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Research on Impulse Response of Provincial Underground Economy to Environmental Pollution in China–Based on a Spatial Econometric Model

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Abstract

The distribution of the underground economy in China shows obvious regional differences and has an important impact on the environmental pollution of relevant provinces. The spatial data analysis method is used to study the spatial differences between central and peripheral areas and between developed and backward areas in China's underground economy, and the degree of provincial environmental pollution has significant spatial dependence. On this basis, the spatial error model and spatial lag model are further used to empirically analyze the impact of the underground economy and its scale on China's environmental pollution, and the impact degree of underground economic growth on the ecological environment in various provinces of China is discussed. The research results show that there is a negative correlation between the underground economy and environmental pollution in various provinces of China, and the development of and changes in the underground economy and the way it acts on the macroeconomic determine the sustainability of this relationship. In addition, the impact degree of China's provincial underground economic growth on the ecological environment differs in different regions. The impact of the underground economy on the ecological environment in the eastern and central regions is most significant from the early stage to the middle stage, and the impact of the underground economy on the ecological environment in the western region is most obvious in the middle stage.

Keywords: Underground economy • Ecological environment • Impulse response • Spatial measurement

JEL Classification: O13 • P28 • Q56 • Q57

Introduction

Underground economy is a general term used to refer to various economic activities outside the official statistics and supervision of a country. With the continuous advancement of the economic transformation process of various countries worldwide, the underground economy has developed into a potential force that cannot be ignored; it has had an increasingly profound impact on all aspects of social life in various countries. The development of practice puts forward higher requirements for theory. Scholars started their research on the underground economy in the 1980s. However, in the initial stage of the first decade, most studies were limited to providing a description of general facts and phenomena. The underground economy concept is divided into a narrow sense and a broad sense, and the foreign theoretical circle has not yet formed a completely consistent understanding of the concept; thus, it is necessary to first define it specifically. This paper holds that the most prominent feature of the underground economy lies in its characteristic of escaping from official active detection. Therefore, we define the concept of underground economy as "officially subjectively committed to detection, but the general term of market-based economic activity that cannot be or is difficult to detect". This definition is similar to the definition of previous authors but the latter emphasizes its concealment more. At the same time, this definition does not investigate the projects that the government voluntarily gives up, and accounting is based on the general national economic account accounting practice, that is, the value of some nonmarket output (such as family labor) [1].

The underground economy of many countries worldwide has developed rapidly and has a large scale. The underground economy has a significant and far-reaching impact on economic and social development. Calculated the underground economic scales of 162 countries and found that the average proportion of the global underground economic scales in their Gross Domestic Product (GDP) was 17.1% [2]. After calculation, noted that the underground economy of developed countries accounted for 10%-15% of GDP, while that of developing countries accounted for 30%-40%; for example, the underground economic scale of Panama and Bolivia accounted for 70% of their GDP. The rapid development of the underground economy and the formation of its large scale are bound to have an important and far-reaching impact on the operation of the local social economy [3]. Currently, scholarly research on the underground economy has mainly focused on the following three aspects:

- Research on the positive correlation or benefits between the underground economy and the formal economy. Thinks that the underground economy and formal economy share the same changing trend, but the influence has a time lag [4]. The relationship between the underground economy and economic growth in 18 Asian countries and Canada and found that there was a positive proportional growth relationship between the two variables [5]. Australia found that both the formal economy and the underground economy adapted to the economic cycle and circulated [6]. However, since the underground economy can absorb the employment of the unemployed in the formal economy, it is conducive to the development of the formal economy [7].

- Research on the negative correlation or harm between the underground economy and the formal economy. That the existence of an underground economy can be used in place of or to compensate for the official economy; however, in terms of resource utilization, the underground economy and formal economy compete with each other. Other researchers believe that the existence of an underground economy is harmful to formal economic growth [8]. Through his research on Singapore, a large number of underground economies had more negative effects than positive effects on the formal economy [9]. The cross-sectional data from 73 countries and found that improving the rate

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of return of formal economic activities could effectively curb the expansion of the underground economic scale [10].

- Research on the impact of the underground economy on other aspects of society. That the impact of the underground economy on energy utilization is vague and uncertain; that is, it does not a single negative or positive impact [11]. Analyzed the impact of the underground economy on Chin's energy consumption and found that the relationship between the growth of the underground economy and energy consumption was uncertain [12]. A panel data model to study Latin American countries and found that the underground economy may affect ecological environmental problems [13].

Judging from the development of the existing literature, the current research still has obvious deficiencies in two aspects:

- Most studies focus on the estimation of the overall scale of the underground economy and lack a discussion of or insights into the details and applicability of the model;
- The current research is mainly focused on the relationship with the changes in the formal economy, and there is a lack of research on the spatial characteristics of the distribution of underground economic regions; and
- The existing research has not investigated the relationship between the underground economy and ecological environment. Therefore, this paper introduces the over-danger ratio of the underground economy and measures the composite environmental pollution index. Taking the correlation between the underground economy and environmental pollution in 31 provinces of China as an example, the spatial error model and spatial lag model are used to empirically analyze the impact of the underground economy and its scale on environmental pollution in various provinces, and the impact degree of underground economic growth on the ecological environment is discussed.

The structure of this paper is as follows: the first part is the introduction, which provides background information on the environmental pollution problem caused by the development of China's underground economy and summarizes the relevant research results from studies on the underground economy. The second part puts forward the research model. The calculation method of the underground economic scale is proposed, the composite environmental pollution index is constructed, and the spatial autocorrelation test model and impulse response function is discussed. The third part provides information on the index selection and data sources, providing the data sources of indexes and indicators and explaining the empirical analysis involved in the research model. The fourth part is empirical analysis, which uses 31 provinces in China as the research objects and panel data from 2019 to analyze the spatial correlation between provincial underground economic growth and the ecological environment in China. The fifth part is the conclusion. Based on the results of the empirical research, the research conclusions of this paper are put forward.

Research Methods

The scale of the underground economy

According to the relatively consistent understanding at present and based on the current national economic accounting system, the underground economy should be accounted for but not included in the calculation, that is, the underground economy includes the economic production activities that are not involved in but do exist in the current national economic accounting system [14]. The money demand method is an excellent method to measure the scale of the underground economy, but it cannot estimate the scale of the underground economy in various provinces and regions. Therefore, this paper uses the element distribution method to calculate the scale of the underground economy in each province [15]. According to the principles of economics, income is the sum of consumption expenditure and savings, and the official statistics of consumption expenditure and savings expenditure are relatively accurate; however, people tend to conceal income. Therefore, the labor remuneration income of underground economic departments can be calculated by the difference between consumption, savings and income, as shown in Formula:

Remuneration of workers in the underground economic sector=total consumption expenditure+annual increment of household savings-(per capita living expenses income of urban residents × total urban population+per capita net income of rural residents × total rural population) (1)

Then, according to the proportion of workers' remuneration in the underground economy, that is, the proportion of workers' remuneration in GDP in the formal economic sector, we can estimate the scale of the underground economy in various provinces and regions of China.

Composite environmental pollution index

In this paper, the composite environmental pollution index is used as a measure of the degree of environmental pollution in each province. Compound pollution refers to the simultaneous pollution of various pollutants to the same medium (e.g., soil, water, atmosphere and biota), and compound pollution types are typically transported to each other between cities, which causes correlations of pollution in various cities and the superposition of various high concentration pollutants in time and space. Therefore, the construction of the conformity pollution index can more accurately reflect the degree of influence after various pollutants interact with each other. This is done using the method of the environmental pollution index based on the entropy weight method and by calculating the composite environmental pollution index [16]. The formula for calculating the composite pollution index is as follows:

$$P_i = \beta_{i1}x_{i1} + \beta_{i2}x_{i2} + \cdots + \beta_{ij}x_{ij} \quad (2)$$

Where P_i represents the composite environmental pollution index of a province.

x_{ij} Indicates the value after the selected pollutant index is standardized.

β_{ij} Is the coefficient of the index of item *j* in province *i*, that is, the weight of each pollutant determined by the entropy method, and β_{ij} is:

$$\beta_{ij} = \frac{1-e_j}{m-E_e} \quad (3)$$

Where *m* is the number of indicators, *m* = 5; E_e is the sum of each item e_j.

e_j Represents the entropy value of the index of item *j;* thus, e_j is:

$$e_j = -k\sum_{i=1}^{n} f_{ij}\ln(f_{ij}) \quad (4)$$

Where *n* is the number of provinces, *n* = 31; *k* = *ln*(*n*); and f_{ij} is the proportion of province *f* in this indicator under indicator *j*:

$$f_{ij} = x_{ij} / \sum_{i=1}^{n} x_{ij} \quad (5)$$

Spatial autocorrelation test

By analyzing the spatial distribution between the underground economy and environmental pollution, we can judge whether there is an agglomeration phenomenon in geographic space, namely, spatial autocorrelation. The existence of spatial autocorrelation means there is a lack of independence between the observed values in space, and there is mutual influence among all variables. The intensity and mode of spatial correlation are jointly determined by the absolute position (pattern) and relative position (distance) in space [17]. This paper uses the global spatial correlation test and local spatial correlation test to analyze and measure the geographical agglomeration degree of China's provincial underground economy and environmental pollution [18]. The global spatial autocorrelation coefficient Moran's I proposed, is used to test whether the spatial correlation of regional variables exists, and the calculation formula is as follows [19]:

$$Moran's\ I=\frac{\sum_{i=1}^{n}\sum_{j=1}^{m}W_{ij}(Y_i-\overline{Y})(Y_j-\overline{Y})}{S^2\sum_{i=1}^{n}\sum_{j=1}^{m}W_{ij}} \quad (6)$$

Where represents the observed value of region, represents the total number of regions, and represents the binary adjacent spatial weight matrix, representing any element therein, adopting the adjacent standard or distance standard; its purpose is to define the proximity of spatial objects. The value of the whole is between [-1, 1]. If it is greater than 0, it means there is a positive spatial correlation. Larger values indicate the positive correlation of the space distribution is stronger. In contrast, values less than 0 indicate a negative correlation. If the value is approximately 0, it means that the spatial distribution is random.

Through Moran's index, the underground economic clusters of each province can be divided into four spatial correlation modes: the first quadrant (HH) indicates that provinces with a high underground economic scale are surrounded by provinces with a high underground economic scale; the second quadrant (LH) indicates that provinces with a low underground economy are surrounded by provinces with a high scale; the third quadrant (LL) indicates that provinces with a low underground economy are surrounded by other low provinces; and the fourth quadrant (HL) indicates that provinces with a high underground economy are surrounded by provinces with a low scale. The first and third quadrants show positive spatial autocorrelation, and the second and fourth quadrants show negative spatial autocorrelation. The spatial correlation model of the composite environmental pollution index is the same as above.

Determined the real data generation process, starting from the general linear regression model and extending to the econometric model with spatial lag variables through the test of model setting [20]. This method is better than the method from general to specific force. Therefore, this paper first draws lessons from the existing EKC research paradigm and combines the research purpose of this paper to first construct the following logarithmic linear regression model [21,22]:

$$\ln E=\alpha+\beta_1\ln Y+\beta_2(\ln Y)^2+\beta_3 U+\varepsilon \quad (7)$$

where E indicates the degree of environmental pollution, Y represents the level of economic development, U represents the scale of the underground economy, α and β are a constant term and a random error term, respectively, and $\varepsilon\sim N(0,\sigma^2)$. The estimation results of parameters β_1 and β_2 are used to judge the possible centralized curve relationship between the environment and income. The symbol and size of β_3 reflects the impact of the underground economic scale on environmental quality. On this basis, a spatial econometric model is introduced to revise Formula (7). According to spatial econometrics, spatial effects can be manifested in two basic forms: the Spatial Lag Model (SLM) and the Spatial Error Model (SEM)[23]. In the spatial autoregressive model, the spatial correlation of variables is reflected by the spatial lag term of the dependent variables. The SLM model corresponding to Formula (7) is as follows:

$$\ln E=\alpha+\beta_1\ln Y+\beta_2(\ln Y)^2+\beta_3 U+\rho(W\ln E)+\varepsilon \quad (8)$$

Where $W\ln E$ is the spatial lag dependent variable? ρ is the spatial autoregressive coefficient, and its estimated value reflects the direction and size of spatial correlation, that is, the influence degree and direction of environmental pollution in neighboring provinces on the observed value of the province. In the formula, W is the $n\times n$ spatial weight matrix, in which the elements w_{ij} define the spatial adjacency relationship? If the geographical units i and j are adjacent, w_{ij} is equal to 1; otherwise, it is equal to 0. Because adjacent provinces have common boundaries, this paper chooses the first-order adjacent method to obtain the spatial weight matrix [18].

Assuming that spatial correlation is generated through the error process, the SEM corresponding to Formula (7) is as follows [15]:

$$\ln E=\alpha+\beta_1\ln Y+\beta_2(\ln Y)^2+\beta_3 U+\lambda W\mu+\varepsilon \quad (9)$$

Where λ is the spatial error autocorrelation coefficient, which represents the intensity of spatial correlation between regression residues, and $W\mu$ is the spatial lag error term?

Due to the existence of a spatial effect, if ordinary customer assistant multiplication (OLS) is still adopted to estimate the above two models, it will lead to the deviation or ineffectiveness of the coefficient estimation value. According to the suggestion, this paper uses the maximum likelihood method to estimate the SLM and SEM [24].

Impulse response function

The vector autoregressive (VAR) model was first proposed by Sims in 1980; it is usually used to describe the dynamic influence of the association of time series systems and random disturbance terms on variable systems and has the advantage of obtaining cross-regional information or laws from regional economic event sequences [25]. The mathematical expression of the model VAR_p

is as follows:

$$y_t=Bx_t+A_1y_{t-1}+A_2y_{t-2}+\cdots+A_qy_{t-q}+\varepsilon_t \quad (10)$$

In the formula, yt is a vector of endogenous variables in k dimensions? x_t Is a vector of exogenous variables in d dimensions? t = 1,2,...,T (T Is the number of samples)?

q Is the lag order. A_1, A_2,..., A_q And B are the coefficient matrices. ε_t Is the dimensional disturbance vector in k dimensions?

Based on the above model, the impulse response measure is carried out on the results of environmental pollution impacted by underground economic growth through Eviews 8.0 software.

Stationary tests and integration relationship tests are the basis of impulse responses. 1. Stability test. This paper adopts the ADF test to verify the stationary of each time series data and determine whether all variables are stable at the level of 5%; 2. Integration relation test. Generally, the integration test is used to determine whether there is a long-term equilibrium relationship and short-term fluctuation between time series.

Index selection and data sources

In addition to the indicators selected in the research model, this paper needs some indexes to study the problems, such as the level of economic development , which can use per capita GDP (unit: ten thousand yuan) for measurement, the scale of the underground economy , which can be measured by the per capita underground economic level (unit: ten thousand yuan), and the degree of environmental pollution, which uses the composite environmental pollution index calculated above and can eliminate differences in economic and population scales among different provinces.

This paper studies the relationship between the provincial underground economy and environmental pollution in China. The spatial samples adopted are the 31 provinces in the mainland of China, excluding Taiwan, Hong Kong and Macao, and the panel data for a total of 17 years, from 2003 to 2019, as the research object. The gross domestic product (GDP, 100 million yuan) of each province excluding the influence of price factors (taking 2003 as the base period) is selected as the alternative variable of provincial underground economic growth, and wastewater discharge, chemical oxygen demand (CO., industrial waste gas emissions, sulfur dioxide emissions and industrial solid waste production) are selected as the measures of water, atmosphere, and soil pollution, respectively. Empirical data came from the China Statistical Yearbook, China Energy Statistical Yearbook, China Environmental Statistical Yearbook and website of the China National Bureau of Statistics. All monetary units in this article are converted with 2003 as the base period to eliminate the impact of inflation.

Results and Discussion

The excessive danger ratio (excess risk) can measure the relative severity of the scale of the underground economy and is the ratio of the observed value to the average value of all data [19]. If the excessive danger ratio is less than 1, it indicates that the underground economy scale of this province is smaller than the domestic average. If the excessive danger ratio is greater than 1, it indicates that the underground economy scale of this province is greater than the domestic average, and the danger degree is higher.

From the perspective of the development trend, the scale of China's underground economy shows an obvious diffusion trend from point to surface. As shown in below figures, in 2003, there were 8 provinces in China in which the excessive risk ratio of the underground economy scale was greater than or equal to 1. By 2019, the number of provinces with an over-danger ratio of underground economy scale greater than or equal to 1 reached 19, accounting for 61.29% of all (31) provinces. Therefore, this paper holds that, first; the scale of China's underground economy tends to be serious. Second, from the perspective of regional distribution and evolutionary trends, Beijing, Shanghai, Tianjin, Liaoning, Guangdong and Hainan are always the areas severely afflicted by the underground economy. Third, the underground economy presents the trend of migrating from Beijing and Shanghai as well as from coastal economically developed areas to Inner Mongolia and Northwest China. Fourth, it gradually presents the characteristics of heterogeneity in geographic space, and there are spatial differences between central and peripheral areas and between developed and backward areas (Figures 1 and 2).

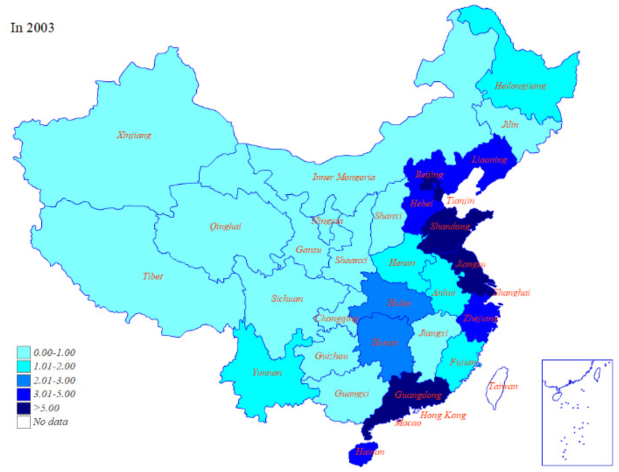

Figure 1. Spatial distribution of the provincial underground economy in China in 2003.

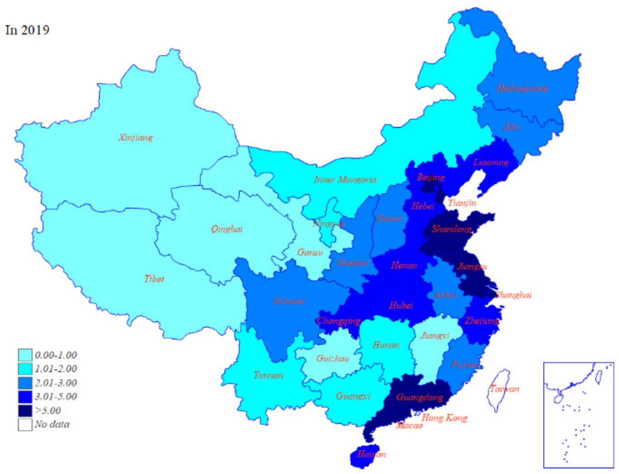

Figure 2. Spatial distribution of the provincial underground economy in China in 2019.

Spatial distribution of environmental pollution degree in provinces of China

As shown in below figures, in 2003, there were 12 provinces with a composite environmental pollution index greater than 0.3, while in 2019, there were 14 provinces with a composite environmental pollution index greater than 0.3. Based on this result, China's environmental situation has not improved in the past ten years. Among the provinces, the environmental pollution index of Shandong, Jiangsu, Henan, Hebei, Sichuan and Guangdong has always been at a high level, while that of Guangxi has declined from a moderately polluted area to a heavily polluted area, and that of Xinjiang has declined from a pollution-free area to a slightly polluted area. Only Shandong's environmental conditions have improved, and it is no longer a heavily polluted area (Figures 3 and 4).

If the degree of environmental pollution in all provinces of China is divided into four levels: nonpolluting, mild pollution, moderate pollution and severe pollution, the environmental pollution situation has the following characteristics: first, similar to the unbalanced situation of provincial economic development, the environmental conditions of each province in China show an obvious hierarchical distribution: the composite environmental pollution index in the western region is the smallest, followed by the composite environmental pollution index in the central region, and the composite environmental pollution index in coastal areas is the highest. Among them, Hebei and Liaoning in the Bohai Rim region; Jiangsu, Zhejiang, Fujian, Guangdong and Guangxi along the coast; and the inland provinces of Henan, Shaanxi, Shanxi, Sichuan, Chongqing, Heilongjiang, jilin and other areas have the highest degree of environmental pollution, i.e., severe pollution. Second, the distribution of environmental pollution presents the characteristics of regional agglomeration and is close to the

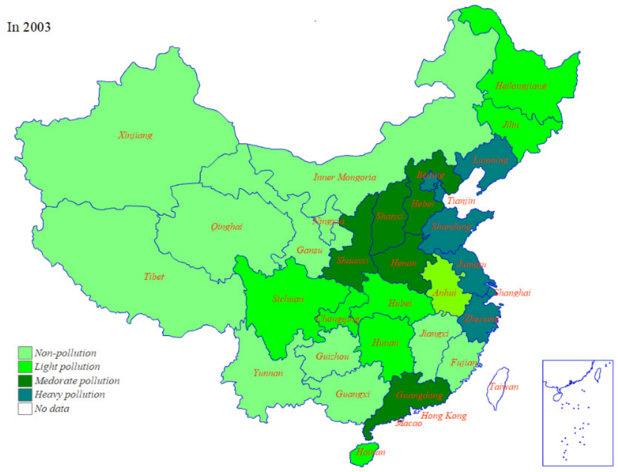

Figure 3. Space of environmental pollution degree in China's provinces in 2003.

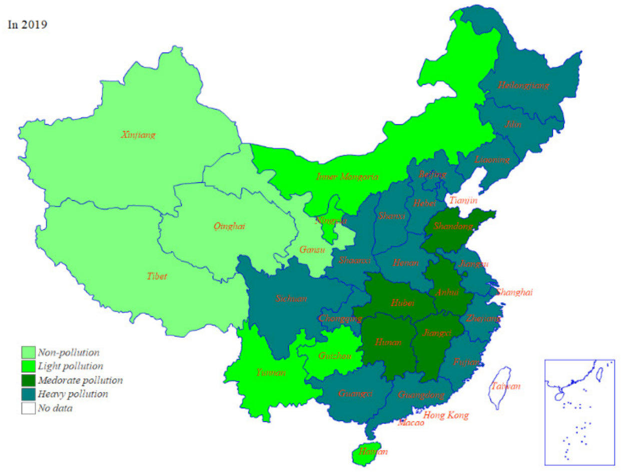

Figure 4. Space of environmental pollution degree in China's provinces in 2019.

areas with higher degrees of pollution; for example, Hubei, Hunan, Anhui and Jiangxi, with moderate degrees of pollution, are close to the Bohai Rim region and the Guangdong and Guangxi regions, which have severe pollution. Sichuan and Chongqing, with severe pollution, are located in "isolated islands" with environmental pollution, and are surrounded by Yunnan, Guizhou, Ningxia, which have slight pollution, and Tibet, Gansu and Qinghai, which have no pollution.

Spatial autocorrelation test of underground economy and environmental pollution in provinces of china

This paper uses the statistical data of underground economic and environmental pollution of 31 provinces in China from 2003 to 2019, and related statistical tests are calculated by Geo Da software. The results show that in each year is positive and basically all values passed the statistical test of the 5% significance level, as shown in below tables. The data in tables show that there is an obvious spatial effect and positive correlation between China's underground economy and environmental pollution in terms of geographical distribution; that is, the geographical distribution pattern of pollution is not random—it actually shows an obvious agglomeration distribution (Tables 1 and 2).

China's provincial underground economy has geographical dependence and heterogeneity, as shown in below figures. The pattern of the core and border areas is a typical distribution pattern: Shanghai, Beijing, Guangdong, etc., which have the highest underground economy scale, are located in the first quadrant and surrounded by other provinces with a lower underground economy scale. The provinces in the western region along the border with a lower underground economic scale are connected and are located in the third quadrant. The provinces located in the second quadrant are not adjacent to each other, and the underground economic scale is very large. The differentiation between the HH and LL modes appears in the accumulation of environmental pollution in China's provinces, and the spatial positive correlation is relatively obvious (Figures 5-8).

The above analysis shows that there is indeed a spatial aggregation phenomenon in the scale expansion of China's provincial underground economy and the degree of environmental pollution, with significant regional differences. Therefore, it is necessary to start from the correlation and heterogeneity of the spatial dimensions, and this spatial measurement analysis (Table 3).

Years	Moran's I	E (I)	SD (I)	z	Results	Years
2003	0.4916	-0.032	0.114	4.736	0.001	2003
2004	0.5182	-0.032	0.117	4.89	0.001	2004
2005	0.4706	-0.032	0.112	5.113	0.002	2005
2006	0.4629	-0.032	0.116	4.928	0.001	2006
2007	0.523	-0.032	0.113	4.871	0.001	2007
2008	0.4857	-0.032	0.115	5.014	0.001	2008
2009	0.4932	-0.032	0.119	5.118	0.001	2009
2010	0.5068	-0.032	0.113	4.739	0.003	2010
2011	0.5291	-0.032	0.117	4.858	0.001	2011
2012	0.4875	-0.032	0.111	4.904	0.002	2012
2013	0.4774	-0.032	0.114	4.83	0.001	2013
2014	0.513	-0.032	0.118	5.133	0.001	2014
2015	0.4729	-0.032	0.116	4.772	0.003	2015
2016	0.484	-0.032	0.113	4.849	0.001	2016
2017	0.4899	-0.032	0.112	4.56	0.002	2017
2018	0.5078	-0.032	0.114	4.997	0.002	2018
2019	0.4835	-0.032	0.117	5.102	0.001	2019

Note: E (I) is -1/(n-1) , representing the expected value of I; SD (I) is the variance of I ; z is the z test value of the I value, and the P value is its accompanying probability.

Table 1. Statistical indicators and of the underground economy in 31 provinces of China from 2003 to 2019.

Years	Moran's I	E (I)	SD (I)	z	Results
2003	0.1859	-0.028	0.116	2.318	0.013
2004	0.2847	-0.028	0.119	2.107	0.011
2005	0.255	-0.028	0.111	2.439	0.117
2006	0.2389	-0.028	0.115	2.515	0.115
2007	0.2776	-0.028	0.114	2.13	0.119
2008	0.2381	-0.028	0.118	2.446	0.008
2008	0.2375	-0.041	0.116	1.832	0.052
2009	0.1247	-0.041	0.118	2.55	0.041
2010	0.2113	-0.041	0.113	2.689	0.037
2011	0.1951	-0.041	0.117	1.756	0.025
2012	0.1639	-0.041	0.118	2.094	0.018
2013	0.2258	-0.041	0.115	1.881	0.011
2014	0.1787	-0.041	0.112	1.779	0.007
2015	0.1596	-0.041	0.114	2.203	0.042
2016	0.2064	-0.041	0.117	2.657	0.035
2017	0.1833	-0.041	0.117	1.893	0.043
2018	0.232	-0.041	0.119	2.501	0.027

Note: E (I) is -1/(n-1) , representing the expected value of I; SD (I) is the variance of I ; z is the z test value of the I value, and the P value is its accompanying probability.

Table 2. Statistical indicators and of environmental pollution in 31 provinces of China from 2003 to 2019.

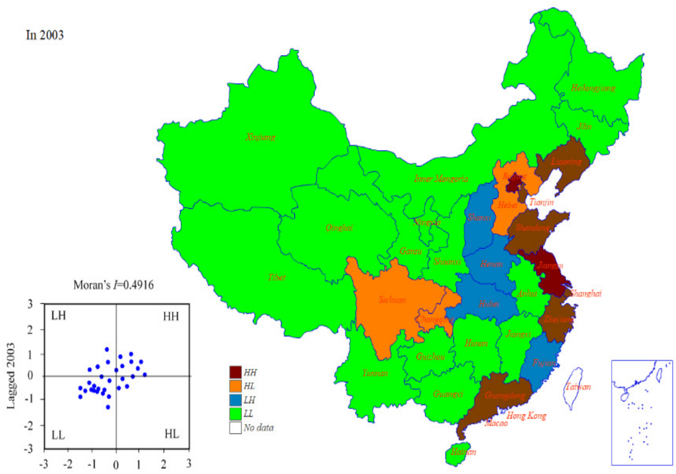

Figure 5. Relevant modes of scale space of China's provincial underground economy in 2003.

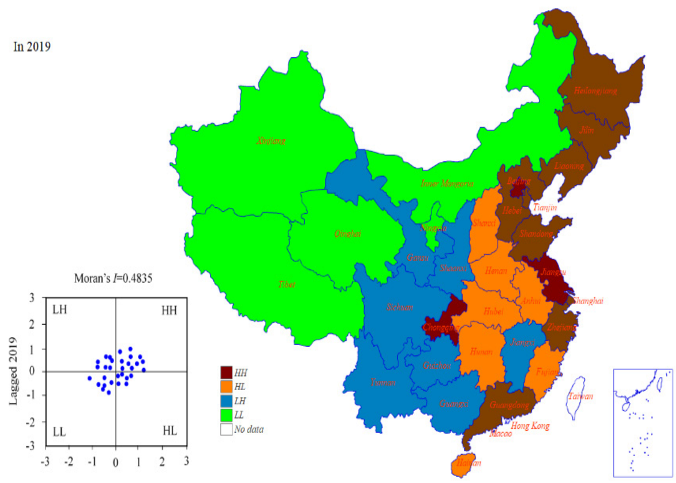

Figure 6. Relevant modes of scale space of China's provincial underground economy in 2019.

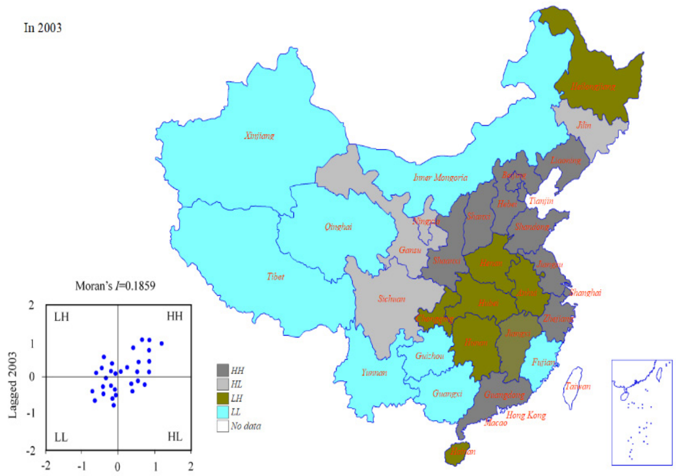

Figure 7. Spatial correlation model of environmental pollution degree in China's provinces in 2003.

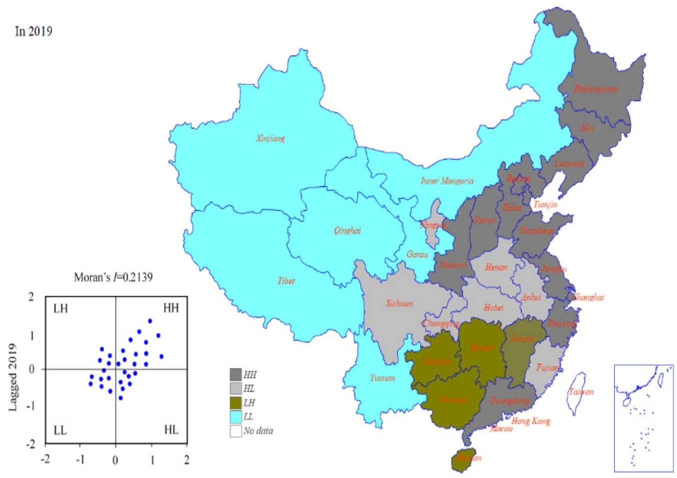

Figure 8. Spatial correlation model of environmental pollution degree in China's provinces in 2019.

Variables	OLS	SLM	SEM
α	-4.271(0.056)	-4.095(0.017)	-4.393(0.025)
ln*Y*	0.730(0.019)	0.904(0.026)	0.912(0.022)
(ln*Y*)^2	-0.057(0.028)	-0.038(0.021)	-0.039(0.028)
ln*U*	-0. 0359 (0.000)	-0. 0276 (0.000)	-0.0281(0.000)
ρ	—	0.054(0.069)	—
λ	—	—	-0.172(0.047)
R^2	0.398	0.479	0.513
LMLAG	0.091(0.672)		
R - LMLAG	1.405(0.256)		
LMERR	0.208(0.054)		
R - LMERR	1.530(0.017)		
Logf like lihood	58.306	59.170	60.745
AIC/*SC*	-113.875/-104.670	-122.805/-108.547	-116.380/-102.394

Table 3. Spatial measurement test results of the underground economy and environmental pollution.

pollution index as the explained variable. Compared with the classical regression OLS model, both the goodness-of-fit test value, and the log-likelihood function value of the SLM and SEM are improved, and the values of A1C and SC are relatively smaller, which shows that, after considering the spatial effect, the model effectively eliminates the spatial autocorrelation and spatial error of environmental pollution. However, the log-likelihood and in the SEM are better than the corresponding statistical values of other models, which means that the environmental pollution of a region is not only impacted by the environmental pollution of neighboring provinces; rather, it is also impacted by the error of the structural differences between regions, which are reflected by the differences between the economic development level of each province itself, the scale of the underground economy and other spatial influencing factors not included in the basic model. Further comparative analysis shows that compared with LMLAG, LMERR are statistically more significant and R-LMERR is also significant. According to the spatial model form discrimination method provided, compared with the SLM, the SEM can better fit the spatial effect [25-27].

The estimated coefficient of the underground economy in the three models is -0.0359, -0.0276, and -0.0281, which means that the existence of an underground economy is conducive to reducing the emissions of major pollutants and has at least a positive effect on the improvement of environmental quality. The negative correlation between the underground economy and environmental pollutants may be caused by the following reasons: first, high energy consumption and high pollution projects have large investments and high risks, and the funds (underground funds) formed by the underground economy because of natural risk aversion are unwilling to enter the above fields. Second, although the extensive growth mode of high energy consumption and high pollution in China has not been fundamentally changed, the supervision of such projects and their enterprises is increasingly strict, and it is difficult for underground funds to enter. Third, most of China's underground economy is hidden in the tertiary industry service industry, which objectively has less of an impact on environmental pollution.

Impulse response analysis of provincial underground economy to ecological environment in China

Through the ArcGIS distribution map, we can analyze the temporal and spatial evolution characteristics of China's provincial underground economy and ecological environment, but we cannot reveal the specific influence relationship between the two. Therefore, this paper uses the VAR model to analyze the impulse response of underground economic growth to the ecological environment in 31 provinces, cities and autonomous regions in China and discusses the internal relationships. The impulse response diagrams of underground economic growth to the ecological environment of each province and city are obtained separately, as shown in below figures [28].

The eastern region of China: the eastern region as a whole shows that the impact of underground economic growth on the ecological environment is most obvious from the early stage to the middle stage. More importantly, in the initial stage of underground economic growth, the development of the underground economy has a certain impact on environmental pollution; however, with a significant improvement in underground economic benefits, the degree of impact on the ecological environment decreases, and the environmental pressure decreases. In the medium term, the impact gradually tends to be gentle, more capital is invested in environmental governance, and the ecological environment gradually improves. Shandong and Guangdong provinces have a strong economic foundation, and the growth of the underground economy is steadily increasing. The impact on the ecological environment is relatively small, and the impact gradually tends to be smooth by the end of the period. The underground economic growth in Beijing, Shanghai, Jiangsu, Zhejiang, Fujian and other places has a significant impact on the ecological environment. The underground economic growth in these areas is relatively large in scale and slows in growth, and the impact on the ecological environment is small. The impact of underground economic growth on the ecological environment in Hebei, Liaoning, Tianjin and Hainan is relatively stable (Figures 9 and 10).

The central region of China: Overall, the impact of underground economic growth on the ecological environment in central China is more obvious in the middle and later periods of the sample period. The underground economic growth in the central region is lower than that in the eastern developed region, and its impact on the ecological environment is smaller than that in the eastern region. The impact of underground economic growth on the ecological environment in Shanxi and Jiangxi provinces is symmetrically distributed. The ecological environment of Henan negatively responded to the impact of economic growth in the early stage of the sample period. Over time, the impact of underground economic growth on the ecological environment tended to stabilize. At the beginning of the sample period, the impact of underground economic growth on the ecological environment in Anhui and Hubei was slightly lower than that in the middle and later periods, but as time progressed, the impact of underground economic growth on the ecological environment formed a relatively stable trend (Figure 11).

The western region of China: the western region as a whole shows that the impact of underground economic growth on the ecological environment is relatively obvious at the beginning of the sample period. Due to the sufficient resource endowment of the western provinces and cities and the great power of energy exploitation, the impact on the ecological environment is obvious. By the middle of the sample period, with the harmonious development of human-land relations, the improvement of

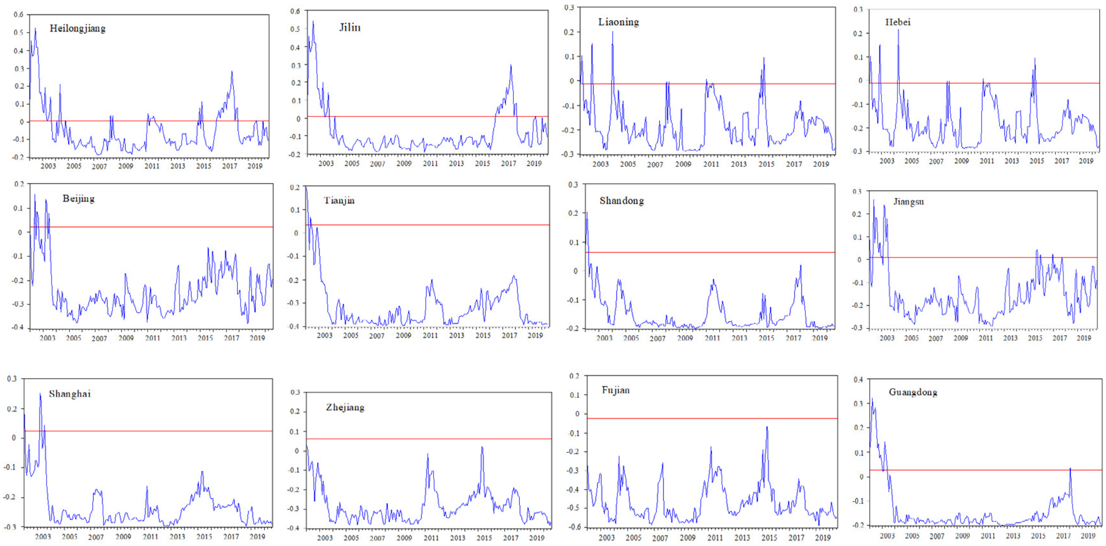

Figure 9. Impulse response diagram of the impact environment of the underground economy in the eastern region.

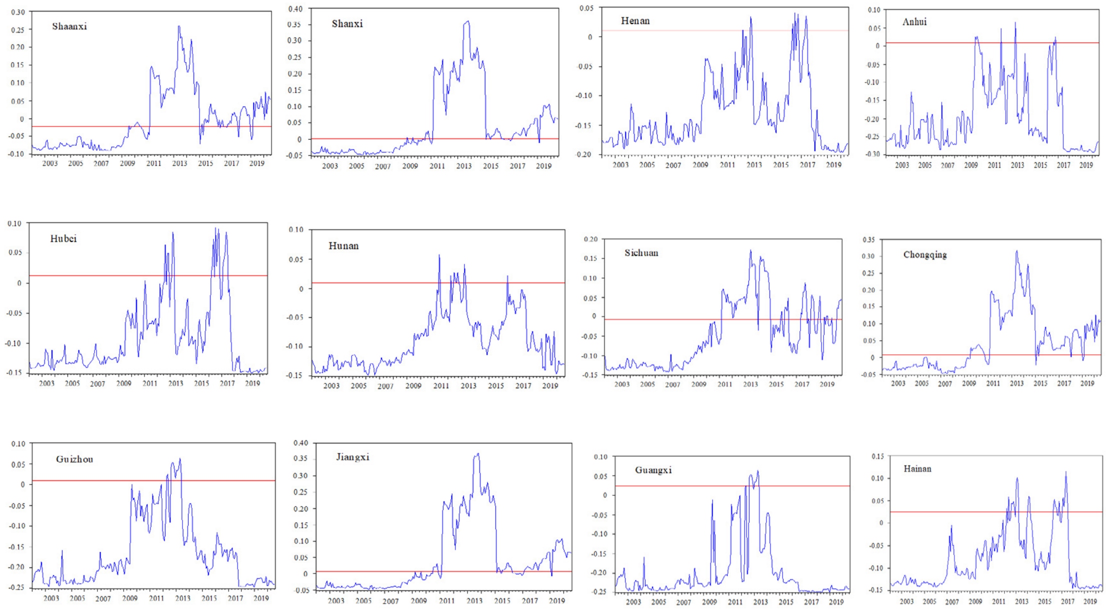

Figure 10. Impulse response diagram of the underground economic impact environment in the central region.

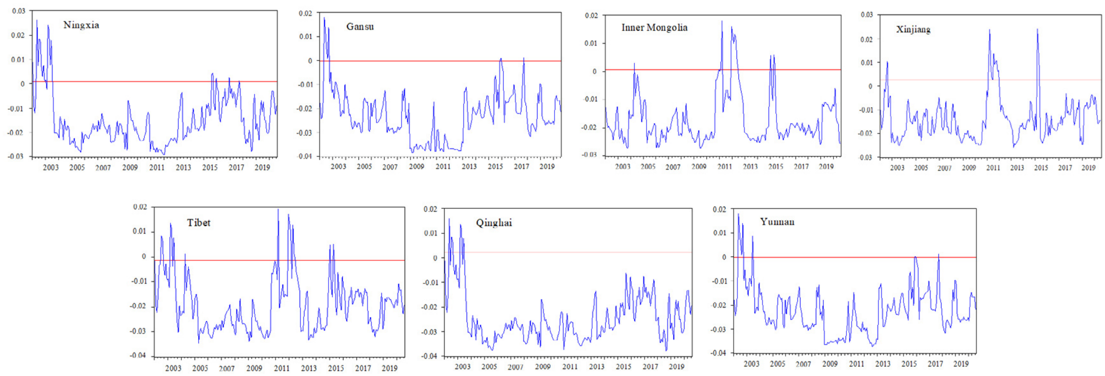

Figure 11. Impulse response diagram of the underground economic impact environment in the western region.

the ecological environment has become an important part of the region's reform. However, the rapid growth of the underground economic level has improved the consumption of energy resources by the formal economy and has had an extreme impact on environmental quality. In general, the impact of underground economy of Gansu and Ningxia on the ecological environment is relatively large in the early stage of sample period. Inner Mongolia and Xinjiang have obvious responses in the medium term of the sample period. Tibet's response is obvious in the middle and late period of the sample period, while Yunan and Qinghai's response is weak in the whole sample period.

Overall, the impact of underground economic growth on the ecological environment in eastern China has had the largest impact, followed by that in the middle and the west of China. On the one hand, judging from the development speed of the underground economy, the underground economy in eastern China has developed faster, followed by that in the central region, while it has been slower in the western region. There are certain differences in the impact on the environment during the development of the underground economy in various provinces and cities. On the other hand, from the perspective of energy resource endowment of the three major regions, the advantages of energy resources in the central and western regions are obvious, but the consumption speed is slower than that in the eastern regions; thus, the impact trend on the ecological environment is also different.

Conclusion

The spatial data analysis method was used to analyze the distribution pattern and evolution trend of the current underground economy and environmental pollution in various provinces of China. The SEM and SLM are further adopted to empirically analyze the impact of the economic development level and scale expansion of the underground economy on environmental pollution. This paper obtains the following conclusions and insights:

- The degree of environmental pollution in China's provinces has significant spatial dependence, showing ladder-like distribution characteristics from being high in the east to low in the west.
- The underground economy shows heterogeneous characteristics in geographic space, with spatial differences between central and peripheral areas and between developed and backward regions.
- Most provinces are located in the left half of the EKC curve, indicating a negative spatial correlation between underground economic scale and degree of environmental pollution.

Declaration of Interest

- The authors have no relevant financial or non-financial interests to disclose.
- The authors have no conflicts of interest to declare that are relevant to the content of this article.
- All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.
- The authors have no financial or proprietary interests in any material discussed in this article.

Availability of Data and Material

The data used to support the findings of this study are available from the corresponding author upon request.

Authors' Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Feng Zhao, Jie Zhang and Dongning Zhang. The first draft of the manuscript was written by Feng Zhao and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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