Analysis of the Influencing Factors of Light Pollution in China: A Regression Model of Light Pollution Based on City-level Panel Data

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Abstract. Light pollution has become one of the main pollution that perplexes human being. However, there is no unified evaluation criteria. Panel regression model can be used to evaluate the degree of light pollution. In this paper, China's 161 cities as the study object, from the humanities, economy, society, biological aspects of these four selected 10 indicators for analysis. Through the FE model, the linear formula of light pollution level and the evaluation range of the index are established. The influence of certain strategy on light pollution in a certain area is known by the VAR model and the pulse function. High GDP cities are usually accompanied by very serious light pollution, population density is also one of the main factors causing light pollution. Therefore, we can take measures to promote the construction of ecological greening, increase the area of greening, and promote the development of the third service industry to reduce the level of light pollution.

Keywords: Light pollution · FE model · Var model · Pulse function

1 Introduction

With the development of the global economy, the problem of light pollution has become increasingly serious. Human circadian rhythms, changes in biodiversity, soaring crime rates, etc., are all inseparable from the continuous impact of light pollution. However, due to the difficult to measure the characteristics of light pollution, how to formulate reasonable measurement standards has become an urgent problem to solve light pollution incidents.

Olsen et al. [1] uses a unique US dataset to study the economic causes of light pollution at the local (county) level. The results highlight the importance of economic variables, especially local economic development, in explaining the existence and extent of light pollution. In order to describe a methodology for modelling light pollution, Chalkias et al. [2] uses geographical information systems (GIS) and remote sensing (RS) technology. Rodrigo et al. [3] points out the complexity of the subject of solving the problem of light pollution. Pothukuchi et al. [4] reviews adverse impacts in multiple categories, highlights mitigation strategies, and makes the case for more engagement in

R. Lotfi et al. (Eds.): UPRE 2023, AEBMR 253, pp. 131–137, 2023.
https://doi.org/10.2991/978-94-6463-218-7_16

planning scholarship and practice especially in the United States. Cabello et al. [5] informs about partial results obtained through the estimation of main characteristic factors of the light pollution of a city placed at the North-Western area of Argentina. Riza et al. [6] emphasizes that data analysis, as an integral part of efforts to understand light pollution, needed to be used efficiently and effectively by all stakeholders in the pursuit of sustainability.

This paper will consider various factors to construct a reasonable light pollution evaluation model to optimize the current light pollution evaluation system. We selected 10 metrics to ensure the comprehensiveness of the data. Collect a large amount of data from official online datasets (e.g., China Statistical Yearbook, China Urban Statistical Yearbook, etc.) to ensure the reliability of the data. For multidimensional data, we use a variety of panel regression models to determine the influence of various factors on light pollution, so as to comprehensively consider the level assessment of light pollution.

Aiming at the intervention strategy and potential impact of problematic light pollution, we used the FE model in the panel regression model to fit and calculate the collected data to help evaluate light pollution levels at different types of sites. In view of how to select more effective intervention methods to reduce the harm of light pollution, we use the VAR model and draw the corresponding function image through the impulse response function, and select the intervention method more effectively through the image.

2 Methods

The model is based on 161 city datasets from 2018 to 2020 based on 10 indicators, and uses panel regression techniques to evaluate the causal relationship of our regression variables, namely the establishment of Air Quality Index, Green coverage of built-up area, Primary sector of the economy as a percentage of GDP, Tertiary Sector of the economy as share of GDP, Population density, Urbanization rate, Industrial dust emission, Electricity consumption of urban residents, Traffic light pollution and nighttime light index data (i.e. light pollution) in Chinese cities.

First, the general form of panel data is:

$$y_{it}, i = 1, 2, \ldots, N; t = 1, 2, \ldots, T, \tag{1}$$

N indicates that the panel data has N cross-sectional units, take 10 here. T is the length of the time series, here take 3.

If the fixed t is constant, then y_{i*}, (i = 1, 2,…, N) is N random variables on the cross-section;

If the fixed I is constant, then y_{*t}, (t = 1, 2,…, N) is a time series on the longitudinal profile;

The general model of panel data is:

$$y_{it} = a_{it} + \sum\nolimits_{j}^{K} x_{it}^{(j)} \beta_{it}^{(j)} + \varepsilon_{it} \tag{2}$$

y_{it} is the explanatory variable, which represents the numerical magnitude at the cross-section i and the moment t, and $x_{it}^{(j)}$ is the jth explanatory variable, ε_{it} is the random error term, a_{it} is the random constant term, representing heterogeneity or individual effects (which can be observable or unobservable), and β_{it} is the slope coefficient, the variation of which can be seen as a structural effect.

There are N × T equations in cross-sectional form (from a horizontal view, one point represents an equation, a total of $T \times N$ T × N equations)

$$y_{i*} = a_{i*} + \sum_{j}^{K} x_{i*}^{(j)} \beta_{i*}^{(j)} + \varepsilon_{i*}, i = 1, 2, \ldots, N \quad (3)$$

$$\begin{cases} y_{i1} = a_{i1} + x_{i1}^{(1)} \beta_{i1}^{(1)} + x_{i1}^{(2)} \beta_{i1}^{(2)} + x_{i1}^{(k)} \beta_{i1}^{(k)} + \varepsilon_{i1} \\ y_{i2} = a_{i2} + x_{i2}^{(1)} \beta_{i2}^{(1)} + x_{i2}^{(2)} \beta_{i2}^{(2)} + x_{i2}^{(k)} \beta_{i2}^{(k)} + \varepsilon_{i2} \\ \vdots \\ y_{iT} = a_{iT} + x_{iT}^{(1)} \beta_{iT}^{(1)} + x_{iT}^{(2)} \beta_{iT}^{(2)} + x_{iT}^{(k)} \beta_{iT}^{(k)} + \varepsilon_{iT} \end{cases} \quad (4)$$

Expand in the form of a time series (from the vertical view, one point represents an equation, a total of T × N equations)

$$y_{*t} = a_{*t} + \sum_{j}^{K} x_{*t}^{(j)} \beta_{*t}^{(j)} + \varepsilon_{*t}, t = 1, 2, \ldots, T \quad (5)$$

$$\begin{cases} y_{1t} = a_{1t} + x_{1t}^{(1)} \beta_{1t}^{(1)} + x_{1t}^{(2)} \beta_{1t}^{(2)} + x_{1t}^{(k)} \beta_{1t}^{(k)} + \varepsilon_{1t} \\ y_{2t} = a_{2t} + x_{2t}^{(1)} \beta_{2t}^{(1)} + x_{2t}^{(2)} \beta_{2t}^{(2)} + x_{2t}^{(k)} \beta_{2t}^{(k)} + \varepsilon_{2t} \\ \vdots \\ y_{NT} = a_{NT} + x_{NT}^{(1)} \beta_{NT}^{(1)} + x_{NT}^{(2)} \beta_{NT}^{(2)} + x_{NT}^{(k)} \beta_{NT}^{(k)} + \varepsilon_{NT} \end{cases} \quad (6)$$

Finally, considering the results of F-test, BP test and Hausman test, the FE model is adopted as the final adopted cross-sectional regression model. Next, the calculation methods and results of fixed-effect models are discussed.

The intercept is different, but the slope is the same; Individual effects are correlated with explanatory variables.

Individual fixed-effect model (intercept varies with individual)

$$y_{it} = a_i + \sum_{j}^{K} \beta x_{it}^{(j)} + \varepsilon_{it} \quad (7)$$

Time-point fixed-effect model (intercept over time)

$$y_{it} = a_t + \sum_{j}^{K} \beta x_{it}^{(j)} + \varepsilon_{it} \quad (8)$$

Time-point individual fixed-effect model (intercepts vary in different individuals at different times)

$$y_{it} = a_{it} + \sum_{j}^{K} \beta x_{it}^{(j)} + \varepsilon_{it} \quad (9)$$

3 Results and Solutions

The linear expression of light pollution standard is obtained by FE model calculation. The resulting linear expression is:

$$y = 11.153 - 4.626x_1 + 0.308x_4 + 0.013x_5 + 0.006x_6 + 0.104x_7 + 0.024x_8 - 0.038x_9 + 0.412x_{10}$$

In this linear expression, where x_1 stands for air quality index(AQI); x_2 stands for green coverage of built-up area(GCBA); x_3 stands for primary sector of the economy as a percentage of GDP(PSGDP); x_4 stands for secondary sector of the economy as share of GDP(SSGDP); x_5 stands for tertiary sector of the economy as share of GDP(TSGDP); x_6 stands for Population density(PD); x_7 stands for urbanization rate(UR); x_8 stands for industrial dust emission(IDE); x_9 stands for electricity consumption of urban residents(ECUR); x_{10} stands for traffic light pollution(TLP).

Based on this expression, we can use the AQI, GCBA, PSGDP, SSGDP, TSGDP, PD, UR, IDE, ECUR and TLP data for that year in any region to obtain the total risk of light pollution for that year. The top 22 cities with the highest light pollution are shown in the following Table 1.

In order to show the light pollution level of each region more clearly, the score value needs to be data encoded to achieve grading. The score dataset is divided into quartiles, and the final classification of light pollution level standards is shown in the following Table 2.

Through the analysis, the evaluation model of Light Pollution Index is established, and the following preliminary conclusions are drawn:

Table 1. Top 22 cities with the highest light pollution.

City	Total score	Overall ranking	City	Total score	Overall ranking
Shenzhen	114.1664912	1	Wuxi	48.9474822	12
Shanghai	89.3990744	2	Zhuhai	47.83348776	13
Nanking	67.244063	3	Xi'an	47.0590242	14
Xiamen	66.7052024	4	Qingdao	46.92202036	15
Chongqing	61.16713068	5	Guangzhou	46.5571256	16
Chengdu	59.2921088	6	Zhengzhou	45.3291788	17
Changchun	58.95421296	7	Jinan	44.557954	18
Wuhan	57.00577	8	Foshan	43.3543176	19
Tianjin	54.29248752	9	Haikou	42.76677448	20
Beijing	54.07421144	10	Hefei	42.4529392	21
Suzhou	51.3966874	11	Hangzhou	39.16732596	22

Table 2. Final classification of light pollution level standards

Divide the ranks	**Light**	**Common**	**Worse**	**Serious**
Total score range	11.1910–36.9349	36.9349–62.6787	62.6787–88.4226	88.4226–114.1665

Cities with high GDP are also accompanied by very serious light pollution, and when we randomly select some cities and use the model for fitting, cities such as Shanghai, Shenzhen, Wuhan, Tianjin and other cities always rank high. Population density is also one of the main factors causing light pollution, and places with a large population are often accompanied by an explosive increase in residential electricity consumption, which invisibly aggravates the severity of light pollution. With the continuous expansion of the urban edge, that is, the continuous increase in urbanization rate, the severity of light pollution in some places has been indirectly aggravated. The government, communities, schools and other local institutions should strengthen the popularization of knowledge of "light pollution" and how to effectively prevent and resist the harm caused by light pollution.

4 A Strategy and Its Implications

Vigorously promote the construction of ecological greenery and increase the area covered by greenery, while promoting the development of tertiary service industry. Potential impact of the action on light pollution.

As shown in the following impulse response diagram (Fig. 1). In the case of simultaneous impact of X4 and X7 on Y(GCBA and TSGDP impact on LP, in such a general environment, the first and second pre, Both GCBA and TSGDP have a negative shock effect on LP. This caused a rapid decline in LP and reached a trough of about −2% and −3% in the second period. This is followed by a brief rebound in the short term, with a slight positive effect on light pollution followed by a decline from the third period onwards. Eventually the dynamics tends to zero and the effect of both on light pollution gradually decreases with the expansion of time.

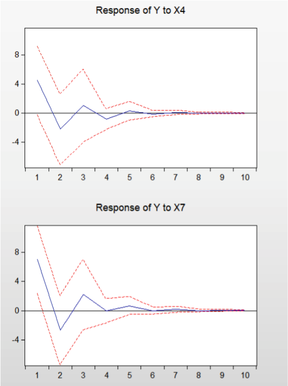

Fig. 1. Pulse function diagram

5 Conclusion

In order to construct a thoughtful evaluation standard of light pollution and determine the level of light pollution in all cities in China, a linear formula of light pollution level is established by using finite element model, and the comprehensive value of light pollution in each region in China is obtained and the level determination range is divided. Using the VAR model and impulse function, we know the impact of a certain strategy, such as simultaneously expanding green area and enhancing tertiary industry, on light pollution in a certain type of area.

The study concludes that cities with high GDP tend to have very serious light pollution. For example, Shenzhen and Beijing are the city clusters with the most severe light pollution. The lower the air quality, the lower the light pollution due to particles and suspended solids. Population density is one of the main factors causing light pollution. In places with large population, the explosive growth of electricity is accompanied by the surge of residential population, which invisibly aggravates the severity of light pollution. Light pollution exists on traffic roads, such as street lamps and road refraction, which will also affect the quality of life of surrounding residents. With the continuous expansion of urban fringe, that is, the continuous improvement of urbanization rate, the severity of light pollution in some places is indirectly aggravated.

In addition, measures can also be taken such as: promoting the limit of electricity consumption, stratified setting of electricity price, ecological green construction, increase green area, reduce traffic time, promote the development of the third service industry, etc.

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