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Research Article

Dynamic Measurement Analysis of Urban Innovation Ability and Ecological Efficiency in China

Xing Li and Fuzhou Luo

School of Management, Xi'an University of Architecture and Technology, Xi'an 710055, China

Correspondence should be addressed to Xing Li; shinelixing@hotmail.com

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To establish the evaluation index system of urbanization innovation level and ecological efficiency, the entropy method is applied to measure the comprehensive index of urbanization innovation level and ecological efficiency, the VAR model is established, and empirical measurement is used to study the internal relationship and dynamic development between urbanization innovation level and ecological efficiency. The empirical results show the following: (1) The overall development of the innovation level in 30 cities in China is uneven, there is a large gap between the urban innovation level in backwards areas and economically developed areas, and there is a certain coupling effect between the urban innovation level and ecological efficiency. (2) There is a long-term dynamic equilibrium relationship between the urban innovation level and ecological efficiency, which will exert certain pressure on the ecological environment in the process of urbanization. However, the continuous improvement of urbanization will have a positive impact on the improvement of the ecological environment. (3) The improvement of ecological efficiency will also promote the improvement of the urban innovation level. Therefore, this paper puts forwards policy suggestions to promote the harmonious development of urbanization and the ecological environment and provides a reference for realizing the balanced development of urbanization and ecological efficiency in China.

1. Introduction

With the rapid development of China's economy and the continuous improvement of the urbanization level, urban innovation ability plays an important role in promoting the transformation of China's social and economic structure. However, due to the agglomeration effect of the urban industrial structure and large rural population migration, research on urbanization and urban innovation ability has become a hot topic. A number of scholars have studied the impact of urban expansion and industrial agglomeration on the urban ecological environment and ecological efficiency. According to statistics, China's urbanization rate increased from 22% in 1990 to 52.57% in 2012. It exceeded 60% in 2020 and will reach approximately 66% by 2030 [1]. It can be predicted that the level of urbanization will bring certain urban ecological pressure. At the same time, the concept of a sustainable development society promoted by China also requires important changes to the process of urbanization. Therefore, we need to correctly understand the internal relationship between the innovation ability of urbanization and ecological efficiency to achieve the harmonious development of cities and the environment through analysis, judgement, coordination, and planning.

2. Literature Review

The development of the urban economy cannot be separated from urban population growth, the flow of economic factors, the development and utilization of resources, etc. From a sustainable development perspective, the urban ecological environment is an important part of the urban system, and the level of the urban economy should be kept in balance with the ecological system; therefore, many scholars devote themselves to the study of the relationship and development logic between the urban economic level and the urban ecological environment.

First, there are concerns about the impact of urbanization on the ecological environment [2–4]. International scholars of environmental science have shown commitment to studying the relationship between urbanization and the ecological environment. Grossman and Krueger found that the evolution of the relationship between urban economic level and environmental quality presents an inverted "U" shape through econometric theory, that is, the environmental Kuznets curve (EKC curve) [5, 6]. Kharabshen also carried out corresponding mathematical statistical research on the impact of ecological factors such as urbanization and water quality degradation in the Jordan River area [7]. Schiller and Atzmon [8] analysed the impact of the increase in agricultural consumption on the environment during the period of rapid population growth.

Second, the relationship between the urban governance level and the urban environment is studied. For example, Liu et al. [9] selected industrial emissions as a research variable to analyse the environmental Kuznets curve, while Hua and Yind [10] focused on the EKC curve analysis of industrial carbon emissions. Based on the analysis of the relationship between urban air pollution and the regional economy by Tiening and Lina [11], Huang and Fang [12] hold that the relationship between urbanization and the ecological environment conforms to the characteristics of a "double exponential curve." Wen-Long Shang et al. analysed the relationship between urban management level and environment from urban transportation system, and studies big data and traffic path planning by using GIS technology, which shows the importance of information technology in urban management [13–15].

Subsequently, many experts and scholars conducted in-depth research on ecology and resources [16–18], technology and economy [19, 20], and economic consumption [21–23] to obtain regional and representative results [24–29]. Many studies have illustrated a certain correlation between the regional economy and ecological environment [30–32], and in-depth demonstrations and research have been carried out to explore the internal relationship and law governing urbanization level and ecological efficiency [33–36]. Urbanization, urban spatial form, and expansion mode present different modes in different regions [8, 37, 38], and their complexity also differs, so pressure on the urban ecological environment is expected to be substantial [39–42].

The above research focuses on the urban environment and urban economic relations, but China's vast territory and economic development are also facing regional innovation imbalances and other issues. Cities are not just the birthplace and hub of regional innovation, but also the centre of spatial heterogeneity of innovation. Peng Xiao introduced the concept of an innovative city and formulated the evaluation index [43]. Zhang et al. [44] stated that the city is the basic unit for constructing an innovative country; therefore, it is necessary to strengthen the construction at the urban innovation level. Miao and Guo [45] used the entropy method to measure the level of urban innovation and found that it has a positive impact on economic development.

Building an innovative country is the trend of for future urban. With continuous improvements at the economic level, the innovation level of cities also gradually improves as a result of economic support; however, a series of environmental problems accompanies these changes [46–48]. Previous studies have focused on various urban pollution indicators and regional economic indicators, but the relationship of urban innovation to the ecological environment has not been researched in depth. This study combines the evaluation index of the urban innovation level and eco-efficiency index, constructs a multidimensional observation system of the urban innovation level, economic level and eco-environment, attempts to find the internal relationship and dynamic development relationship between the urban innovation level and ecological environment change through econometric demonstration, analyses the contradictions between them in light of development, and provides a reference for the Chinese government for achieving the goal of a sustainable development society.

3. Materials and Methods

3.1. Evaluation System. Thirty provinces (cities) in China are selected as research objects (limited to data availability, excluding Hong Kong, Macau and Taiwan Province) and the sample time range used for the study is from 2006 to 2019. Variables are selected that are operable, easy to understand and frequently used and which are in line with the evaluation of urban innovation ability and ecological efficiency, and they are used to establish an index system. The evaluation of urbanization innovation ability is divided into two categories: input index and output index as the first-class index. The input indicators are specifically divided into capital investment and manpower investment, while the output indicators include three three-level indicators, namely, scientific research output, technological transformation and economic output. Ecological efficiency adopts two primary indices, namely, the input index and output index, and specifically includes three secondary indices, namely, the environmental input index, capital input index and economic output. In addition, the third-level indicators include waste discharge, general industrial waste discharge (10,000 tons), sulfur dioxide discharge (10,000 tons), energy consumption index, regional GDP and other indicators to measure and evaluate. The establishment of the index system is based on the Pressure-State-Response (P-S-R model) jointly promoted by Organization for Economic Co-operation and Development (OCED) and United Nations Environment Programme (UNEP), which is now used globally for studying the conflicts between the needs of cities and the environment. Table 1 shows the evaluation indices and characteristics.

3.2. Entropy Weight TOPSIS Method (Technique for Order Preference by Similarity to an Ideal Solution). The widely used comprehensive evaluation methods include the factor analysis method, analytic hierarchy process, fuzzy comprehensive evaluation method, grey relation method, TOPSIS method and entropy weight method [40]. The TOPSIS method, an effective method for multiobjective decision-making uses simple calculation, small sample size requirements and reasonable results, while the entropy

Table 1: Urban innovation level and ecological efficiency index system.

Evaluation object	Primary indicators	Secondary indicators	Tertiary indicators	Effect
Urbanization innovation ability	Input indicators	Capital input	Internal expenditure of research and experimental development (R&D) funds (10,000 yuan).	Positive (+)
			R&D input intensity	Positive (+)
		Human input	Full-time equivalent of research and experimental development (R&D) personnel (man-years)	Positive (+)
	Output indicators	Scientific research output	Patent acceptance letter	Positive (+)
		Technology transformation	Market technology export area (contract amount) (10,000 yuan)	Positive (+)
		Economic output	Gross regional product	Positive (+)
Ecological efficiency	Input indicators	Environmental input	Wastewater discharge	Negative(-)
			General industrial waste discharge (10,000 tons)	Negative (−)
			Emission of sulfur dioxide (10,000 tons)	Negative (−)
		Capital input	Capital stock	Positive (+)
		Human input	Urban employed persons	Positive (+)
		Resource input	Energy consumption	Negative (−)
	Output indicators	Capital output	Comprehensive utilization rate of solid waste	Positive (+)
		Energy output	Carbon dioxide emission	Negative (−)

weight method determines the weight according to the information reflected by the variation degree of each evaluation index value, eliminating the influence of subjective factors and accurately calculating the weight of each index. This study combines the entropy weight method and the TOPSIS method to accurately measure the development level of "zero-waste cities" in various provinces in China. The calculation process is as follows:

(1) Construct the original matrix and normalize it:

$$X_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} \left(x_{ij} \text{ is a positive indicator}\right),$$
$$X_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})} \left(x_{ij} \text{ is a negative indicator}\right), \tag{1}$$

where X_{ij} is the normalized data of the j-th evaluation index of the i-th province (city) and x_{ij} is the raw data of the j-th evaluation index of the i-th province (city).

(2) Calculate information entropy (e_j):

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^{n} \frac{X_{ij}}{\sum_{i=1}^{n} X_{ij}} \quad \ln\left(\frac{X_{ij}}{\sum_{i=1}^{n} X_{ij}}\right)\left(\frac{1}{\ln n} > 0,\ e_j \geq 0\right), \tag{2}$$

where j is the serial number of the evaluation index; i is the serial number of the province (city); and n is the total number of provinces (cities).

(3) Determine index weight (w_j):

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{m} \left(1 - e_j\right)}, \tag{3}$$

where m m is the total number of evaluation indices.

(4) Calculate the weighted value (y_{ij}) of the j-th evaluation index of the i-th province and obtain the optimal solution (y_j^+) and the worst solution (y_j^-):

$$y_{ij} = w_j \times X_{ij}. \tag{4}$$

(5) The comprehensive score was calculated by the Euclidean distance (C_i):

$$C_i = \frac{\sqrt{\sum_{j=1}^{m} \left(y_{ij} - y_j^-\right)^2}}{\sqrt{\sum_{j=1}^{m} \left(y_{ij} - y_j^+\right)^2} + \sqrt{\sum_{j=1}^{m} \left(y_{ij} - y_j^-\right)^2}} \ (0 \leq C_i \leq 1). \tag{5}$$

The results of the calculation are shown in Table 2.

3.3. Cointegration Test. Since some economic variables observed are dynamic in practice, the relevant data, such as the mean and variance, may also fluctuate, but there may be stable linear relationships among the different economic variables. This stable linear relationship between many factors is called cointegration, and the resulting system of linear equations is called the cointegration equation.

It is important to note that cointegration is only possible when the time series of two variables are of the same order and single integral sequences. The cointegration cannot

Table 2: Index system of urbanization innovation level and ecological efficiency.

Target layer	Indicator layer	Effect	Index weight
Urbanization innovation ability	Internal expenditure of research and experimental development (R&D) funds (10,000 yuan)	Forwards direction	0.168
	R&D input intensity	Forwards direction	0.221
	Full-time equivalent of research and experimental development (R&D) personnel (man-years)	Forwards direction	0.127
	Number of patents accepted	Forwards direction	0.096
	Market technology export area (contract amount) (10,000 yuan)	Forwards direction	0.1436
	Gross regional product	Forwards direction	0.245
Ecological efficiency	Wastewater discharge	Negative direction	0.098
	General industrial waste discharge (10,000 tons)	Negative direction	0.110
	Emission of sulfur dioxide (10,000 tons)	Negative direction	0.086
	Capital stock	Forwards direction	0.116
	Urban employed persons	Forwards direction	0.087
	Energy consumption	Negative direction	0.128
	Comprehensive utilization rate of solid waste	Forwards direction	0.176
	Carbon dioxide emission	Negative direction	0.199

judge all nonstationary sequences. Before judging whether there is a cointegration relationship between two variables, a stationarity test needs to be performed, as follows.

3.3.1. Unit Root Test. The time series can be tested to analyse whether the series of data has stability. If a time series has a stable mean, variance and autocovariance, it can be judged as stable; otherwise, it should be judged as unstable. The nonstationary time series can be considered a stationary series with stable mean, variance and autocovariance after d-order difference, and then the sequence is marked as d-order Integration and I (D). The unit root test is a way to show the nonstationarity of a sequence. We can use the ADF Test (Augment Dickey-Fuller Test) to test whether a variable is stable, and there is no unit root; otherwise, there is a unit root. Therefore, the H0 hypothesis of the ADF test is the existence of a unit root. If the significance test statistic is less than three (10%, 5%, 1%), then there should be (90%, 95%, 99%) confidence to reject the original hypothesis.

3.3.2. Johansen Cointegration Test. When the unit root test is used to determine whether a sequence is a single-integer sequence, the cointegration relationship between the sequences is further determined. At present, the common cointegration test method is the unit root test for the residual of the regression equation. The regression test for the VAR model proposed by Johansen offers another method; this study adopts this method because it fully utilizes the benefits of the cointegration test when there are multivariable equations.

3.3.3. Granger Causality Test. A significant correlation exists between the variables, however, a causal test is required to determine whether it is economically significant. The Granger causality test can determine whether variable B can be explained by variable A when considering the influence of time and whether the explanation degree can be improved; it is calculated that there is a significant relationship between variable A and variable B in the statistical correlation coefficient, which determines that variable B is caused by variable A.

3.3.4. Impulse Response Analysis and Variance Decomposition. The impulse response function describes the impact of an endogenous variable on other endogenous variables in the VAR model. By analysing the contribution of each structural shock to the change in endogenous variables (usually measured by variance), the impulse response function further evaluates the importance of different structural shocks. Therefore, the variance decomposition of the impulse response function gives information about the relative importance of each random disturbance that has an effect on the variables in the VAR model.

3.4. Data Description. In the dynamic measurement analysis of urbanization innovation capability and ecological efficiency, it is necessary to involve urbanization innovation capability indicators and ecological environment indicators. Data from the feasibility study and analysis inform the ecological environment indicators. Among these indicators, carbon emissions do not yet have an established systematic calculation method. Therefore, the calculation method is done mainly in accordance with the 2006 IPCC report [49].

4. Dynamic Analysis of the Relationship between the Urban Innovation Level and Ecological Efficiency

4.1. Data Calculation. According to the characteristics of energy consumption in urban development and the relevant data of the China Statistical Yearbook, 14 kinds of energy sources, including raw coal, coke, gasoline, kerosene, diesel oil and liquefied petroleum gas, are considered. After summing the converted standard coal quantities, the carbon emissions are obtained through conversion on a unified scale, from which the energy consumption data of China from 2008 to 2019 (the data description is as follows: (1) As a result of the impact of novel coronavirus pneumonia in 2020, the data are abrupt. To maintain the stability of data and avoid affecting the dynamic fitting results, the data of 2008–2019 are selected as the basis for calculation. (2) As the public statistics of Tibet are not comprehensive enough, the relevant indicators of Tibet have not been calculated yet) (Table 3), and the national carbon emissions data (Table 4) and the evaluation scores of the urban innovation level obtained after calculation are shown in Table 5.

Figure 1 shows that among the 30 provinces and cities in China, Beijing, Jiangsu and Guangdong have a higher level of urban innovation, and their evaluation scores are higher than 50 points, belonging to the top echelon. Second, Tianjin, Shanghai, Zhejiang, Shandong, and Chongqing belong to the second echelon, with scores ranging from 30 to 50. Other provinces and cities scored less than 30 points, belonging to the third echelon. The difference between the highest score (Jiangsu: 54.36) and the lowest score (Qinghai: 17.99) was 36.37 points, indicating that the overall development of the urban innovation level is unbalanced, and there is a large gap between the urban innovation level in backwards areas and economically developed areas, which needs to be paid enough attention.

The score of ecological efficiency [50, 51] calculated by the entropy weight TOPSIS method is shown in Table 6.

According to the above data, the average distribution of ecological efficiency of 30 provinces and cities in China from 2008 to 2019 is shown in Figure 2.

Figure 2 shows that the Beijing region has the highest level of ecological efficiency in China. This is because, at the microlevel, effective environmental management mechanisms were implemented in 2008, leading to changes in the urban ecological situation, and Beijing has maintained a high level of ecological efficiency since then, with carbon emissions declining each year. Therefore, we can focus on the relevant management methods and measures in this area, propagate them to similar types of cities and promote the ecological efficiency of the whole country. The ecological efficiency of Shanxi and Guizhou Provinces is low, which is mainly due to the acceleration of urbanization in these two provinces and cities since 2008, resulting in a large amount of carbon emissions in urban infrastructure construction. Although the level of urban innovation is increasing year by year, the rate of increase is slower than that of carbon emissions. Therefore, in future urban management, we should pay attention to adjusting policies to accelerate the urbanization process and at the same time realize a recyclable society and build a green economy. Ningxia and Xinjiang are the last echelon members of China's ecological efficiency, mainly because their industrial level is still low and possesses many industrial characteristics of high energy consumption and high emissions, and the overall economic level in China is low as well. Therefore, to strengthen the ecological efficiency of these two provinces and cities, we should consider improving the production level, promoting industrial transformation and increasing economic income.

To further analyse the relationship between the urban innovation level and ecological efficiency, Figure 3 can be obtained by comparing the two evaluation scores:

By comparing the average value of the urban innovation level with the average value of ecological efficiency in 30 provinces and cities in China, it can be found that there is a certain coupling effect, and the overall urban innovation level and ecological efficiency show obvious fitting. The two indicators are positively correlated to a certain extent; that is, areas with high urban innovation levels have higher ecological efficiency. However, there are some differences between the innovation level and the fluctuation of ecological efficiency in individual cities. Among them, the urban innovation level in Shanghai, Jiangsu, Guangdong, Guizhou, Ningxia and Xinjiang is higher than the ecological efficiency, which indicates that the improvement of the urban innovation level in the above six provinces and cities has not played a full driving role in promoting the ecological efficiency of the region. Among them, the trend in Jiangsu Province is the most obvious, and the coupling effect between the urban innovation level and ecological efficiency is not fully exerted.

To measure and analyse the relationship between the urbanization innovation level and ecological efficiency in detail, a vector autoregression model (VAR) can be established for dynamic econometric analysis. First, the unit root test is used to determine whether the urbanization innovation level and ecological efficiency are stationary series. Then, a cointegration test is used to analyse whether there is a stable relationship between the urbanization innovation level and ecological efficiency. Second, Granger causality analysis is used to determine the causal relationship between the two comprehensive indices. Finally, impulse response and variance decomposition are used to analyse the impact of the urbanization innovation level on ecological efficiency.

Table 3: Energy consumption data of 30 provinces and cities in China (standard coal: 10,000 tons).

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Beijing	6327	6570	6954	6995	7178	6724	6831	6803	6917	7088	7270	7360
Tianjin	5364	5874	6818	7598	8208	7882	8145	8319	8078	7832	7973	8241
Hebei	24322	25419	27531	29498	30250	29664	29320	31037	31458	32083	32185	32545
Shanxi	15675	15576	16808	18315	19336	19761	19863	19029	18974	19581	20199	20859
Inner Mongolia	14100	15344	16820	18737	19786	17681	18309	18784	19310	19763	23068	25346
Liaoning	17801	19112	20947	22712	23526	21721	21803	21362	20847	21365	22321	23749
Jilin	7221	7698	8297	9103	9443	8645	8560	7020	6886	6881	7000	7132
Heilongjiang	9979	10467	11234	12119	12758	11853	11955	11104	11070	11258	11436	11614
Shanghai	10207	10367	11201	11270	11362	11346	11085	10931	11242	11382	11454	11696
Jiangsu	22232	23709	25774	27589	28850	29205	29863	30374	31210	31602	31635	32526
Zhejiang	15107	15567	16865	17827	18076	18640	18826	19610	20276	21030	21675	22393
Anhui	8325	8896	9707	10570	11358	11696	12011	12301	12663	13019	13295	13870
Fujian	8254	8916	9809	10653	11185	11190	12110	11863	12036	12555	13131	13718
Jiangxi	5383	5813	6355	6928	7233	7583	8055	8423	8730	8972	9286	9665
Shandong	30570	32420	34808	37132	38899	35358	36511	39332	40138	40098	40581	41390
Henan	18976	19751	21438	23062	23647	21909	22890	22343	22323	22162	22659	22300
Hubei	12845	13708	15138	16579	17675	15703	16320	15477	15897	16180	16682	17316
Hunan	12355	13331	14880	16161	16744	14919	15317	14514	14845	15200	15544	16001
Guangdong	23476	24654	26908	28480	29144	28480	29593	30117	31211	32309	33330	34142
Guangxi	6497	7075	7919	8591	9155	9100	9515	9806	10110	10456	10823	11270
Hainan	1135	1233	1359	1601	1688	1720	1820	1916	1984	2080	2170	2264
Chongqing	6472	7030	7856	8792	9278	8049	8593	7747	7982	8279	8557	8889
Sichuan	15145	16322	17892	19696	20575	19212	19879	18306	18756	19229	19916	20791
Guizhou	7084	7566	8175	9068	9878	9299	9709	9344	9606	9846	10036	10423
Yunnan	7511	8032	8674	9540	10434	10072	10455	10425	10726	11164	11590	12158
Shaanxi	7417	8044	8882	9761	10626	10610	11222	11746	12146	12549	12900	13478
Gansu	5346	5482	5923	6496	7007	7287	7521	7489	7300	7504	7823	7818
Qinghai	2279	2348	2568	3189	3524	3768	3992	4125	4101	4193	4364	4235
Ningxia	3229	3388	3681	4316	4562	4781	4946	5438	5591	6461	7100	7648
Xinjiang	7069	7526	8290	9927	11831	13632	14926	15666	16302	17386	17694	18490

4.2. Unit Root Test. According to the time series, whether the series of data is stable or not can be tested. If a time series has a stable mean, variance and autocovariance, it can be judged as stable; otherwise, it should be judged as unstable. Nonstationary time series can have a stable mean, variance and autocovariance after a D-fold difference and become stationary series. At this time, the series is marked as D-order Integration and $I(d)$. Unit is a way to express the nonstationarity of a sequence, and the ADF test can be used to test whether the variables are stable or not. The ADF test judges whether a sequence has a unit root; if the sequence is stable, there is no unit root. Otherwise, there will be a unit root. Therefore, the H0 hypothesis of the ADF test is that there is a unit root. If the statistics of the significance test are less than three confidence levels (10%, 5%, 1%), the original hypothesis should be rejected with the assurance of (90%, 95%, 99%). First, the unit root test is used to determine whether the urbanization innovation level and ecological efficiency are stationary series, then the series is tested for stationarity, and the augmented Dicket-Fuller test (ADF) is used for testing [52]. Eviews software is used for calculation, and the order calculation results after automatic selection according to SIC criteria are shown in the following Table 7:

The test results of the above unit root show that in the mean value of the urban innovation level and ecological efficiency, the sequence of the urban innovation level is stable, and the sequence of ecological efficiency is unstable at significance levels of 1%, 5%, and 10%. Therefore, the stability test of the first-order difference sequence is carried out. In the first-order difference series test, the urban innovation level series and ecological efficiency series are stable, which is a first-order single integration series and meets the prerequisite of the cointegration test.

4.3. Johansen Cointegration Test. The Johansen cointegration test is used to test whether there is a long-term stable relationship between the urban innovation level and ecological efficiency, and Eviews software is used for calculation. The test results are shown in Table 8.

According to the above calculation results, at a significance level of 5%, there is a cointegration relationship between the urbanization innovation level and ecological efficiency. This indicates that there is a long-term dynamic equilibrium relationship between the urbanization innovation level and ecological efficiency.

4.4. Granger Causality Test. The Johansen cointegration test demonstrates that there is a long-term dynamic equilibrium relationship between the urbanization innovation level and ecological efficiency, and then the Granger causality test can be carried out on these two variables. The Eviews software calculation results are shown in Table 9.

Table 4: Carbon emission data of 30 provinces and cities in China (unit: 10,000 tons).

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Beijing	12136.36	12308.09	12390.69	11480.12	11327.24	9991.70	10122.18	9107.55	8164.02	7915.20	7776.44	7664.45
Tianjin	13710.50	14735.76	17968.38	19699.88	19718.33	20229.73	19351.18	18722.68	17414.40	17084.55	17376.41	17402.23
Hebei	70212.34	74799.00	80386.28	90869.82	91964.11	91970.00	87291.05	90909.79	90900.05	90044.71	91653.49	91445.99
Shanxi	63481.47	62757.23	66859.08	73590.23	76655.02	79381.74	81200.89	92819.29	91873.98	96797.42	103383.35	108664.42
Inner Mongolia	67185.47	71163.97	78973.24	94575.33	98569.48	94040.32	95561.74	95355.77	97835.22	101886.88	117364.61	132622.73
Liaoning	43833.27	45949.39	49978.18	54104.00	55080.81	53132.44	53424.72	51220.41	50638.68	52108.59	52962.70	55095.02
Jilin	24200.80	25836.00	28193.19	31771.83	31527.41	30136.65	29985.33	24637.53	24677.36	23971.23	24609.80	24982.03
Heilongjiang	30305.15	30636.43	33754.33	35956.54	37983.84	36856.73	36189.32	35440.49	34903.27	35391.61	35986.60	38633.15
Shanghai	25267.80	26185.23	28726.95	29221.91	28328.21	29551.82	28450.64	28516.08	29446.75	29138.96	29678.32	29731.93
Jiangsu	56251.46	58464.23	65288.64	75477.77	76204.08	76825.41	75518.75	77108.00	79013.14	78750.30	75828.10	79425.65
Zhejiang	32534.77	33460.17	35234.83	37244.10	36241.45	36294.18	36387.86	36339.97	35924.79	37314.96	36703.58	35230.27
Anhui	26421.33	30185.25	33149.64	34726.99	36771.74	38803.37	42442.16	43043.50	43106.90	43705.57	45405.29	47085.65
Fujian	17513.79	19490.42	20098.65	23567.62	23177.28	22556.56	22824.17	21755.26	20729.05	22034.75	24952.80	25694.46
Jiangxi	26875.51	28973.54	32679.60	35246.79	36394.72	39122.53	42761.65	45718.72	50271.70	54621.31	60028.87	62247.52
Shandong	81854.62	84333.43	93357.19	98475.80	103274.40	97959.39	102477.94	111745.02	113300.66	112793.12	107151.67	108367.99
Henan	54802.24	55884.14	60467.57	66388.12	61074.77	60823.30	62206.55	59238.08	58010.36	57206.62	56683.84	52687.31
Hubei	28204.35	30017.42	34382.51	39823.67	40484.82	34102.64	33549.08	31874.22	31697.47	31462.65	33166.08	34941.76
Hunan	33446.57	36916.58	40767.86	43399.19	42686.29	42092.06	41665.12	41650.76	42862.30	43849.81	46072.17	45098.65
Guangdong	38347.30	39082.35	44178.29	50521.41	50351.20	48430.00	48711.57	48330.57	49234.33	52097.73	52063.74	51994.07
Guangxi	14726.48	16139.97	18557.41	20648.41	21526.55	21185.18	21347.60	20374.10	21371.79	21573.90	22821.33	24285.39
Hainan	1737.53	1950.57	2242.86	2669.54	2918.76	3006.81	3003.73	3045.81	2921.12	3140.99	3305.21	3250.39
Chongqing	13164.48	14241.22	15698.70	17812.72	17370.32	14791.60	17374.68	15608.93	15766.25	16269.65	15563.22	16495.12
Sichuan	26810.98	30099.33	30076.89	30730.17	32261.41	33281.91	32580.87	26012.64	25631.89	24550.17	24184.35	25253.07
Guizhou	20937.31	22954.82	23135.90	25578.54	27988.32	28979.72	27927.15	27889.34	29154.66	30524.77	29757.14	30541.05
Yunnan	26121.50	28242.42	30233.51	30970.81	32440.44	31946.25	29410.51	26780.87	25686.53	25794.14	26342.10	26944.75
Shaanxi	24503.58	26658.84	30983.87	35276.67	40027.49	42787.60	44806.13	44355.21	45715.13	47313.61	46111.11	50192.26
Gansu	11536.22	11110.30	13086.95	15105.69	15851.67	16379.18	16808.48	16184.86	15611.92	15467.31	16350.24	16514.40
Qinghai	3842.33	3962.40	3810.62	4061.16	5878.36	6526.43	6011.85	5601.83	6786.45	6487.36	5924.35	5825.89
Ningxia	15087.25	16242.40	19149.06	24528.58	24766.02	25734.65	26648.44	26562.25	25922.77	30887.41	33786.39	35977.90
Xinjiang	13905.69	17302.24	19088.98	22976.09	27924.00	32857.15	36466.05	39364.67	41730.72	44892.59	47395.40	51147.42

Table 5: Evaluation scores of the urban innovation level of 30 provinces and cities in China.

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Beijing	52.20	53.19	47.92	50.31	46.11	50.73	50.11	50.45	52.61	52.56	54.30	53.22
Tianjin	37.24	37.44	35.89	38.29	34.09	36.13	36.61	36.49	34.15	33.71	32.14	28.83
Hebei	22.54	25.20	23.26	24.44	26.67	23.02	20.88	21.l4	20.89	24.23	21.97	21.86
Shanxi	23.01	24.69	23.83	23.16	20.68	21.68	21.20	20.61	18.17	17.93	19.14	19.82
Inner Mongolia	20.53	21.87	20.46	23.49	26.18	23.73	19.23	21.44	18.22	18.32	19.11	18.14
Liaoning	32.11	33.02	28.93	31.77	31.28	28.85	27.19	26.88	24.46	22.26	22.44	22.73
Jilin	26.61	24.37	22.20	27.14	20.76	22.64	20.69	18.95	18.53	19.00	20.48	18.80
Heilongjiang	25.28	27.67	22.84	24.05	24.61	23.55	21.22	20.65	21.16	19.51	19.19	18.53
Shanghai	52.99	52.44	46.23	49.38	42.28	47.18	46.59	45.62	46.04	44.81	46.00	45.63
Jiangsu	48.81	55.63	52.27	55.49	53.84	57.58	58.86	58.01	57.20	53.30	51.73	49.58
Zhejiang	41.09	44.61	41.23	42.83	38.48	42.40	41.46	42.05	37.94	37.66	38.88	38.80
Anhui	28.51	31.92	28.56	27.81	30.08	29.75	30.47	29.86	32.02	28.36	28.72	28.70
Fujian	28.16	29.86	24.16	28.62	26.48	29.33	28.80	29.25	27.20	25.77	26.30	26.56
Jiangxi	24.48	25.82	22.07	24.52	24.32	23.53	22.86	23.34	21.85	22.04	21.61	23.31
Shandong	37.96	40.41	37.34	39.04	36.71	37.73	37.93	37.49	36.29	33.77	33.64	33.12
Henan	26.80	28.40	25.96	27.05	25.26	26.21	24.33	25.90	26.44	20.50	24.91	25.07
Hubei	29.60	32.76	30.61	29.35	28.35	28.71	28.82	28.59	29.07	29.35	29.45	29.21
Hunan	27.67	28.94	29.79	29.81	28.45	28.25	28.59	29.01	27.77	26.63	26.59	26.82
Guangdong	52.65	53.65	51.89	54.88	49.38	53.00	52.44	52.71	53.62	55.24	59.55	59.49
Guangxi	20.87	22.70	22.56	23.41	22.67	23.06	22.30	23.62	22.81	21.19	21.87	21.17
Hainan	23.40	21.31	21.95	21.46	23.30	24.10	26.79	28.03	25.68	22.49	22.79	22.90
Chongqing	27.44	29.53	29.85	30.77	28.08	33.88	32.90	32.99	32.04	30.05	30.30	30.87
Sichuan	29.10	33.61	29.95	31.07	28.35	27.16	26.98	26.39	29.07	27.52	27.04	28.03
Guizhou	21.13	23.31	19.00	22.62	20.77	22.60	20.41	21.22	25.64	22.19	22.27	23.60
Yunnan	21.69	24.32	20.74	21.78	19.37	21.32	21.13	20.30	19.72	20.43	21.48	21.11
Shaanxi	28.21	29.12	27.79	29.80	27.48	27.68	26.86	27.14	29.29	26.05	26.49	27.34
Gansu	19.21	20.93	19.83	22.41	19.70	22.20	23.58	21.68	22.06	20.82	20.05	20.10
Qinghai	18.05	18.99	16.30	18.41	17.62	17.65	16.19	17.71	15.78	18.13	20.97	20.11
Ningxia	18.12	20.16	20.89	19.72	16.80	20.32	17.64	18.52	20.04	20.68	19.45	20.94
Xinjiang	19.17	22.93	20.38	20.81	20.32	20.39	18.49	18.04	19.86	20.04	19.93	18.19

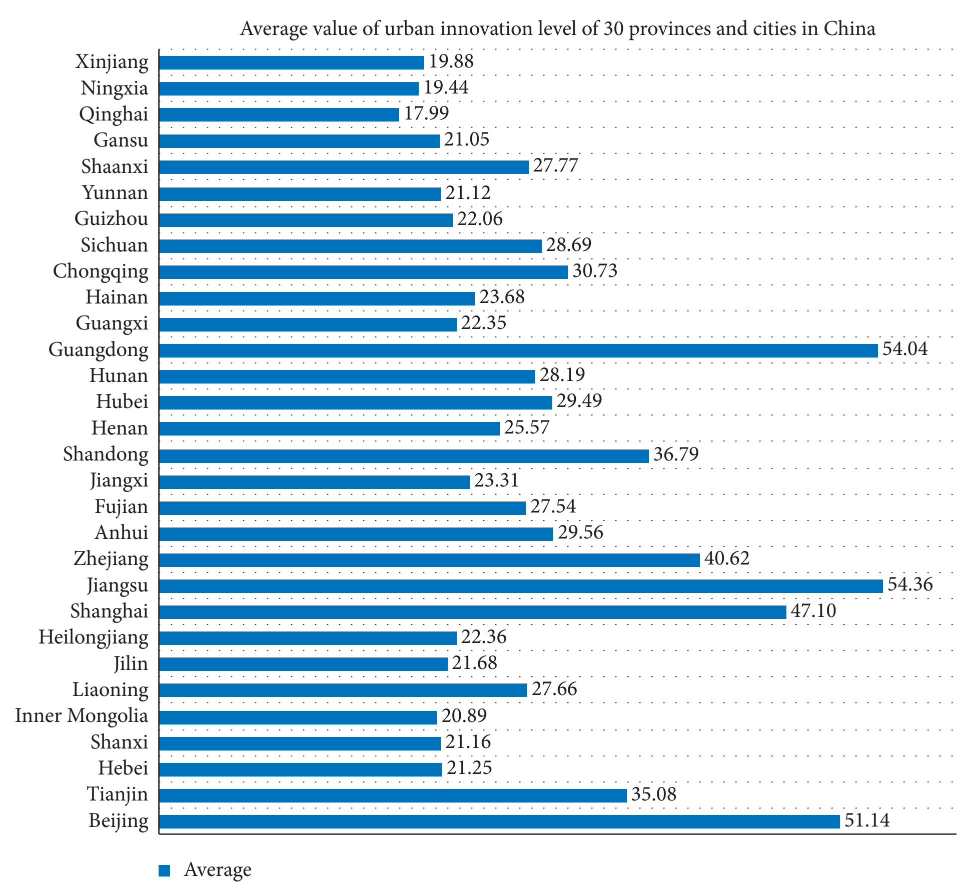

Figure 1: Average value of the urban innovation level of 30 provinces and cities in China (2008–2019).

Table 6: Ecological efficiency scores of 30 provinces and cities in China.

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Beijing	0.916	0.920	0.899	1.000	0.926	1.000	0.930	0.928	0.949	0.932	0.937	1.000
Tianjin	0.763	0.744	0.714	0.685	0.672	0.665	0.672	0.667	0.686	0.698	0.690	0.529
Hebei	0.650	0.622	0.625	0.621	0.590	0.566	0.554	0.524	0.525	0.582	0.550	0.499
Shanxi	0.516	0.458	0.449	0.454	0.404	0.333	0.305	0.269	0.261	0.308	0.338	0.278
Inner Mongolia	0.577	0.579	0.573	0.569	0.549	0.509	0.493	0.456	0.429	0.355	0.363	0.307
Liaoning	0.652	0.635	0.642	0.635	0.627	0.609	0.607	0.614	0.515	0.544	0.548	0.509
Jilin	0.617	0.595	0.596	0.601	0.602	0.579	0.578	0.615	0.610	0.611	0.592	0.442
Heilongjiang	0.627	0.555	0.544	0.551	0.520	0.507	0.506	0.491	0.481	0.478	0.468	0.362
Shanghai	0.838	0.818	0.812	0.769	0.750	0.727	0.733	0.727	0.735	0.728	0.725	0.744
Jiangsu	1.000	0.964	0.945	1.000	0.884	0.707	0.703	0.692	0.694	0.702	0.707	0.714
Zhejiang	0.856	0.819	0.820	0.817	0.797	0.781	0.761	0.746	0.752	0.746	0.756	0.782
Anhui	0.701	0.663	0.653	0.651	0.620	0.569	0.540	0.512	0.512	0.523	0.484	0.551
Fujian	0.802	0.760	0.751	0.715	0.691	0.676	0.659	0.650	0.653	0.649	0.631	0.678
Jiangxi	0.660	0.642	0.634	0.629	0.596	0.560	0.526	0.484	0.466	0.465	0.430	0.430
Shandong	0.739	0.713	0.697	0.683	0.663	0.653	0.640	0.611	0.609	0.608	0.617	0.571
Henan	0.691	0.643	0.627	0.593	0.583	0.551	0.522	0.512	0.513	0.535	0.551	0.599
Hubei	0.697	0.672	0.654	0.622	0.607	0.625	0.618	0.625	0.628	0.638	0.636	0.652
Hunan	0.688	0.659	0.639	0.633	0.619	0.614	0.609	0.606	0.602	0.600	0.582	0.569
Guangdong	1.000	0.972	0.926	0.887	0.862	0.802	0.779	0.757	0.759	0.757	0.750	0.757
Guangxi	0.752	0.696	0.681	0.674	0.650	0.633	0.624	0.622	0.614	0.630	0.581	0.545
Hainan	0.851	0.797	0.770	0.741	0.708	0.678	0.666	0.647	0.648	0.642	0.642	0.650
Chongqing	0.656	0.669	0.635	0.590	0.572	0.596	0.536	0.566	0.564	0.550	0.550	0.590
Sichuan	0.715	0.674	0.677	0.675	0.656	0.603	0.603	0.633	0.633	0.642	0.645	0.656
Guizhou	0.466	0.434	0.398	0.359	0.315	0.281	0.288	0.292	0.280	0.288	0.296	0.298
Yunnan	0.575	0.502	0.452	0.445	0.394	0.361	0.375	0.372	0.365	0.367	0.345	0.505
Shaanxi	0.622	0.600	0.585	0.573	0.539	0.485	0.454	0.396	0.379	0.398	0.428	0.401
Gansu	0.578	0.534	0.513	0.484	0.439	0.336	0.300	0.225	0.213	0.241	0.262	0.241
Qinghai	0.509	0.497	0.512	0.492	0.419	0.375	0.382	0.368	0.327	0.299	0.319	0.271
Ningxia	0.356	0.379	0.393	0.403	0.350	0.300	0.271	0.242	0.261	0.246	0.262	0.206
Xinjiang	0.558	0.448	0.475	0.440	0.387	0.314	0.278	0.189	0.120	0.112	0.204	0.202

According to the Granger causality test, EE is not the Granger cause of UIL, and UIL is not the Granger cause of EE, which shows that there is no one-way coercion between the urban innovation level and ecological efficiency. However, EE and UIL are Granger causalities after the first-order difference and show that the two factors influence each other in the view of incremental economics, the result have been shown in Figure 4.

4.5. Impulse Response Analysis. By using Eviews software, the impulse response analysis of the urban innovation level and ecological efficiency is carried out for 10 periods, and the image shown in Figure 5 is obtained. The solid line indicates the impulse response coefficient, and the dashed line indicates the deviation zone of plus or minus two standard deviations. It can be seen from the figure that the urban innovation level (UIL) will have a negative direction impact on ecological efficiency in the first four stages, which means that the ecological efficiency will decline while the urbanization innovation level is improved. However, after reaching the valley value in the fourth period, it slowly rises before the seventh period, indicating that there is a forwards direction impact in this section, which means that the level of urbanization innovation will promote the improvement of ecological efficiency, and then the two enter a balanced and stable state. However, the impulse effect of ecological efficiency on the level of urbanization innovation is complicated in 10 periods of observation. First, it presents the forwards direction effect before the second period, which means that the improvement of ecological efficiency can boost the level of urban innovation. After that, it suddenly declined from the second to the third period and slowly rose from the third period until it reached a balanced and stable state.

4.6. Variance Decomposition. On the basis of impulse response analysis, the function of variance decomposition further reflects the contribution rate of self-shocks and shocks of other variables to understand the relative importance of shocks of various variables to endogenous variables in the Model [53, 54]. The variance decomposition results are shown in Table 10.

From the data of variance decomposition, it can be seen that the ecological efficiency is mainly affected by itself. The first period is completely immune to other variables and then becomes stable in the probability range of more than 95% from the second phase to the tenth phase, and the impact of the urban innovation level is small. In the second phase, there is a gradual impact on EE, but the degree of impact is not high and remains stable within the level of 5% probability during 10 issues. Relatively speaking, the level of urban innovation is mainly affected by ecological efficiency,

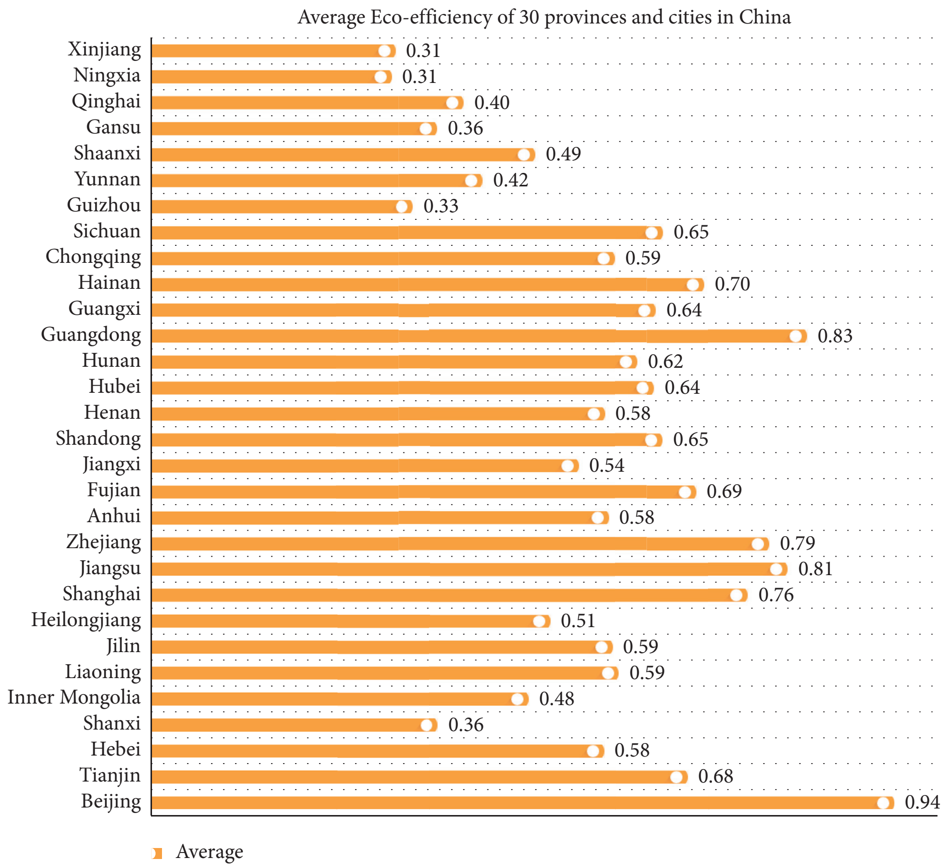

Figure 2: Average eco-efficiency of 30 provinces and cities in China (2008–2019).

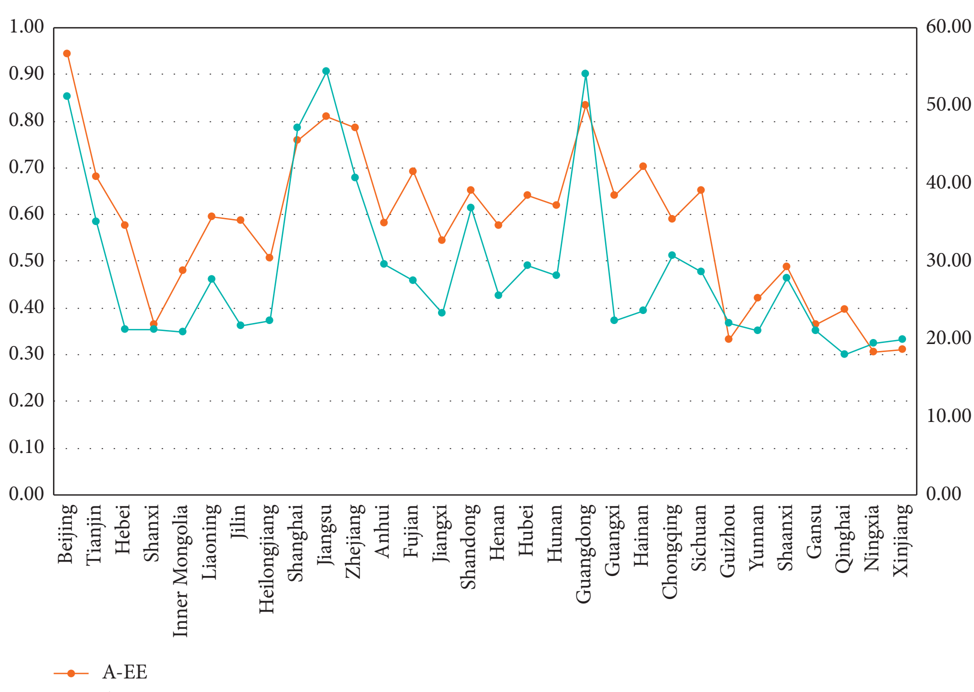

Figure 3: Comparison of the urban innovation level and ecological efficiency average in 30 provinces and cities of China ((1) Urban innovation water average (A-UIL): average value of urban innovation level of 30 provinces and cities in China. (2) average ecological efficiency (A-EE): average eco-efficiency of 30 provinces and cities in China).

Table 7: ADF test results of the urban innovation level and eco-efficiency.

Variable	(C, T, L)	ADF test statistic	T-statistic (1%)	T-statistic (5%)	T-statistic (10%)	Prob.*	Conclusion
A-UIL	(C, T, 0)	−3.9561	−3.6793	−2.9678	-2.6230	0.0051	Stable
A-EE	(0, 0, 0)	−1.6465	−3.6892	−2.9719	-2.6251	0.4464	Unstable
ΔA-UIL	(C, T, 0)	−6.4652	−3.6892	−2.9719	-2.6251	0.0000	Stable
ΔA-EE	(0, 0, 0)	−7.5123	−3.6893	−2.9719	-2.6251	0.0000	Stable

Table 8: Johansen cointegration test results.

Hypothesis	Eigenvalue	Trace test			Maximum eigenvalue		
		Trace statistic	0.05 critical value	Prob.**	Max-eigen statistic	0.05 critical value	Prob.**
None*	0.4854	20.10813	15.4947	0.0094	18.6047	14.2646	0.0097
At most 1	0.0523	1.5034	3.8415	0.2201	1.5034	3.8415	0.2201

*means to reject the original hypothesis at the significance level of 5%.

Table 9: Granger causality test results.

Null hypothesis	Obs	*F*-statistic	*P* value		Conclusion
EE does not Granger cause UIL	28	1.13922	0.3375	Accept	EE does not Granger cause UIL
UIL does not Granger cause EE	28	1.29900	0.2921	Accept	UIL does not Granger cause EE
ΔEE does not Granger cause ΔUIL	27	18.3203	0.0003	Reject	ΔEE does Granger cause ΔUIL
ΔUIL does not Granger cause ΔEE	27	8.71903	0.0069	Reject	ΔUIL does Granger cause ΔEE

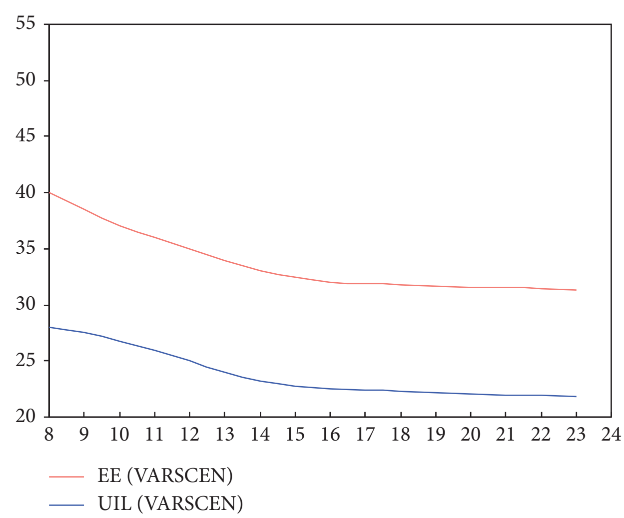

Figure 4: Granger causality test of urban innovation level and ecological efficiency based on first-order difference.

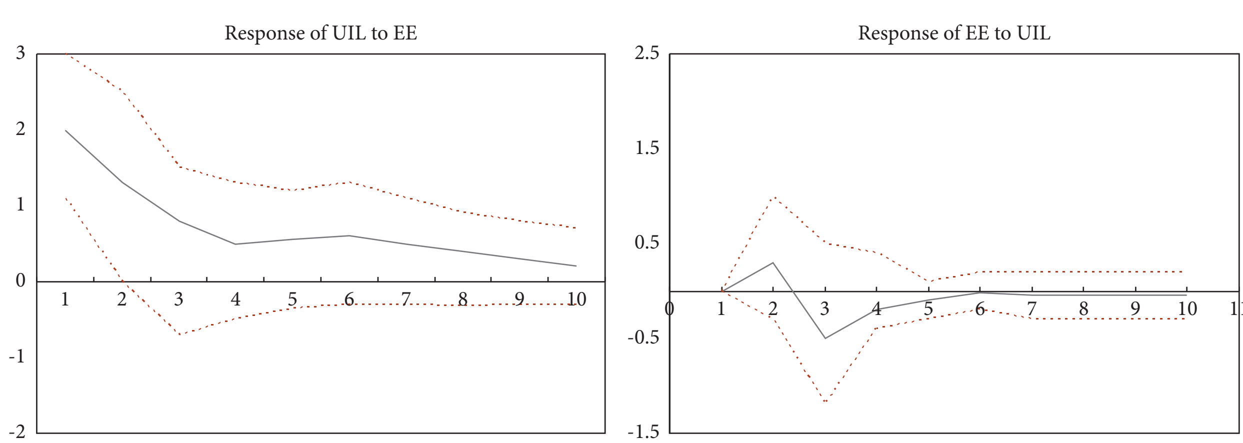

Figure 5: Impulse response of urban innovation level and ecological efficiency.

Table 10: Variance decomposition results.

Issue no.	EE-variance decomposition results			UIL-variance decomposition results		
	S.E.	EE (%)	UIL (%)	S.E.	EE (%)	UIL (%)
1	0.1957	100	0.0000	0.2476	61.5253	38.4747
2	0.2273	98.0853	1.9147	0.2831	68.7240	31.2760
3	0.2507	96.6027	3.3973	0.2919	67.1339	32.8661
4	0.2580	96.1475	3.8525	0.2952	66.2967	33.7033
5	0.2655	96.0973	3.9027	0.2979	66.8944	33.1056
6	0.2704	96.2252	3.7748	0.3010	67.5277	32.4723
7	0.2742	96.2750	3.7250	0.3027	67.8886	32.1114
8	0.2764	96.2790	3.7210	0.3037	68.0249	31.9751
9	0.2780	96.2753	3.7247	0.3042	68.1270	31.8730
10	0.2791	96.2838	3.7162	0.3047	68.2212	31.7788

with probability intervals of more than 65%, and the contribution rate of self-impact is approximately 30%. It can be seen that ecological efficiency has an important explanatory ability for the level of urban innovation, while the level of urban innovation has less explanatory ability for the impact change of ecological efficiency.

5. Conclusions

By measuring the changes in the urbanization innovation level and ecological efficiency level in 30 provinces and cities in China and carrying out dynamic econometric analysis on the relationship between the two variables, the following conclusions are drawn:

(1) The overall development of the urban innovation level of 30 provinces and cities in China from 2008 to 2019 is uneven, and there is a large gap between the urban innovation level of backwards areas and economically developed areas. At the same time, by comparing the average ecological efficiency of the same region in this time interval, it can be found that there is a certain coupling effect between the urban innovation level and ecological efficiency. The two indicators are positively correlated to a certain extent; that is, areas with high urban innovation levels have higher ecological efficiency. However, there are some differences between the innovation level and the fluctuation of ecological efficiency in some cities, and the urban innovation level does not play a full driving role in the ecological efficiency of the region.

(2) Through dynamic econometric analysis, it is found that there is a long-term dynamic equilibrium relationship between the two variables of urban innovation level and ecological efficiency, which verifies the coupling effect of the two variables and shows that the improvement of urban innovation level has a fluctuating impact on the improvement of ecological efficiency. The improvement of the urban innovation level in the early stage will have a negative impact on ecological efficiency, which indicates that the process of urbanization will exert certain pressure on the ecological environment. However, the continuous improvement of urbanization will have a forwards direction impact on the improvement of the ecological environment.

(3) The improvement of ecological efficiency will also promote the improvement of the urban innovation level. In the long run, the contribution of ecological efficiency to the urban innovation level is significant, which means that the evaluation of ecological indicators should not be ignored in the evaluation of the urban innovation level.

In summary, there is a close relationship between the urban innovation level and ecological efficiency, and it is an important indicator that cannot be ignored in the process of urbanization in China. By discovering the relationship between the urban innovation level and ecological efficiency, the following suggestions can be provided for the harmonious development of urban innovation and the ecological environment in the future:

(1) Strengthen policies and legislation to promote the construction of ecological civilization. We should firmly establish the idea that Jinshan and Yinshan are green mountains and green hills, strengthen the punishment for environmental damage by constantly improving the laws and regulations of environmental protection, establish a comprehensive evaluation index system of urbanization level and ecological environment, pay close attention to the development of index reform, dynamically adjust relevant measures, and continuously promote the coordinated development of urban innovation and ecological civilization construction.

(2) Promote industrial transformation and change the energy structure. On the path of China's new urbanization, we will promote the optimization and transformation of traditional industries with large energy consumption and emissions, transform the industrial structure of cities, increase the proportion of tertiary industry, promote the optimization of the energy structure and improve the utilization rate of resources. This improves the relationship between urban innovation, urbanization level, ecological civilization, environmental protection and efficient utilization of resources and forms a forwards direction effect.

(3) Promote regional integration. China has a vast territory and uneven urbanization level. Therefore, the regional economy can be constructed by regional integration, planning docking, policy coordination, industrial cooperation and other methods to promote the benign and high-level development of the regional economy, enhance the radiation-driven capacity of the central cities, and develop the agglomeration areas from point to point, thus contributing to the realization of China's comprehensive goal of new urbanization and resource-saving society.

To achieve sustainable social development, development of the urban economy should maintain a close relationship with the ecological environment, and the ecological environment should maintain dynamic equilibrium with the urban economy; therefore, in the future, it is necessary to carry out research exploring the endogenous problems between economic development and the ecological environment to improve the level of urban governance through urban innovation to reduce the destruction of the urban ecological environment.

Data Availability

The datasets generated or analyzed during this study are available in the China Statistical Yearbook (http://www.stats.gov.cn/english/).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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