No. 1705 [EN]

IMI Working Paper

Urbanization, Economic Development and Environmental Change

Li Shushu and Ma Yong

INTERNATIONAL MONETARY INSTITUTE

For further information, please visit
http://www.imi.org.cn/en/

Weibo

WeChat

IMI Working Paper No. 1705 [EN]

Urbanization, Economic Development and Environmental Change

By* LI SHUSHU and MA YONG

March 2017

Abstract

This paper applies the pressure-state-response (PSR) model to establish environmental quality indices for 30 administrative regions in China from 2003 to 2011 and employs panel data analysis to study the relationships among the urbanization rate, economic development and environmental change. The results reveal a remarkable inverted-U-shaped relationship between the urbanization rate and changes in regional environmental quality; the "turning point" generally appears near an urbanization rate of 60%. In addition, the degree and mode of economic development have significant, but anisotropic effects on the regional environment. Generally, at a higher degree of economic development, the environment will tend to improve, but an extensive economic growth program that simply aims to increase GDP has a clear negative impact on the environment. Overall, the results of this paper not only further confirm the "environmental Kuznets curve hypothesis", but also expand it in a manner. The analysis in this paper implies that the inverted-U-shaped evolving relationship between environmental quality and economic growth (urbanization) is universally applicable.

Keywords: urbanization process; economic development; environmental change; PSR model

* Li Shushu, Institute of Policy and Management, Chinese Academy of Sciences, Beijing 100190, China. Ma Yong, IMI Research Fellow, Renmin University of China, Haidian District, 59 Zhong Guan Cun Street, Beijing 100872, China

1. Introduction

The harmonious progress of urbanization, economic development and the environment is an important field of research that combines the social and natural sciences. From a theoretical perspective, urbanization, economic development and the natural environment are linked by a series of positive and negative effects. In most countries, the process of urbanization is generally accompanied by rapid economic growth, relocation of populations from rural areas to cities and towns, the agglomeration of secondary and tertiary industries in urban areas and an increase in the number of towns that are becoming larger on a daily basis. The process of urbanization affects the condition of the environment by changing the levels of polluting emissions as a consequence of the shift in production and changes in the population's behavior patterns after migrating from rural to urban areas. Developing a methodology to determine and evaluate the dynamic effects of urbanization and economic development on the environment of a country or region is not only an important theoretical problem, but also a crucial practical issue.

Since the 1960s, the negative ecological and environmental consequences of urbanization have been a focus of global economic and social development. Urbanization affects more than the development of the economy and the population's health, education and socialization; it impacts and is concerned with environmental protection and remediation, in addition to the exploitation of natural resources. In recent years, as empirical research on the relationship between humans and the environment has grown, many researchers have begun to turn their attention to strategies that balance improvements in the urbanization process and the environment. The quantitative literature on this subject primarily attempts to determine the relationship between environmental indices and the urbanization rate by using quantitative models that focus on three issues. First, these models address the causal relationship between urbanization and its corresponding environmental pressure. In this respect, Li [1] concluded that there is a dynamic, U-shaped relationship between urbanization and the environment, by analyzing the quantitative effects of urbanization on environmental pressure, environmental quality and environmental regulation. Second, these models employ explanatory variables—such as the urbanization rate and economic development—to conduct quantitative analyses of environmental pressure. Using data from the EU, Halkos[2] observed an inverted-U-shaped relationship between regional environmental efficiency and regional per capita GDP, whereas Wang [3] discovered the same inverted U-shaped relationship; using panel data on per capita GDP, environmental deterioration and its remediation costs, it studied the empirical relationship between urbanization and air quality. Third, certain studies have considered the urbanization rate alone to explain the level of polluting emissions, such as Srinivasan[4], who analyzed the vulnerability relationship between urbanization and water resources. Applying an overall regional perspective, these scholars conducted empirical multi-factor comparative analyses on the relationship between urbanization and the environment to determine the interaction between, and the manageability of, urbanization and changes in the natural environment; they then put forth advanced urban development strategies that provided a blueprint for the harmonious and sustainable development of a region.

At the end of the 19th century, the British scholar, Howard, advanced the garden city theory, which was an attempt to employ rational planning to coordinate the development of urbanization and the urban ecological environment. Using econometric techniques, Grossman and Krueger[5] assessed panel data from 42 developed countries and found a U-shaped relationship between the development of an urban economy and the city's environmental quality; this study advanced the well-known environmental Kuznets curve (EKC) hypothesis. Selden and Song [6] and Shfik[7]posited that increased incomes and improved standards of living would lead individuals to be increasingly concerned about the quality of the environment. When a clean environment gradually becomes a "luxury", the income elasticity of environmental quality demand will be above one, which will result in a shift in the economic structure to mitigate the deterioration of the environment. On this basis, Zaim[8] discussed the quantitative relationship between economic development and the environment and developed a model to analyze this relationship, employing large samples of ecological efficiency index values from low-income countries. Martinez [9] discussed the too poor to be green problem in developing countries. Stem[10] employed a simplified methodology to investigate the relationship between per capita income and polluting emissions and suggested in 2004 that developing countries may bypass certain EKC development modes. Managi[11]discussed the quantitative relationship between economic growth and decreased environmental degradation and proposed that estimating environment quality is key to the quantitative evaluation of both factors. In 2008, Managi[12] demonstrated that there is a relationship between environmental productivity and regional income using panel data on India for the 1991–2003 period and highlighted the negative effects of income on environmental productivity. Other studies have assessed the EKC relationship between pollution emissions and per capita incomes and have concluded that a certain level of income will result in increased attention to the problems associated with environmental degradation [13,14]. Economic growth affects environment quality through changes in economic scale, technology and structure [5]. The scale effect indicates that an expansion of the scale of economic activity will lead to increased investment in resource exploitation and polluting emissions, which leads, in turn, to decreased environmental quality. The technological effect refers to increased economic efficiency through innovation and technological progress (such as more efficient resource use and reduced emissions to improve environmental quality). Finally, the structural effect implies that economic development will eventually result in a shift in the structure of the economy to a low-pollution equilibrium. Environmental quality will change in response to the changes in the relative contributions of these three effects. The scale effect is dominant during the initial stage of economic growth. As economic development continues, the technological and structural effects will eventually dominate the scale effect and result in a gradual improvement in environmental quality [15]. In addition to econometric approaches, scholars employ system dynamics, sensitivity models and energy flow models to reveal the ways in which urbanization and changes in the ecological environment are related [16]. In the 1980s, the Organization for Economic Cooperation and Development (OECD) and the United Nations Environment Program (UNEP) jointly proposed the environmental indices for the pressure-state-response (PSR) conceptual model. Walter [17] stipulated that the key to advancing the process of urbanization while preserving and improving the ecological environment lies in the rational utilization of resources, improving the efficiency of resource use and focusing on global long-term development. In 1997, an international urban ecological symposium was held in Leipzig, Germany, concerning all aspects of the urban ecological environment. In 2002, the "Shenzhen Declaration" presented a series of summary findings on issues, such as urbanization, the development of ecologically-friendly and sustainable cities, *etc.*, with a particular focus on population pressures, the economy and urbanization during the development of an ecologically-friendly city. This declaration also established a direction for research on the development of worldwide urbanization.

Overall, most recent studies on the relationships among urbanization, economic development and environmental change have further advanced the field, and quantitative research using econometric models has further confirmed that urbanization has had a definite impact on the environment. However, a quantitative consensus on the connection between urbanization and comprehensive environmental quality in China remains elusive. Furthermore, for economies that have enjoyed rapid urbanization and high-speed economic growth, such as China's, studies on the relationships among urbanization, economic development and environment change remain rare. To fill this gap in the literature, this paper establishes systematic environmental indices for China's 30 administrative regions to conduct a systematic empirical analysis of the relationships among urbanization, economic development and the environment. This analysis contributes to the scientific understanding of the environmental impacts of urbanization and assesses the role of legislation on the relationship between the status of the urbanization process and regional environmental conditions. The remainder of this paper is organized as follows: the second section constructs a comprehensive environmental index and partial environment index based on the PSR model; the third section empirically analyzes the relationships among urbanization, economic development and environmental change; based on the results of the analysis in the second and third sections, the fourth section predicts and assesses the potential environmental impacts of urban construction in China over the next 10 years; finally, a concluding evaluation is provided at the end of the paper.

2. Establishment of Environmental Indices

2.1. The Establishment of Set of Indices

Environmental indices used in this paper are selected based on the "A" conceptual model jointly proposed by the OECD and UNEP. Current research rarely discusses the man-land relationship in the course of environmental change, based on the environmental change evaluation index system of the PSR framework, which can compensate for the deficiency.Therefore,this paper explains thesystem of the PSR conception and puts forward the index system based on the PSR model.Theoretically, when individuals migrate from rural to urban areas, their daily activities will change substantially. Generally, the volume of services and products they consume will substantially increase, and their daily emission volumes will also increase correspondingly. During the migration process, the economy's production activities will also change substantially as agricultural production activities are replaced by commercial production activities. Accordingly, the volume of polluting emissions will also change. Shifts in consumption needs that result from urbanization lead to changes in productive activities, thereby altering levels of industrial pollution. As the rate of urbanization has risen in China, all its regions are suffering from environmental problems and are attempting to use policy, legislation and capital to address the effects of both daily household consumption and industrial production.

Using "environment change" as subject words, 47,681 articles were collected from the China Journal Net database. We analyze those papers by frequency statistics. Combined with the index system of "The Construction of Ecological Province City County Index" of China, and the indexstructure of the China Statistical Yearbook(2003–2011), we select the index from the aspects of the environment state, environmental impact and the corresponding environment to reflect the development and trends of the urban ecological environment (the specific indices are presented in

Table 1). To avoid subjective bias, the comprehensive index is calculated by summing its sub-items and assigning them equal weights. The comprehensive environmental index (*E1*) is the sum of three sub-items: $E1=(E2+E3+E4)/3$; which is intended to capture the overall environmental quality of a region. The three sub-items are the state of the environment (*E2*), the environmental impact (*E3*) and the environmental response (*E4*). The state of the environment (*E2*) refers to the current status of the urban environment and its tendency to change in response to direct or indirect pressure from the economy, society, population growth, *etc.*, and its three constituent indices are: total emissions volume ofindustrial exhaust gas, particulate matter(PM10) emissions and total urban sewage emission volume. Environmental impact (*E3*) refers to the effects of changes in the urban environment on the eco-system and on the economic and social systems; its constituent indices are: the share of days with air quality readings above Level 2, the urban wastewater disposal rate and the green coverage rate in built-up urban areas. Environmental response (*E4*) refers to individual responses that cope with environmental change, as measured by the compliance rate of industrial wastewater emissions, the share of pollution reduction costs in GDP and the disposal rate of household waste.

Table 1. System of the indices for the state of the environment during the urbanization process.

Variables		**Index Interpretation**	**Index Selection**
E1	Comprehensive Environment Index	Reflects the state of, impact on and response to the environment due to economic growth and social development	
E2	State of the Environment	Refers to the current urban environment and its trend given direct or indirect pressure from the economy, society, population growth, *etc.*	Total emission volume of industrial exhaust gas
			particulate matter(PM10) emissions
			Total emission volume of urban sewage
E3	Environmental Impact	Refers to the effects of changes in the urban environment on its eco-system and the economic and social systems	Share of days with air quality values above Level 2
			Urban wastewater disposal rate
			Green coverage rate in urban, built-up areas
E4	Environmental Response	Refers to human responses to cope with environmental change	Compliance rate of industrial wastewater emissions
			Share of pollution reduction costs in GDP
			Disposal rate of household waste (%)

2.2. The Data Sources and Standardizing the Index

The data of the paper areselected from the China Statistical Yearbook(2003–2011) and China Statistical Yearbook on Environment(2003–2011). The specific indices are presented in Table 2.

Table 2. The datasources.

Index Selection	Sources of Data
Total emission volume of industrial exhaust gas	Main Pollutant Emission in Waste Gas
PM10 emissions	Ambient Air Quality in Major Cities
Total emission volume of urban sewage	Main Pollutant Emission in Waste Water in Main Cities
Share of days with air quality values above Level 2	Ambient Air Quality in Major Cities
Urban wastewater disposal rate	Discharge and Treatment of Waste Water in Major Cities
Green coverage rate in urban, built-up areas	Basic Statistics on Parks and Green Areas in Cities by Region
Compliance rate of industrial wastewater emissions	Discharge and Treatment of Industrial Waste Water by Region
Share of pollution reduction costs in GDP	Investment in the Treatment of Environmental Pollution by Region
Disposal rate of household waste (%)	Collection, Transport and Disposal of Consumption Wastes in Cities by Region

The original data used in the environmental indices differ with respect to type and unit; there is a substantial disparity in their orders of magnitude, and the standards applied in collecting them are not uniform. Consequently, direct comparisons cannot be made. Therefore, it is necessary to standardize the original data to eliminate the influence of different units of measurement in the indices. We standardize the data using min-max standardization methods. Min-max standardization is a linear transformation of original data. Suppose that $\min_A$ and $\max_A$ are the minimum and maximum values of a certain type of data A in a model index. The calculation method to standardize the original mapping of a value v in A to the range [new_ $\min_A$, new_$\max_A$] is as follows:

$$[\ v' = \frac{v - \min_A}{\max_A - \min_A}(new\_\max_A - new\_\min_A) + new\_\min_A\ ] \quad (1)$$

If the range of the sample data can be identified as [0, 1], then the formula can be simplified as:

$$[\ v' = \frac{v - \min_A}{\max_A - \min_A}\ ] \quad (2)$$

After standardization, the values of the comprehensive environment indices in 30 administrative regions across China are presented in Table 3. The overall change in mean values over the period considered is presented in Figure 1.

Table 3. Environment index values.

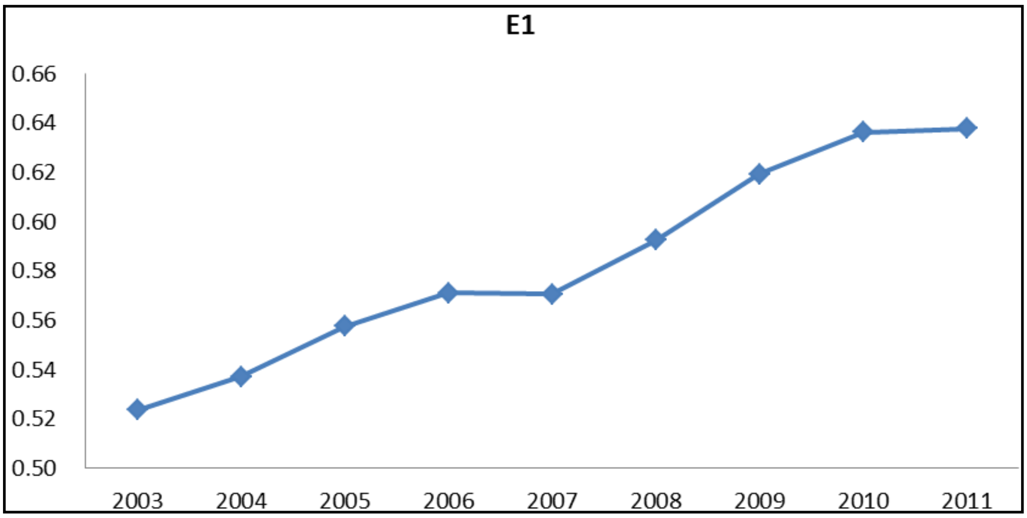
	E1	**Rank(*E1*)**	***E2***	**Rank(*E2*)**	***E3***	**Rank(*E3*)**	***E4***	**Rank(*E4*)**
Beijing	0.68	5	0.61	18	0.63	10	0.79	1
Tianjin	0.69	3	0.72	10	0.59	15	0.76	2
Hebei	0.53	22	0.38	28	0.64	9	0.59	10
Shanxi	0.51	26	0.56	23	0.48	24	0.50	21
Inner Mongolia	0.58	14	0.71	11	0.52	18	0.51	19
Liaoning	0.54	20	0.44	26	0.62	12	0.57	11
Jilin	0.55	19	0.76	7	0.52	18	0.36	27
Heilongjiang	0.49	27	0.68	13	0.40	28	0.39	25
Shanghai	0.63	10	0.61	18	0.73	4	0.54	15
Jiangsu	0.64	9	0.38	28	0.79	1	0.74	3
Zhejiang	0.62	12	0.55	25	0.63	10	0.69	6

Table 3. *Cont.*

	E1	Rank(*E1*)	*E2*	Rank(*E2*)	*E3*	Rank(*E3*)	*E4*	Rank(*E4*)
Anhui	0.58	13	0.63	17	0.59	15	0.53	16
Fujian	0.73	2	0.78	5	0.76	3	0.64	7
Jiangxi	0.66	6	0.77	6	0.65	8	0.56	14
Shandong	0.58	15	0.37	30	0.67	6	0.70	5
Henan	0.56	17	0.57	22	0.60	13	0.51	19
Hubei	0.52	24	0.56	23	0.54	17	0.47	22
Hunan	0.52	23	0.65	16	0.49	22	0.43	24
Guangdong	0.51	25	0.41	27	0.67	6	0.46	23
Guangxi	0.66	7	0.76	7	0.60	13	0.61	8
Hainan	0.78	1	0.99	1	0.77	2	0.57	11
Chongqing	0.62	11	0.69	12	0.48	24	0.71	4
Sichuan	0.55	18	0.61	18	0.52	18	0.52	18
Guizhou	0.54	21	0.81	2	0.46	27	0.35	28
Yunnan	0.68	4	0.81	2	0.72	5	0.53	16
Shaanxi	0.57	16	0.67	14	0.49	22	0.57	11
Gansu	0.36	30	0.61	18	0.18	30	0.29	30
Qinghai	0.45	29	0.75	9	0.22	29	0.38	26
Ningxia	0.64	8	0.79	4	0.52	18	0.61	8
Xinjiang	0.48	28	0.67	14	0.48	24	0.31	29

* Allof the data is form the“China Statistical Yearbook on Environment (2003–2011)”.

Figure 1. The overall change in the mean value for all investigated areas.



According to Figure 1, the comprehensive environment index has risen since 2003. The index’s mean value rose by 23% by 2011 and 4.5% in 2009, whereas the difference in the index’s mean value between 2007 and 2006 is relatively small. According to time series data for all regions, areas, such as Hainan, Fujian, Tianjin, Yunnan and Beijing, perform better on the comprehensive environmental index than other regions, whereas areas, such as Shanxi, Heilongjiang, Xinjiang, Qinghai and Gansu, perform worse than other regions; Jiangxi Province has experienced a rise in performance in recent years and ranks first among the provinces in 2011. The results for Chongqing, Mongolia and Shanxi indicate that these regions have all enjoyed increases in index values, albeit to different extents, whereas, in recent years, Shanghai's comprehensive environmental index ranking declined somewhat to rank 26th among the 30 investigated areas in 2011.

3. Empirical Analysis

To analyze the dynamic correlations among urbanization, economic development and environmental change, this section includes a statistical evaluation of the correlations among all of the variables by constructing an empirical model and assessing panel data from the 30 administrative regions of China during the period 2003–2011; this section then analyzes the regions' experiences and interprets the relevant results.

3.1. Model Setup and Summary Statistics

The data employed in this paper include pooled time series and cross-sectional data, which are convenient for use in a panel data model. A panel data model can identify changes in relationships in two dimensions while accounting for time-specific and cross-sectional effects, which is more effective than the common OLS (ordinary least squares)model and can extract more polymorphic features from the data. We specified a fixed-effects model,because we only study data from the 30 administrative regions of China (and the Hausman test rejected the original hypothesis that would have supported a random-effects model).With respect to the econometric methodology, we selected generalized least squares (GLS) for the analysis based on the data characteristics to minimize the impact of heteroscedasticity that might be caused by cross-sectional data.

To address the research object of this paper, the regression equation is specified as follows:

$$[\, E_{i,t} = \alpha_{it} + \beta_1 E_{i,t-1} + \beta_2 C_{i,t} + \beta_3 C_{i,t}^2 + \beta_4 X_{i,t} + \varepsilon_{i,t} \,] \tag{3}$$

On the left-hand side of the regression equation above, $E_{i,t}$, which is the dependent variable, represents the environmental indices in different regions in different years. On the right-hand side of the regression equation, α_{it} is the intercept, $E_{i,t-1}$ is the environmental index value lagged by one period and $C_{i,t}$ and $C_{i,t}^2$ are the urbanization rate and its squared term, respectively. The squared term is included to investigate the potential inverted-U-shapedrelationship between environmental change and urbanization. The vector $X_{i,t}$ represents other control variables. In the index selection, city development level in China is different according to the different conditions and environment.

We choose the provincial data in the research object in order to maintain the consistency of data sources. We choose environmental indicesas the core index to build assessment system, because the city level data sources have varied widely. Environmental indicators are selected based on the provincial level in accordance with the other indicators.Meanwhile, we rely on the degree of concern in the same type of research to choose the index, including related 11indexes,such as the macroeconomic situation, characteristics of the industrial structure, health development level and the level of education. According to the correlation analysis, we screen out the 7 most related indexescharacterizedwhich include the following: (rgp) per capita GDP, reflecting macroeconomic conditions; (egr) the economic growth rate;(cpi) the currency inflation rate;(ind) GDP, representing the regional industrial structure;(ser) GDP, representing the value of service industry output; (med), representing the number of beds in medical institutions to proxy for regional public health status;(edu), representing the number of students enrolled in universities per 100,000 personsto indicate the regional education level; β_1,β_2,$\beta_3$and β_4 are the vectors of regression coefficients; and $\varepsilon_{i,t}$ is the error term.

The data used to construct the variables are from 2003 to 2011 and include all 30 provincial regions across China (except for Tibet). There are nine data sampling pointsalong the time dimension, and each cross-section has 30 elements, which yields a total sample volume of 270. To obtain a smooth data chart and mitigate the impact of heteroscedasticity, we take the natural logarithmsof per capita GDP(rgp), the number of beds in medical institutions (med) and the number of students enrolled in universities per 100,000 persons (edu). Definitionsforthe variables discussed above and summary statistics are presented in Table4.

Table 4. Summary statistics and description of the variables.

Variables	Definition	Average Value	Standard Difference	Maximum	Minimum	Observation Value
E1	Integrated environmental indicator	0.583	0.107	0.808	0.324	270
E2	Sub-environmental indicator-state	0.643	0.155	0.997	0.253	270
E3	Sub-environmental indicator—impact	0.566	0.166	0.866	0.103	270
E4	Sub-environmental-response	0.540	0.163	0.930	0.108	270
C	The urbanization rate**	0.460	0.125	0.893	0.220	270
rgp	Per capita GDP	0.648	0.642	2.122	−0.998	270
egr	The GDP growth rate	12.87	2.178	23.80	5.400	270
cpi	Currency inflation rate	3.109	2.263	10.09	−2.346	270
ind	Industrial output value/GDP	0.474	0.078	0.664	0.218	270
ser	Service sector output/GDP	0.389	0.077	0.761	0.274	270
med	Number of beds in medical institutions*	11.57	0.731	12.94	9.622	270
edu	The number of people per 100,000 students in Colleges and Universities *	7.521	0.452	8.839	6.614	270

Note: * indicates variables in natural logarithms; and ** urbanization rate = urban population/total population. The data is from "China Statistical Yearbook(2003–2011)".

3.2. Empirical Results

Based on the model specified above and taking correlation among the variables into consideration, we conduct a regression analysis in a stepwise fashion, adding additional control variables gradually (see Table 5 for specific results). In addition to the urbanization rate and the control variables, we also account for the delayed effects of environmental change, which indicates that the state of the environment in the previous period would have a substantial impact on its state in the current period. Therefore, in the regression analysis, we include the lagged values of the environmental variables in the regression as explanatory variables. In Table 5, we list the results of six different regression equations. Equation (1) reflects the results when only the relationship between environmental quality and the urbanization rate are considered; Equation (2) introduces the squared term of urbanization to determine whether there is a U-shaped relationship between environmental quality and the urbanizationrate; Equations (2), (3) and (6) control for macroeconomic factors, industrial structure factors, social factors and educational factors. Based on the results, we arrive at the following conclusions:

(1) At the 1% confidence level, the comprehensive environmental index in the previous period has a substantial impact, indicating that the rate of environmental changeis constant and that the state of the environmental in the previous period has a significant impact on environmental change in the current period. Regarding regression coefficients, after controlling for related factors, the coefficient is between

58% and 62%, which indicates that 60% of the state of the environment in the previous period would persist into the current period.

(2) The urbanization rate and the comprehensive environmental index exhibit a clear inverse U-shaped relationship. According to the results of Equations (1) and (2), the urbanization rate *C* and the comprehensive environmental index are positively related andhavea negative relationship with the environmental index (the significance level is often 1% or better), which indicates that this quadratic relationship is statistically significant. Moreover, according to the results of Equations (3)–(6), after controlling for all possible factors influencing environmental change, including macroeconomic factors, industrial structure factors, social factors and educational factors, the urbanization rate and the comprehensive environmental indices continue to clearly exhibit a quadratic relationship, which indicates that the finding of an inverse U-shaped relationship is robust.

(3) The level of economic development and the economic development strategy have substantial, but opposite effects on the regional environment. According to the results, the rate of economic growth and the cpi have negative relationships with environmental quality, and environmental quality has a positive relationship with GDP per capita. This indicates that, as the economy develops, environmental quality will improve, whereas an extensive mode of economic growth will have a negative impact on environmental quality. Underdeveloped provinces frequently initiate energy-wasting, high-pollution projects to pursue a high rate of GDP growth, which tend to rapidly deteriorate the state of the environment.

(4) Improvements in public health have a clear, positive impact on environmental quality. The results of Equation (5) presented in Table 5 show that the number of beds in medical institutions and the comprehensive environmental indices have a positive relationship at the 1% level. As the number of beds in medical institutions is regarded as a proxy for the level of public health in a region, this result suggests that developing the regional public health industry improves the regional environment. In addition, the results of Equation (5) do not permit a clear inference regarding the coefficient of education.

Moreover, we should note that, although the results of the empirical analysis for the urbanization rate and *E1* are presented, we also conducted regression analyses of the relationships between the urbanization rate and the three other environmental indices (*E2*, *E3* and *E4*) to consider the potential differences across indices. The results of these robustness checks support the finding of an inverse U-shaped relationship between the urbanization rate and environmental change.

Table 5. Urbanization, economic development and comprehensive environmental index.

	The Dependent Variable is the Comprehensive Environmental Index (*E1*)					
	Equation 1	**Equation 2**	**Equation 3**	**Equation 4**	**Equation 5**	**Equation 6**
$E(-1)$	0.766285***	0.675209***	0.623015***	0.581094***	0.569507***	0.577029***
	(16.56079)	(13.98954)	(12.03095)	(10.60322)	(10.27357)	(10.43163)
C	0.110660***	1.162854***	0.628664**	0.590912**	0.525618*	0.673482**
	(1.865738)	(5.626873)	(2.348484)	(2.171141)	(1.866496)	(2.235822)
C^2		−0.966342***	−0.640027***	−0.588442***	−0.516369**	−0.659994***
		(−5.380880)	(−3.074182)	(−2.727634)	(−2.312709)	(−2.711629)
rgp			0.036235***	0.032809***		0.039890**
			(3.214149)	(2.875333)		(2.443021)
egr			−0.002330*	−0.002449*	−0.002354*	−0.002369*
			(−1.745297)	(−1.822420)	(−1.765896)	(−1.752127)
CPI			−0.002264**	−0.002340**	−0.002111**	−0.002479**
			(−2.348404)	(−2.315604)	(−2.249827)	(−2.381170)
ind				0.177236**	0.172490**	0.175416**
				(2.141423)	(2.329468)	(2.109488)
ser				0.018086		0.019493
				(0.176644)		(0.190201)
med					0.079720***	
					(3.145562)	
edu						−0.019239
						(−0.625385)
Cons.	0.097163**	−0.116440**	0.098516	0.040971	−0.831378***	0.161311
	(3.687128)	(−2.419174)	(1.283554)	(0.403481)	(−3.590973)	(0.734228)
Obs.	240	240	240	240	240	240
Provinces	30	30	30	30	30	30
F-statistic	73.29610	73.87312	63.49567	61.40237	64.51919	59.89887
D-W stat.	2.205026	2.228669	2.240162	2.177569	2.141307	2.178759
Adjusted R^2	0.903636	0.907038	0.901498	0.903391	0.905372	0.903518

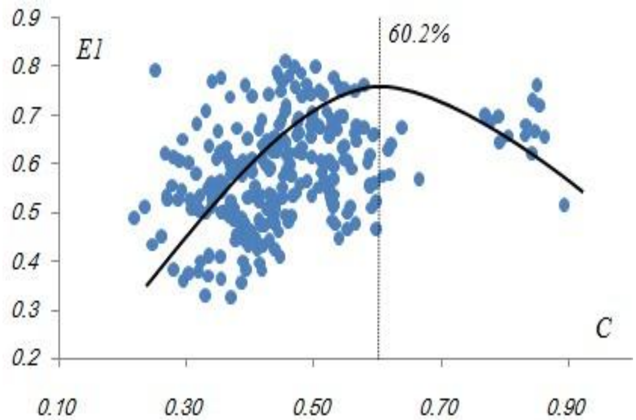
Note: In parentheses is the T Statistics; ***Show the 1% confidence level significantly; ** Show the 5% confidence level significantly; * Show the 10% confidence level significantly.

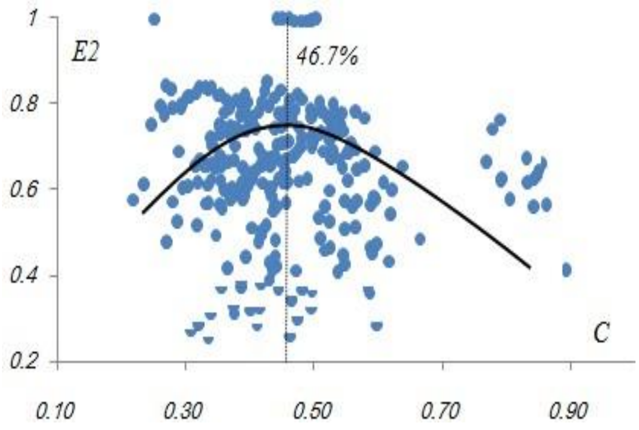
3.3. Further Discussion on the Relationship between Urbanization and the Environment: Determining the Inflexion Point and Elasticity Coefficient

The empirical analysis above confirms that there is an inverted-U-shaped relationship between the urbanization rate and environmental change from a qualitative perspective. In what follows, we will analyze the relationship between urbanization and environmental change from a quantitative perspective. There are questions in this respect that must be resolved:first, the elasticity coefficient of the impact of the urbanization rate on environmental quality; second, the location of the inflexion point, from the perspective of the urbanization rate, in the inverse U-shaped relationship between the urbanization rate and environmental change. To consider possible differences across different environmental indices, we will focus our analysis on the comprehensive environmental indices and the three sub-indices. The results are presented in Table 6, which also presents the regression results for models with and without lagged environmental variables, among which,Models 8, 10, 12 and 14 employ lagged environmental variables. From the perspective of model optimization, models with lagged environmental variables are obviously more tenable. Therefore, we employ a ternary regression model to analyze the relative effects when discussing the elasticity coefficient and determining the inflexion point of the inverted-U-shaped relationship.

With respect to the inflection point, it can be identified using the regression coefficients from Equations (8), (10), (12) and (14) in Table 6. First, according to the quadratic relationship between comprehensive environmental index *E1* and the urbanization rate, the inflexion point of the inverted-U shape is at a 60.2% urbanization rate; second, according to the quadratic relationship between sub-item environmental index *E2* and the urbanization rate, the inflexion point of the inverted-U shape is at a 46.7% urbanization rate; third, according to the quadratic relationship between sub-item environmental index *E3* and the urbanization rate, the inflexion point of the inverted-U shape is at a 64.9% urbanization rate; fourth, according to the quadratic relationship between sub-item environmental index *E4* and the urbanization rate, the inflexion point of the inverted-U shape is at a 67.0% urbanization rate. We illustrate the conclusion above in Figure 2 using scatter plots.

Figure 2. The inflexion point of the urbanization rate in the inverted-U-shaped relationship.





1
E2
46.7%
0.8
0.6
0.4
0.2
C
0.10
0.30
0.50
0.70
0.90

Figure 2. *Cont.*

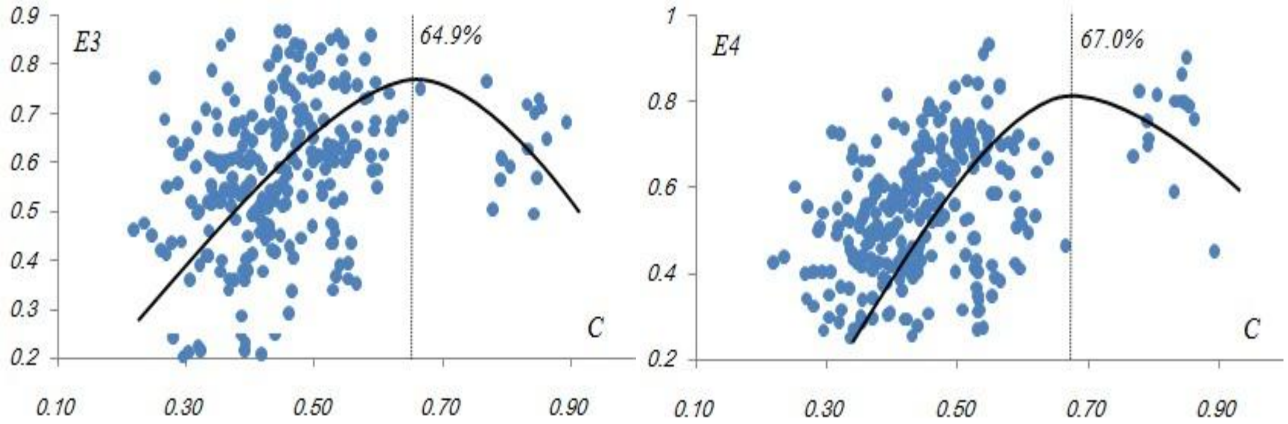


Table 6. Urbanization and environmental index of "inverted U".

	The Dependent Variable(*E1*)		The Dependent Variable(*E2*)		The Dependent Variable(*E3*)		The Dependent Variable(*E4*)	
	Equation 7	**Equation 8**	**Equation 9**	**Equation 10**	**Equation 11**	**Equation 12**	**Equation 13**	**Equation 14**
C	2.113065*** (10.50599)	1.162854*** (5.626873)	1.086534*** (5.451241)	0.499421** (2.247635)	2.620592*** (8.816426)	1.610145*** (4.602620)	2.373726*** (6.908686)	2.235423*** (5.899553)
C^2	−1.552077*** (−8.149981)	−0.966342*** (−5.380880)	−0.864116*** (−4.190281)	−0.534542** (−2.380394)	−1.891616*** (−6.923183)	−1.240111*** (−4.064560)	−1.584727*** (−4.930872)	−1.668867*** (−5.058342)
$E(-1)$		0.675209*** (13.98954)		0.410385*** (6.981203)		0.607842*** (11.10901)		0.438431*** (7.585782)
Cons.	−0.036200 (−0.696662)	−0.116440** (−2.419174)	0.340005*** (6.984679)	0.279086*** (4.728398)	-0.209727*** (−2.692481)	−0.230356*** (−2.689489)	−0.191761*** (−2.130021)	−0.338437*** (−3.516374)
Obs.	270	240	270	240	270	240	270	240
Provinces	30	30	30	30	30	30	30	30
F-statistic	43.41956	73.87312	80.31190	497.6562	70.30698	93.74622	28.46965	33.49984
D-W stat.	1.140397	2.228669	1.314666	2.138094	1.161652	2.046739	1.377395	2.249693
Adjusted R^2	0.830177	0.907038	0.901381	0.985185	0.888729	0.925473	0.759941	0.813134

Note: In parentheses is the T Statistics; ***Show the 1% confidence level significantly; ** Show the 5% confidence level significantly; * Show the 10% confidence level significantly.

After confirming the location of the inflexion point, we can now conduct further analysis to determine the elasticity coefficient between environmental change and the urbanization rate. Using the quadratic relationship between comprehensive environmental index *E1* and urbanization rate *C*, we can determine the corresponding equation, as follows, according to Equation:

$$[\, E_1 = -0.116 + 0.675E_1(-1) + 1.163C - 0.966C^2 \,] \tag{4}$$

Taking the first-order derivative of *C*, we obtain:

$$[\, \frac{\partial E_1}{\partial C} = 1.163 - 1.932C \,] \tag{5}$$

From the simple calculation of the elasticity coefficient using Equation (3), we can conclude the following: the elasticity coefficient between *E1* and the urbanization rate decreases gradually before reaching the inflexion point at 60.2%. The comprehensive index would increase by 39% if the urbanizationrate were to increase by 1%; after passing the inflexion point at 60.2%, the elasticity coefficient between the urbanization rate and comprehensive environmental index *E1* is negative and gradually increasing. The comprehensive index would decrease by 29% if the urbanization rate were to increase by 1%.

Using the same measures and procedures as above, according to Equations (10), (12) and (14), we can calculate the elasticity coefficients of *E2*, *E3* and *E4*. The results are presented in Table 7. According to Table 7, comprehensive index *E2* would increase by 13% if the urbanization were to increase by 1% before reaching the inflexion point at 46.7%; thereafter, comprehensive index *E2* would decrease by 21% if the urbanization rate were to increase by 1%. Second, comprehensive index *E3* would increase by 72% if the urbanization rate were to increase by 1% before reaching the turning point at 64.9%; thereafter, comprehensive index *E3* would decrease by 28% if the urbanization rate increased by 1%. Third, comprehensive index *E4* would increase by 1.03% if the urbanization rate increased by 1% before reaching the turning point at 67%; thereafter, *E4* would decrease by approximately 33% if the urbanization rate were to increase by 1%.

Table 7. Analysis of the comprehensive environmental index and the elasticities of the environmental indices.

Environmental Index	First-order Derivative Equation	Inflection Point Location	Mean Elasticity before Inflexion Point	Mean Elasticity after Inflexion Point
E1	$\frac{\partial E_1}{\partial C} = 1.163 - 1.932C$	0.602	0.39	−0.29
E2	$\frac{\partial E_2}{\partial C} = 0.499 - 1.069C$	0.467	0.13	−0.21
E3	$\frac{\partial E_3}{\partial C} = 1.610 - 2.480C$	0.649	0.72	−0.28
E4	$\frac{\partial E_4}{\partial C} = 2.235 - 3.338C$	0.670	1.03	−0.33

Given the agreement between the results discussed above and experience, the state of the environment is substantially affected by the pressures of rapid urbanization.

Moreover, as urbanization increases, local governments have introduced a series of policies to address environmental problems. Consider Hebei Province; in 2003, its urbanization rate was 33.52%, and its PM10 was 0.175 mg/m^3, which was the best result in the country. In 2007, its urbanization rate increased to 40.26%, and its exhaust volume reached 4803.6 billion m^3 from 15,758m^3, which made it the most polluted area in the country. With the consistent increase in the urbanization rate, sewage volume reached 1,471,840,000 tonsin 2009 from 1,183,057,000 tons in 2005. The urbanization rate increased 45.60%, and the environment faced an even more substantial impact, which is in keeping with model projections. The number of days in which air quality was below Level 2 reached a maximum of 141 in 2003 in Beijing, which accounted for 39% of the total, and there were many hazy days. A plan to cope with hazy days was launched in 2007. In 2008, the share of hazy days fell to 25%, and the effect of this change is obvious. During this period, the urbanization rate rose by 5%. The environmental impact and its lagged terms conform to the model's predictions.

4. The Environmental Impact of Urbanization over the Next Decade: Forecast and Assessment

This paper analyzes the environmental state, impact and response in China's 30 administrative regions using the environment assessment methodology presented in Section2 above. According to the forecast values presented above, the relationship between the state of the environment and urbanization is reflected in a 46.7% urbanization rate. Based on data from the 30 provinces, the urbanization rate in 2008 was 46.23%, which approached the inflexion point in the relationship between the urbanization rate and the state of the environment.

Employing 2011 as the assessment year, the state of the environment in Hainan province is better than that in other regions according to the results in Figure 3, followed by that of Inner Mongolia and the southern regions; the environment in Shanghai, Jiangsu and Guangdong is in relatively poor condition. Regarding environmental impact results, Jiangxi, Yunnan and Fujian are relatively less affected than other regions of the country; the impact in the east is lower than in the west, and Gansu suffers from the largest impact among the regions considered. Regarding environmental response, the northern areas have responded more forcefully than those in the south; the eastern regions perform better than those in the west. Chongqing, Mongolia and Tianjin have higher levels of environmental response than other regions; the environmental response in Gansu is relatively weak, but not significantly weaker. With respect to the comprehensive environmental index assessment, the coastal areas exhibit higher values than the inland regions; environmental conditions in Hainan and Jiangxi are the best of the regions considered, and the state of the environment in Gansu is relatively poor.

According to the assessment above, the inflection point in the effect of the urbanization rate on the environment, *i.e.*, the point at which it becomes positive, appears at an urbanization rate of 0.602. According to the current level of urbanization level, the state of the environment and urbanization in Beijing, Tianjin and Shanghai are enjoying rapid, but stable improvement; regarding the area around the inflexion point in the relationship between changes in urbanization and environmental impacts, Guangdong, Liaoning, Zhejiang, Jiangsu and Fujian are close to shifting from a positive relationshipto a negative one. Therefore, care should be exercisedto ensure sustainable urbanization while preserving the environment.Conflicts between the two objectives should be managed to maintain the environment as urbanization continues.The state of the environment in eight provinces, including Mongolia, Chongqing and Shandong, hasa positive relationship with urbanization, such that further urbanizationwould improve the environment.The state of the environment in seven provinces, including Qinghai, Jiangxi and Sichuan,shows a positive relationship with urbanization, although those relationships areboth low and stable.The level of urbanization in Gansu, Yunnan and Guizhou is very low, which has little effect onthe environment; thus, it would be advisable to increase the rate of urbanization to generate environmental benefits in those provinces. The projectionsaredepicted in Figure 4:

Figure 3. Depiction of the comprehensive environment index and sub-item environment indices for the 30 administrative regions of China.

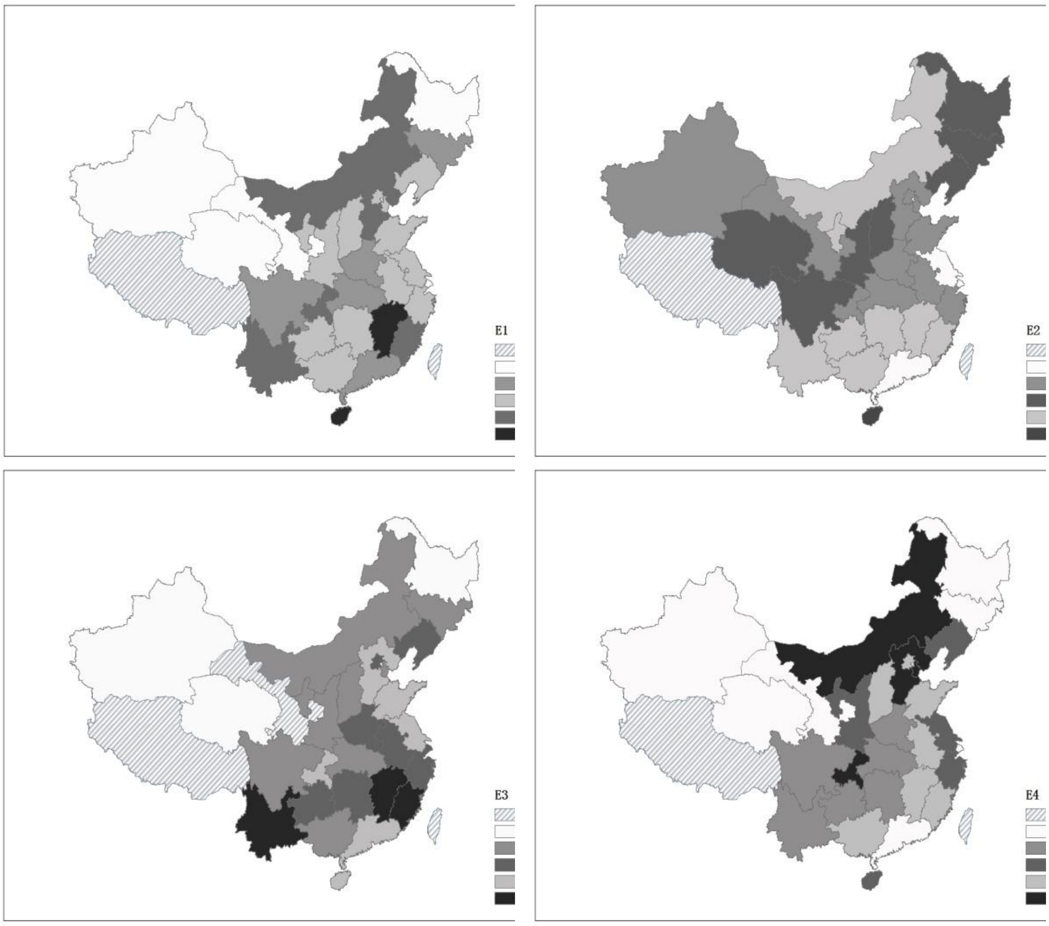


Figure 4. Depiction of the urbanization ratesin the 30 administrative regions: 2011—2025.

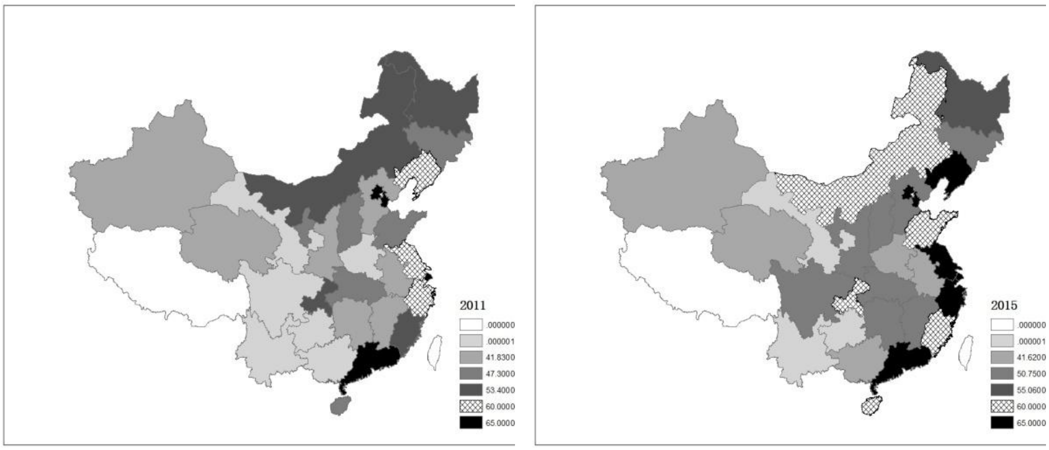
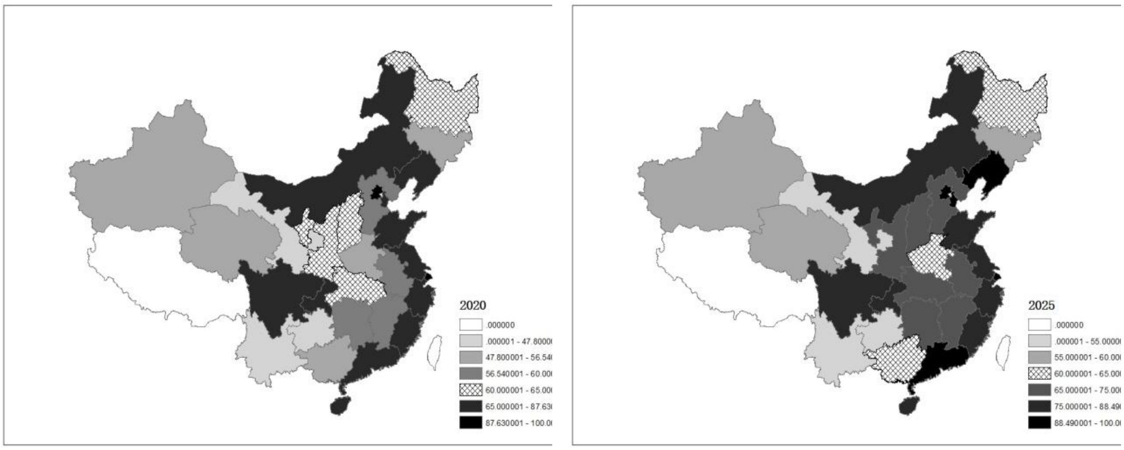


Figure 4.*Cont.*



As of the analysis above demonstrates that the urbanization process in coastal regions may place additional pressure on the environment. The urban population is projected to increase by 8% annually during the years 2011 to 2015. The national average is expected to increase to 54.5% by 2015. Regions, including Mongolia, Chongqing, Fujian and Shandong, would begin to feel the negative impacts of urbanization as the inflection point is reached. The government should attach greater importance to mutually beneficial changes in the two goals of urbanization and environmental protection to realize sustainable urban and environmental development. By the year 2020, the urbanization rates of 12 cities around the country will be in a positive relationship with the state of the environment. The urbanization rates of multiple regions, including Hubei, Shaanxi, Shanxi, Heilongjiang, Ningxia and Sichuan, would reach levels between 60% and 65%, entering developmental levels at which urbanization has positive consequences for the state of the environment. By 2025, only six cities will have urbanization rates that exhibit a positive relationship with the state of the environment. The urbanization rates of Guangxi, Heilongjiang and Henan will reach levels between 60% and 65%, entering the region in which the urbanization rate has positive effects on the state of the environment. We should attempt to balance the relationship between the two to maintain stable development.

5. Conclusions

Based on the PSR model, this paper establishes environmental quality indices for the 30 administrative regions of China from 2003 to 2011 and studies the relationships among urbanization, economic development and environmental change by empirically analyzing panel data. The results indicate that the urbanization rate and rate of change in regional environmental quality exhibit an inverted-U-shaped relationship. This relationship remains robust after controlling for various other factors with the potential to influence environmental change. Further analysis reveals that the inflexion point in the inverted-U-shaped relationship between the comprehensive environmental index *E1* and urbanization rate is located at an urbanization rate of 60.2%. The inflexion point in the inverted-U-shaped relationship between the urbanization rate and the sub-item environment indices *E2*, *E3* and *E4* appears at an urbanization rate of 46.7%, 64.9% and 67.0%, respectively.

Regarding the relationship between economic development and environmental change, our empiricalanalysis reveals that the mode and level of economic development have different, but significant impacts on the regional environment. Specifically, as the economy develops, the environment will improve. However, an extensive development pattern would have a significantly negative effect on the environment. This conclusion provides an important policy insight for many industrial or developing countries: during the process of industrialization and urbanization, a more intensive mode of economic development must be pursued to realize the dual goals of economic development and environmental improvement.

Generally, on the one hand, this paper provides further support for the EKC assumption proposed by Grossman andKrueger (1991; on the other hand, it represents an extension. The analysis in Grossmanand Krueger (1991) is based on a GDP index and international data, whereas this paper is based on the urbanization rate and regional environmental data. Therefore, the analysis in this paper indicates that the inverted-U-shaped relationship between environmental quality and economic growth remains tenable for developed and developing countries; it is suitable to address changes in environmental quality, not only at the country level, but also at the regional level. Therefore, it is widely applicable.

In addition, the assessments in this paper have substantial implications for the environmental issue in question. According to the empirical conclusions of this paper, the relationship between the state of the environment and the urbanization rate in the 30 administrative regions appeared to exhibit an inflexion point in 2008. As urbanization accelerates, environmental quality declines; by the year 2024, the environmentimpact will clearly increase with consistent growth in the urbanization rate; by the year 2027, the environmental response will lag behind the urbanization rate. Overall, comprehensive environmental quality will decline as urbanization accelerates, and then, the former will stabilize at a relatively high level, at which point increases in the urbanization rate also increase environmental quality.

References

Li, Y.; Li, Y.; Zhou, Y. Investigation of a coupling model of coordination between urbanization and the environment. *J. Environ. Manag.*2012, *98*, 127–133.

Halkos, G.E.; Tzeremes, N.G. A conditional directional distance function approach for measuring regional environmental efficiency: Evidence from UK regions. *Eur. J. Oper. Res.*2013, *227*, 182–189.

Wang, Q.; Yuan, X. Research on interactive coupling mechanism and regularity between urbanization and atmospheric environment: A case study in Shandong Province, China. *Stoch. Environ. Res. Risk Assess.* 2012, *26*, 887–898.

Srinivasan, V.; Seto, K.C. The impact of urbanization on water vulnerability: A coupled human-environment system approach for Chennai, India. *Glob. Envion. Chang.-Hum. Policy Dimens.*2013, *23*, 229–239.

Grossman, G.W.; Krueger, A.B. Environmental impacts of a North American free trade agreement. In Conference on the Mexico-US Free Trade Agreement1993; MIT Press: Cambridge, MA, 1993; pp. 13–56.

Selden, T.M.; Song, D.Q. Environmental-Quality and development—Is there a Kuznets Curve for air-pollution emissions. *J. Environ. Econ. Manag.*1995, *29*, 162–168.

Shafik, N. Economic-development and environment-quality—An economentric-analysis. *Oxf. Econ. Pap.-New Ser.*1994, *46*, 757–773.

Zaim, O.; Taskin, F. A Kuznets Curve in environmental efficiency: An application on OECD countries. *Environ. Resour. Econ.*2000, *17*, 21–36.

Martinez, A.J. The environment as a luxurygood or “too poor to be green”. *Ecol. Econ.*1995, *13*, 1–10.

Stern, D.I. Progress on the environmental Kuznets curve? *Environ. Dev. Econ.*1998, *3*, 173–196.

Managi, S. Are there increasing returns to pollution abatement? Empirical analytics of the Environmental Kuznets Curve in pesticides. *Ecol. Econ.*2006, *58*, 617–636.

Managi, S.; Jena, P.R. Environmental productivity and Kuznets curve in India. *Ecol. Econ.*2008, *65*, 432–440.

Dinda, S. Environmental Kuznets curve hypothesis: A survey. *Ecol. Econ.*2004, *49*, 431–455.

Stern, D.I. The rise and fall of the environmental Kuznets curve. *World Dev.*2004, *32*, 1419–1439.

Vukina, T.; Beghin, J.C.; Solakoglu, E.G. Transition to markets and the environment: Effects of the change in the composition of manufacturing output. *Environ. Dev. Econ.*1999, *44*, 582–598.

Brajer, V.; Mead, R.W. Searching for an environmental kuznets curve in China’s air pollution. *China Econ. Rev.*2011, *22*, 383–397.

Walter, B. Sustainable Cities: Conespts and Strategies for Eco-City Development; Eco-Home Media: Los Angeles, CA, USA, 1994.