., 2019).

4.2.4. Threshold variables

Green technology innovation: Given that the ratio of outputs to inputs is a better measure of the efficiency and quality of innovative technologies, we have chosen to use the ratio of the number of green patent applications to science and technology expenditures as a measure.

Digitization level: The level of digitization involves many aspects, so a single indicator often fails to reflect its complexity and diversity (Lin and Huang, 2023). For this reason, we use comprehensive indicators to portray the development of digitization level more comprehensively to avoid assessment errors. The urban digitization indicator system constructed in this paper includes the proportion of employees in the information transmission, computer services and software industry, the per capita postal service volume, the per capita telecommunication service volume, and the proportion of cell phone users. We adopt the entropy weight method to measure the comprehensive evaluation indicators as a way to measure the digitization level.

Public transportation: urban rail transit is the core component of modern urban public transportation system, and is the main carrier of urban passenger transportation services. Therefore, this paper adopts the length of rail transit per unit city area to measure the level of urban public transportation development.

4.3. Data sources

Considering the availability and completeness of the data, the research sample of this paper is the panel data of 17 prefecture-level cities in China from 2011–2019, and the data are obtained from the Chinese Football Association, the China City Statistical Yearbook and the Economy Prediction System database. In this paper, linear interpolation is used to fill in individual missing values, while the variables of the benchmark regression model are logarithmized to prevent heteroskedasticity from biasing the regression results.

5. Analysis of empirical results

5.1. Descriptive analysis

Table 1. Descriptive statistics of variables.

Category	Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
explanatory variable	carbon intensity (CI)	153	4.311	0.560	2.800	5.460
explanatory variable	soccer events (SE)	153	30.072	14.869	9.000	88.000
control variables	trade openness (TO)	153	13.127	0.916	10.216	14.705
	financial scale (FS)	153	4.103	1.171	2.356	7.506
	government intervention (GI)	153	0.270	0.078	0.160	0.473
	industrial structure (IS)	153	1.503	0.757	0.654	5.168
	population density (PD)	153	4066.282	2891.013	1135.527	15055.000
Threshold variables	green technology innovation (GTI)	153	0.53	0.32	0.15	0.87
	≤0.440	87	0.309	0.082	0.146	0.440
	>0.440	66	0.803	0.309	0.441	1.866
	digitization level (DI)	153	0.170	0.144	0.017	0.722
	≤0.360	136	0.128	0.070	0.017	0.360
	>0.360	17	0.512	0.126	0.361	0.722
	public transportation (PT)	153	0.016	0.017	0.000	0.153
	≤0.018	44	0.034	0.023	0.018	0.153
	>0.018	109	0.009	0.004	0.000	0.018

Table 1 presents the descriptive statistics of the variables, and the results show that the mean value of carbon intensity is 4.311, the minimum value is 2.8, and the maximum value is 5.46, indicating that there is a significant difference in the carbon intensity of different cities; the mean value of soccer events is 30.072, and the standard deviation is 14.869, indicating that there is a large gap in the scale of the events in different cities, which can be used to carry out further analysis. In addition, the mean and variance of the control variables show that there are some differences in other

characteristics between cities, and these characteristics will affect the change of carbon intensity in cities, so it is necessary to include the control variables in the research model. In addition, to ensure the transparency of the data, we show the statistical description of the variables for different years and cities in the Appendix.

5.2. Model testing

5.2.1. Multicollinearity test

A high degree of correlation between the explanatory variables would reduce the credibility of the regression results. Therefore, this paper chooses the variance inflation factor to check the correlation between explanatory variables. As the results are shown in **Table 2**, the VIF of Ln SE, Ln TO, Ln FS, Ln GI, Ln IS, and Ln PD are all less than 5, which indicates that there is no multicollinearity among the explanatory variables.

Table 2. Results of multicollinearity test.

Variable	Variance inflation factor
Ln SE	1.16
Ln TO	1.14
Ln FS	3.16
Ln GI	1.74
Ln IS	3.29
Ln PD	1.15

5.2.2. Model selection

Table 3. Results of over-identification test.

Variable	(1) City	(2) Time
Sargan-Hansen statistic	57.609	47.411
P-value	0.0000	0.0000

Considering that the residuals of the model may not satisfy the assumption of homoskedasticity, this paper selects robust standard errors for adjustment at the time of regression to ensure that more reliable regression results are obtained. The Hausman test is a conventional method for selecting fixed-effects and random-effects models, but he presupposes that the residuals are homoskedastic. The over-identification test can also be used to select the model type, using the uncorrelation of the regressors with the idiosyncratic group errors as a restriction on over-identification. This method does not require the model to satisfy the assumption that the residuals are homoskedastic. Therefore, in this paper, the Test of overidentifying restrictions is chosen to select the model type. The test results are shown in **Table 3**, Column (1) and Column (2) are the results of testing fixed city and time, respectively, and the *p*-value is 0.0000, which indicates that the regressors are correlated with the errors of individual and time groups. To ensure that the regression results are more interpretable, the characteristics of city and time should be fixed in the model. Therefore, in this paper, the two-way fixed-effects model of city and time is chosen to examine the effect of soccer events on carbon intensity.

5.3. Benchmark regression analysis

Based on the theory and model above, this paper uses two-way fixed effect model to explore the effect of soccer events on carbon intensity, and the results are shown in **Table 4**. The coefficient of soccer events in the table is 0.021, which passes the 10% significance level test, indicating that soccer events can significantly promote the increase of carbon intensity, so hypothesis 1 is established.

Table 4. Benchmark regression analysis results.

Variable	Ln CI
Ln SE	0.021* [0.012]
Ln TO	−0.232** [0.096]
Ln FS	0.229*** [0.048]
Ln GI	−0.099** [0.039]
Ln IS	−0.084 [0.065]
Ln PD	0.039*** [0.011]
_cons	1.320*** [0.259]
Year effect	YES
City effect	YES

Note: *, * * and * * * represent 10%, 5% and 1% significance levels, respectively. Standard deviations are shown in parentheses.

5.4. Threshold effect analysis

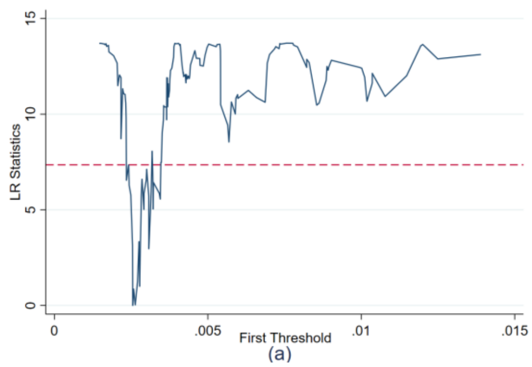
5.4.1. Threshold effect test

In order to verify the threshold effect of green technology innovation, digitalization level and public transportation on the promotion of carbon intensity of soccer events, firstly, this paper adopts Bootstrap method to repeat sampling 300 times to test whether the threshold effect exists. **Table 5** shows the test results of single threshold effect and double threshold effect of the three threshold variables. The results show that green technology innovation has a single threshold value of 0.440 with a p-value of 0.087 < 0.1, indicating that it passes the test of significance at the 10% level, and a double threshold value of 0.358 with a p-value of 0.143, which fails the test of significance. Therefore, there is a single-threshold effect of green technological innovation on soccer events to increase carbon intensity. The single-threshold value of digitalization level is 0.360 with a p-value of 0.087, which passes the significance test at the 10% level, and the double-threshold p-value is 0.783, which does not pass the 10% significance test, indicating that there is a single-threshold effect of the digitalization level on the soccer events to increase carbon intensity. The single threshold value for public transportation is 0.018 with a p-value of 0.078, which passes the 10% significance test, while the double threshold test is passes the significance test, indicating that there is only a single threshold effect for public transportation. Likelihood ratio (LR) functions are plotted in **Figures 1a–c** for green innovation technologies, digitization levels, and public transportation, respectively. The dashed line is the LR threshold corresponding to the 5% significance level. The results confirm that the thresholds are below the critical value and pass the LR test, indicating that the estimated thresholds are valid.

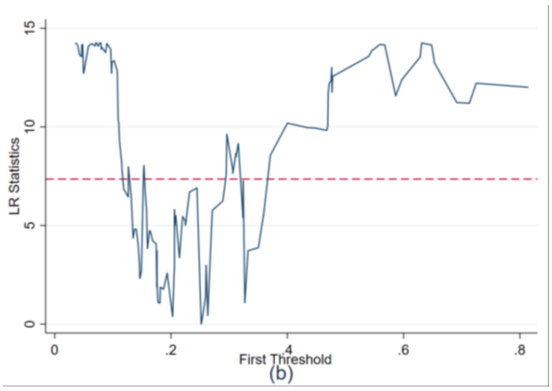
Table 5. Threshold effect test results.

Threshold variable	Model	Threshold	Lower	Upper	Prob
green technology innovation	single	0.440	0.423	0.441	0.087
	double	0.258	0.244	0.263	0.143
digitalization level	single	0.360	0.290	0.361	0.087
	double	0.384	0.372	0.433	0.783
public transportation	single	0.018	0.015	0.018	0.078
	double	0.008	0.008	0.008	0.800

Note: lower and upper denote the lower and upper limits of the confidence interval at the 95% level, respectively.



(a)



(b)

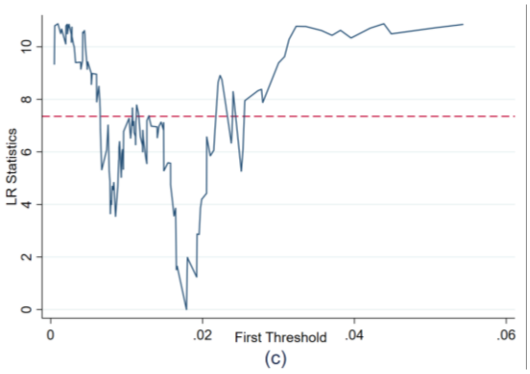


Figure 1. Likelihood ratio plot for the threshold test. **(a)** green innovation technologies; **(b)** digitization levels; **(c)** public transportation.

5.4.2. Analysis of threshold model results

Table 6. Panel threshold model regression results.

Variable	(1)	Variable	(2)	Variable	(3)
Ln SE (GTI ≤ 0.440)	0.026*** [0.009]	Ln SE (DL ≤ 0.360)	0.016* [0.009]	Ln SE (PT ≤ 0.180)	0.025*** [0.0093]
Ln SE (GTI > 0.440)	0.018** [0.009]	Ln SE (DL > 0.360)	0.006 [0.010]	Ln SE (PT > 0.180)	0.019** [0.0093]
Ln TO	−0.222*** [0.062]	Ln TO	−0.203*** [0.063]	Ln TO	−0.196*** [0.0638]
Ln FS	0.257*** [0.035]	Ln FS	0.213*** [0.034]	Ln FS	0.233*** [0.0341]
Ln GI	−0.101*** [0.03]	Ln GI	−0.085*** [0.031]	Ln GI	−0.092*** [0.0306]
Ln IS	−0.055 [0.034]	Ln IS	−0.067** [0.034]	Ln IS	−0.100*** [0.0339]
Ln PD	0.034*** [0.009]	Ln PD	0.035*** [0.009]	Ln PD	0.041*** [0.0091]
_cons	1.292*** [0.208]	_cons	1.334*** [0.210]	_cons	1.212*** [0.2138]
Year effect	YES	Year effect	YES	Year effect	YES
City effect	YES	City effect	YES	City effect	YES
adj. R-sq	0.825	adj. R-sq	0.822	adj. R-sq	0.775
N	153	N	153	N	153

Note: *, * * and * * * represent 10%, 5% and 1% significance levels, respectively. Standard deviations are shown in parentheses.

Table 6 shows the results of threshold effect estimation, and column (1) demonstrates the regression results of green technology innovation as a threshold variable. When green technological innovation is lower than the threshold, the regression coefficient of soccer events is 0.026 and passes the significance test at 1% level, while when green technological innovation is higher than the threshold, the regression coefficient of soccer events decreases to 0.018 and passes the significance test at 5% level. This indicates that the increase in the level of green technology innovation can inhibit the promotion effect of soccer events on carbon intensity. So far, hypothesis 2 is established. During the study period, Nanjing's green technology innovation level always exceeded the threshold value, and the average level was 1.75 that of other cities. At the same time, Nanjing actively applied green and innovative technologies to the whole process of hosting the soccer tournament and strengthened the low-carbon management of the event. For example, in terms of energy utilization, Nanjing has built a photovoltaic power generation system at the event venue on the one hand to actively optimize the energy structure, and on the other hand, it has improved the efficiency of energy utilization with the help of intelligent energy management system, energy storage and other technologies.

Column (2) shows the regression results of digitization level as a threshold variable. When the digitization level is below the threshold, the regression coefficient of soccer events is 0.016 and passes the significance test at the 10% level, when the digitization level crosses the threshold, the regression coefficient of soccer events decreases to 0.006 and fails to pass the significance test at the 10% level, the soccer events still lead to the increase of carbon intensity, but the effect is not significant and stable. This indicates that the level of digitization can weaken the promotion effect of soccer events on carbon intensity. At this point, hypothesis 3 is established. Among the sample cities, Hangzhou's digitization level develops rapidly and is at a high level. In 2019, Hangzhou's digitization level is ranked fourth, after Shanghai, Guangzhou and Shenzhen, and Hangzhou's digitization level's growth rate in 8 years exceeds that of Guangzhou and Shenzhen. Hangzhou's Huanglong Stadium applied digital technology to the field of energy saving and emission reduction, monitored real-time energy consumption of the stadium's buildings and built a special energy management monitoring platform to manage energy consumption. At the same time, Huanglong Stadium, as the only large stadium unit, was selected as one of the second batch of model units of energy-saving public organizations. The impact of soccer tournaments promoting carbon emissions in Hangzhou has weakened after effectively applying digital development to the event's decarbonization management. Hangzhou's carbon intensity decreased the highest among the sample cities, reaching 23.11%.

Column (3) shows the results of the regression with public transportation as a threshold variable. When the level of public transportation crosses the threshold, the coefficient of the impact of soccer events on carbon emissions decreases from 0.025 to 0.019, and both pass the 5% significance test. At this point, Hypothesis 4 is tested. Beijing's public transportation levels exceeded the threshold in 2014, the earliest city in the sample to achieve it. Over the nine-year period, Beijing hosted 520 soccer events, making it the city that hosted the most soccer events. Corresponding to this is a 21.01% decrease in carbon intensity, which is much higher than the average, showing that the development of public transportation can reduce the impact of soccer events increasing urban carbon emissions to a certain extent.

5.5. Robustness tests

To verify the robustness of the research conclusions, this paper uses adjusting the sample data, replacing the regression model and lagged explanatory variables to conduct the robustness test. First, to prevent outliers from biasing the regression results, this paper applies a 1% shrinkage to the sample data, and the regression results are shown in column (1) of **Table 7**, which shows that soccer events can still positively affect carbon intensity. Secondly, a 50% quantile model is used to regression analyze the sample data, and the results are shown in column (2) of **Table 7**, which shows that soccer events can still increase carbon intensity; Thirdly, the random effects model was used for the regression, and the results are shown in column (3) of **Table 7**, which indicates that soccer tournaments can significantly increase carbon intensity. Finally, in order to prevent the endogeneity problem caused by reverse causality, we choose to regress the explanatory variables with one period lag, and the results are shown in column (4) of **Table 7**, which indicates that soccer events can still increase carbon intensity. Taken together, organizing soccer events will lead to an increase in carbon intensity.

Table 7. Results of robustness analysis.

Variable	(1)	(2)	(3)	(4)
Ln SE	0.022*	0.029**	0.0289**	0.0148*
	[0.012]	[0.013]	[0.0123]	[0.0074]
Ln TO	−0.228**	−0.244***	−0.423***	−0.439***
	[0.095]	[0.090]	[0.1159]	[0.0873]
Ln FS	0.229***	0.210***	0.145**	0.184***
	[0.048]	[0.049]	[0.0686]	[0.0396]
Ln GI	−0.099**	−0.065	−0.0980**	−0.129***
	[0.040]	[0.044]	[0.0381]	[0.0372]
Ln IS	−0.076	−0.057	−0.287***	−0.186***
	[0.067]	[0.048]	[0.0329]	[0.0582]
Ln PD	0.039***	0.040***	0.0492***	0.0428***
	[0.012]	[0.013]	[0.0153]	[0.0093]
_cons	1.308***	1.248***	1.805***	1.843***
	[0.259]	[0.317]	[0.4303]	[0.2039]
Year effect	YES	YES	153	YES
City effect	YES	YES	YES	YES
N	153	153	YES	136
adj. R-sq	0.7802	/	/	0.7574

Note: *, * * and * * * represent 10%, 5% and 1% significance levels, respectively. Standard deviations are shown in parentheses.

6. Conclusions and policy recommendations

Soccer events play an important role in promoting the economic and social development of cities, enhancing their competitiveness, enriching their cultural life and promoting regional integration. However, soccer events consume a lot of energy during the preparation and infrastructure construction of the event, transportation, accommodation and catering, spectator activities, waste disposal, and the operation of the event, which leads to carbon emissions. To explore the theoretical mechanism of action and practical utility between soccer events and urban carbon emissions, this paper selects 17 cities in China from 2011 to 2019 as research objects to investigate the threshold effects of green technology innovation, digitalization level and public transportation on soccer events affecting urban carbon emissions. The results show that at this stage, the holding of soccer events in China significantly increases urban carbon emissions, while green technological innovation, digitalization level and public transportation all inhibit can inhibit the increasing effect of soccer events on urban carbon intensity.

Based on the findings of this paper, we propose the following policy recommendations:

First, the digital management of the entire process of soccer events should be strengthened. Specific recommendations include: (1) Digital infrastructure development: invest in smart grids and intelligent transportation systems to optimize energy use and reduce traffic congestion. (2) Carbon emission monitoring and reporting for stadium management: Use digital tools to establish a carbon emission monitoring and reporting system to provide data support for formulating and adjusting emission reduction strategies. (3) Digital event management: Use digital tools to optimize event management, reduce the use of paper and other materials, and improve work efficiency. (4) Event legacy planning: Use digital platforms to plan and manage event legacies to ensure that venues and facilities can be sustainably used for community sports and recreational activities, and to avoid wasting resources.

Second, actively integrate green technologies into the management of soccer tournaments. Specific recommendations are as follows: (1) Renewable energy utilization: increase the use of renewable energy such as solar and wind energy in soccer event venues and related facilities through policy guidance. (2) Green building design: Develop standards that require new or renovated stadiums to adopt green building standards, such as the use of sustainable materials and energy-saving technologies. (3) Urban Public Transportation Management: Implement transportation demand management measures, such as providing adequate public transportation services and encouraging the use of electric vehicles and shared bicycles. (4) Green Event Certification: Develop a green event certification system to certify and reward events that meet environmental standards. (5) Green Procurement: The government and event organizers should give priority to purchasing environmentally friendly products and services, such as event supplies using biodegradable materials. (6) Waste Management and Recycling: Apply advanced waste treatment technology to waste separation and recycling during the event, and promote the circular economy model.

Third, optimizing urban transport patterns to promote low-carbon and green development. Specific measures include: (1) Upgrading the quality of public transportation services, increasing the frequency and number of vehicles according to demand, and attracting more event participants to choose public transportation. (2) Promote electric and clean energy vehicles to gradually replace traditional diesel public transportation. (3) Build an intelligent transportation system to improve energy management efficiency, ease congestion and reduce energy consumption. (4) Develop a multi-modal transportation system to provide a seamless interchange experience and reduce carbon emissions.

Author contributions: Conceptualization, JJ, LP and JC; methodology, JJ and LP; Data curation, JJ; software, JJ and JC; writing—original draft preparation, JC; writing—review and editing, JJ, LP and JC. All authors have read and agreed to the published version of the manuscript.

Funding: Key project of Undergraduate Education Research and Reform of University of Shanghai for Science and Technology in 2022. Project Number: 10-24-343-003. Current situation and analysis of the training of university student referees in Shanghai.

Conflict of interest: The authors declare no conflict of interest.

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Appendix

Table A1. Statistical description of variables by year.

Year	Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
2011	CI	17	4.658	0.499	3.332	5.460
	SE	17	27.353	10.712	13.000	44.000
	TO	17	12.910	1.011	10.235	14.082
	FS	17	3.646	1.092	2.356	6.256
	GI	17	0.253	0.077	0.164	0.405
	IS	17	1.177	0.607	0.654	3.294
	PD	17	3828.529	2736.885	1428.000	11700.000
	GTI	17	0.354	0.158	0.146	0.721
	DI	17	0.068	0.068	0.017	0.299
	PT	17	0.011	0.011	0.001	0.040
2012	CI	17	4.566	0.532	3.142	5.266
	SE	17	36.294	19.338	16.000	88.000
	TO	17	13.132	0.873	10.767	14.233
	FS	17	3.632	1.032	2.380	6.286
	GI	17	0.258	0.080	0.176	0.416
	IS	17	1.230	0.626	0.726	3.368
	PD	17	4221.882	3190.075	1417.000	13500.000
	GTI	17	0.417	0.211	0.152	0.830
	DI	17	0.093	0.101	0.035	0.461
	PT	17	0.012	0.010	0.001	0.037
2013	CI	17	4.435	0.518	3.050	5.187
	SE	17	28.235	13.344	16.000	52.000
	TO	17	13.227	0.851	11.051	14.336
	FS	17	3.746	1.045	2.477	6.255
	GI	17	0.267	0.074	0.164	0.402
	IS	17	1.277	0.646	0.745	3.443
	PD	17	4548.294	3192.524	1419.000	13300.000
	GTI	17	0.431	0.274	0.165	1.036
	DI	17	0.136	0.121	0.054	0.564
	PT	17	0.013	0.016	0.001	0.074
2014	CI	17	4.386	0.543	2.912	5.136
	SE	17	28.824	12.700	15.000	48.000
	TO	17	13.223	0.855	11.241	14.450
	FS	17	3.825	1.066	2.426	6.235
	GI	17	0.263	0.074	0.160	0.403
	IS	17	1.370	0.673	0.781	3.658
	PD	17	4262.529	3364.037	1440.000	14500.000
	GTI	17	0.484	0.329	0.168	1.390
	DI	17	0.150	0.146	0.055	0.681
	PT	17	0.013	0.010	0.002	0.044

Table A1. (*Continued*).

Year	Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
2015	CI	17	4.270	0.541	2.838	5.133
	SE	17	25.412	11.969	9.000	50.000
	TO	17	13.158	0.903	11.438	14.564
	FS	17	4.287	1.313	2.506	7.436
	GI	17	0.279	0.092	0.170	0.466
	IS	17	1.493	0.745	0.872	4.035
	PD	17	4196.647	3376.434	1462.000	15100.000
	GTI	17	0.509	0.334	0.178	1.484
	DI	17	0.168	0.109	0.072	0.533
	PT	17	0.017	0.017	0.001	0.073
2016	CI	17	4.222	0.553	2.896	5.087
	SE	17	28.059	15.328	15.000	64.000
	TO	17	13.148	0.853	11.310	14.431
	FS	17	4.401	1.201	2.587	7.379
	GI	17	0.283	0.088	0.171	0.473
	IS	17	1.617	0.764	0.915	4.166
	PD	17	3813.706	3138.255	1145.000	14100.000
	GTI	17	0.654	0.436	0.164	1.866
	DI	17	0.186	0.126	0.072	0.599
	PT	17	0.020	0.017	0.002	0.067
2017	CI	17	4.135	0.537	2.906	5.026
	SE	17	29.882	18.214	15.000	83.000
	TO	17	13.270	0.859	11.525	14.705
	FS	17	4.338	1.172	2.508	7.187
	GI	17	0.275	0.081	0.173	0.463
	IS	17	1.662	0.773	0.938	4.238
	PD	17	3834.000	2507.627	1144.000	11100.000
	GTI	17	0.699	0.417	0.232	1.667
	DI	17	0.202	0.136	0.077	0.641
	PT	17	0.022	0.036	0.002	0.153
2018	CI	17	4.045	0.492	2.965	4.857
	SE	17	31.471	15.922	15.000	63.000
	TO	17	13.070	1.049	10.216	14.364
	FS	17	4.439	1.278	2.560	7.506
	GI	17	0.275	0.080	0.181	0.473
	IS	17	1.718	0.795	0.957	4.347
	PD	17	3986.966	2629.481	1135.527	10900.000
	GTI	17	0.638	0.293	0.222	1.194
	DI	17	0.248	0.166	0.086	0.702
	PT	17	0.017	0.012	0.000	0.054

Table A1. (*Continued*).

Year	Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
2019	CI	17	4.079	0.597	2.800	4.799
	SE	17	35.118	14.071	15.000	62.000
	TO	17	13.008	1.115	10.404	14.460
	FS	17	4.612	1.050	2.948	6.727
	GI	17	0.275	0.067	0.193	0.420
	IS	17	1.984	0.917	1.226	5.168
	PD	17	3903.988	2285.122	1136.502	8793.300
	GTI	17	0.513	0.255	0.230	1.249
	DI	17	0.280	0.179	0.090	0.722
	PT	17	0.019	0.011	0.003	0.042

Table A2. Statistical description of variables by city.

City	Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
Shanghai	CI	9	4.327	0.250	3.923	4.654
	SE	9	57.333	12.093	43.000	83.000
	TO	9	14.340	0.129	14.047	14.460
	FS	9	5.346	0.426	4.776	6.255
	GI	9	0.428	0.039	0.383	0.473
	IS	9	2.032	0.429	1.406	2.695
	PD	9	3798.030	42.374	3702.000	3829.572
	GTI	9	0.206	0.053	0.146	0.308
	DI	9	0.195	0.145	0.072	0.565
	PT	9	0.013	0.005	0.002	0.020
Beijing	CI	9	3.666	0.295	3.216	4.072
	SE	9	57.778	12.969	44.000	88.000
	TO	9	13.981	0.405	13.467	14.705
	FS	9	6.807	0.567	6.235	7.506
	GI	9	0.414	0.030	0.374	0.455
	IS	9	3.969	0.601	3.294	5.168
	PD	9	1335.225	187.805	1135.527	1541.000
	GTI	9	0.469	0.097	0.318	0.589
	DI	9	0.258	0.077	0.153	0.372
	PT	9	0.026	0.015	0.008	0.054
Nanjing	CI	9	5.106	0.201	4.799	5.460
	SE	9	21.778	6.515	16.000	35.000
	TO	9	12.823	0.088	12.704	12.931
	FS	9	4.414	0.395	3.950	4.926
	GI	9	0.218	0.010	0.207	0.234
	IS	9	1.432	0.198	1.167	1.726
	PD	9	1490.939	61.568	1417.000	1588.464
	GTI	9	0.811	0.188	0.569	1.078

Table A2. (*Continued*).

City	Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
Nanjing	DI	9	0.177	0.074	0.051	0.263
	PT	9	0.014	0.009	0.001	0.031
Dalian	CI	9	4.495	0.116	4.319	4.671
	SE	9	32.556	9.084	18.000	48.000
	TO	9	13.067	1.053	11.076	14.152
	FS	9	3.123	0.454	2.635	3.736
	GI	9	0.227	0.017	0.193	0.253
	IS	9	1.065	0.215	0.796	1.337
	PD	9	2636.038	193.701	2329.000	2898.818
	GTI	9	0.440	0.259	0.168	1.018
	DI	9	0.134	0.045	0.063	0.191
	PT	9	0.013	0.003	0.009	0.018
Tianjin	CI	9	4.611	0.197	4.352	4.916
	SE	9	38.667	4.848	31.000	44.000
	TO	9	13.946	0.548	13.067	14.564
	FS	9	3.222	0.563	2.813	4.649
	GI	9	0.329	0.045	0.277	0.420
	IS	9	1.207	0.313	0.880	1.801
	PD	9	3550.167	876.116	2636.000	5016.304
	GTI	9	0.281	0.087	0.170	0.391
	DI	9	0.102	0.044	0.040	0.146
	PT	9	0.020	0.020	0.008	0.073
Guangzhou	CI	9	4.138	0.178	3.863	4.421
	SE	9	41.111	10.470	30.000	63.000
	TO	9	13.217	0.170	12.965	13.479
	FS	9	3.778	0.302	3.391	4.353
	GI	9	0.174	0.010	0.160	0.193
	IS	9	2.176	0.362	1.670	2.631
	PD	9	6225.086	1495.956	2835.000	7912.000
	GTI	9	0.373	0.081	0.243	0.539
	DI	9	0.272	0.135	0.101	0.488
	PT	9	0.025	0.015	0.002	0.045
Chengdu	CI	9	3.688	0.249	3.478	4.143
	SE	9	26.778	11.508	9.000	49.000
	TO	9	13.715	0.274	13.305	14.091
	FS	9	4.531	0.130	4.333	4.763
	GI	9	0.223	0.012	0.205	0.243
	IS	9	1.277	0.328	1.069	2.127
	PD	9	6070.460	262.097	5748.000	6536.988
	GTI	9	0.845	0.317	0.433	1.450
	DI	9	0.122	0.053	0.037	0.179

Table A2. (*Continued*).

City	Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
Chengdu	PT	9	0.020	0.016	0.004	0.051
Hangzhou	CI	9	3.858	0.383	3.368	4.380
	SE	9	18.000	4.555	15.000	30.000
	TO	9	13.315	0.159	13.065	13.488
	FS	9	5.071	0.294	4.719	5.529
	GI	9	0.235	0.020	0.211	0.262
	IS	9	1.512	0.368	1.041	2.087
	PD	9	3684.559	181.149	3336.000	3950.352
	GTI	9	0.425	0.088	0.314	0.541
	DI	9	0.218	0.117	0.070	0.384
	PT	9	0.010	0.006	0.002	0.022
Wuhan	CI	9	4.504	0.224	4.197	4.850
	SE	9	24.778	11.366	16.000	50.000
	TO	9	13.469	0.411	12.837	14.023
	FS	9	3.315	0.218	3.052	3.609
	GI	9	0.238	0.030	0.213	0.315
	IS	9	1.167	0.211	0.982	1.645
	PD	9	4898.355	1739.002	2309.000	7075.000
	GTI	9	0.372	0.092	0.271	0.541
	DI	9	0.116	0.057	0.039	0.198
	PT	9	0.012	0.008	0.001	0.027
Shenyang	CI	9	4.560	0.102	4.406	4.715
	SE	9	35.444	7.091	22.000	46.000
	TO	9	12.266	0.798	11.310	13.273
	FS	9	3.913	1.151	2.668	5.458
	GI	9	0.241	0.027	0.195	0.275
	IS	9	1.201	0.380	0.848	1.840
	PD	9	2282.128	870.152	1484.000	3535.093
	GTI	9	0.494	0.259	0.217	0.855
	DI	9	0.090	0.029	0.041	0.125
	PT	9	0.006	0.004	0.001	0.012
Jinan	CI	9	4.593	0.316	4.011	5.045
	SE	9	18.444	4.876	15.000	31.000
	TO	9	12.025	0.259	11.712	12.503
	FS	9	3.751	0.234	3.443	4.040
	GI	9	0.200	0.020	0.164	0.225
	IS	9	1.524	0.172	1.279	1.787
	PD	9	2422.964	126.771	2127.000	2545.545
	GTI	9	1.209	0.422	0.694	1.866
	DI	9	0.131	0.052	0.042	0.188
	PT	9	0.013	0.011	0.003	0.033

Table A2. (*Continued*).

City	Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
Shenzhen	CI	9	2.982	0.168	2.800	3.332
	SE	9	28.111	9.158	16.000	42.000
	TO	9	13.355	0.196	13.039	13.617
	FS	9	4.236	0.815	3.337	5.155
	GI	9	0.301	0.055	0.235	0.377
	IS	9	1.383	0.130	1.152	1.563
	PD	9	5828.162	567.146	5256.000	6727.911
	GTI	9	0.242	0.052	0.164	0.320
	DI	9	0.578	0.135	0.299	0.722
	PT	9	0.023	0.019	0.008	0.067
Guiyang	CI	9	4.733	0.258	4.304	5.170
	SE	9	21.000	7.517	13.000	31.000
	TO	9	11.359	0.604	10.235	12.090
	FS	9	5.565	0.693	4.631	6.434
	GI	9	0.303	0.028	0.271	0.347
	IS	9	1.445	0.126	1.250	1.593
	PD	9	3575.255	1968.049	2157.000	6398.000
	GTI	9	0.327	0.075	0.234	0.421
	DI	9	0.088	0.031	0.040	0.128
	PT	9	0.010	0.012	0.002	0.042
Zhengzhou	CI	9	4.561	0.411	3.946	5.030
	SE	9	16.000	0.866	15.000	17.000
	TO	9	12.836	0.118	12.644	12.996
	FS	9	3.798	0.489	3.028	4.242
	GI	9	0.262	0.025	0.215	0.287
	IS	9	1.005	0.269	0.687	1.480
	PD	9	12600.000	2041.911	8793.300	15100.000
	GTI	9	0.495	0.246	0.276	0.885
	DI	9	0.161	0.151	0.033	0.468
	PT	9	0.008	0.006	0.001	0.019
Chongqing	CI	9	4.637	0.305	4.193	5.114
	SE	9	21.778	9.821	15.000	43.000
	TO	9	13.871	0.032	13.834	13.941
	FS	9	3.120	0.121	2.880	3.294
	GI	9	0.362	0.037	0.296	0.416
	IS	9	1.012	0.228	0.654	1.322
	PD	9	1921.453	82.111	1830.000	2026.425
	GTI	9	0.395	0.106	0.242	0.597
	DI	9	0.062	0.024	0.017	0.090
	PT	9	0.022	0.021	0.003	0.074

Table A2. (*Continued*).

City	Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
Changchun	CI	9	4.692	0.265	4.301	5.043
	SE	9	20.444	7.091	15.000	33.000
	TO	9	12.320	1.316	10.216	13.517
	FS	9	3.231	0.508	2.679	4.349
	GI	9	0.203	0.009	0.191	0.223
	IS	9	0.892	0.146	0.757	1.226
	PD	9	5067.468	3212.053	1331.614	8034.000
	GTI	9	0.678	0.293	0.389	1.249
	DI	9	0.106	0.069	0.037	0.276
	PT	9	0.006	0.006	0.000	0.021
Qingdao	CI	9	4.133	0.289	3.740	4.622
	SE	9	31.222	9.189	16.000	49.000
	TO	9	13.263	0.228	12.803	13.559
	FS	9	2.528	0.175	2.356	2.948
	GI	9	0.225	0.020	0.185	0.245
	IS	9	1.255	0.219	1.002	1.709
	PD	9	1774.405	135.154	1624.000	1972.000
	GTI	9	0.814	0.265	0.388	1.200
	DI	9	0.083	0.035	0.025	0.129
	PT	9	0.030	0.048	0.002	0.153