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Spatiotemporal Relationship Between Ecological Environment and Economic Development in Tropical and Subtropical Regions of Asia

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Abstract

This article is devoted to study the coordination coupling relationship between economic development and ecological environment in tropical and subtropical regions of Asia to reflect the spatiotemporal heterogeneity of the coordination in different regions. Using the entropy method and Geographically and Temporally Weighted Regression model, we empirically analyze 14 tropical and subtropical countries in Asia from 2003 to 2016. The empirical results show that most of the tropical and subtropical sample countries in Asia are at an intermediate coordination coupling level between economic development and ecological environment; the economic development lag type is the main one, and the ecological development lag type is less. At the same time, the positive effects between economic development and ecological environment in most sample countries are more obvious. Spatially, the ecological environment in the north of the Asian tropical and subtropical countries has a positive effect on economic development rather than that in the south and tends to be positive. The positive effect of economic development on ecological environment in the faster economic development areas is better than that in the slower economic development areas, and more areas tend to play negative effects. The research in this article provides a basis for strengthening ecological environment protection in tropical and subtropical regions of Asia, promoting the coordinated development of economic and ecological environment. Further, we put forward some corresponding policy recommendations.

Keywords

economic development, ecological environment, coordination coupling degree measurement, Geographically and Temporally Weighted Regression model, China

Introduction

At present, Asia has become an important pole of global economic growth. In 2018, the gross domestic product (GDP) of the Asian region accounted for more than one third of that in the world, and regional economic growth accounted for more than 60% of the world, prominently manifested in the tropical and subtropical regions of Asia, such as China, India, and Indonesia. Among them, the GDP of China and India is as high as $13.61 trillion dollars and $2.73 trillion dollars, respectively, with each economic growth rate of over 6%, and thus, they become one of the new drivers of global economic growth (International Monetary Fund, 2018). However, these countries are also the areas with the highest population density and low per capita income in Asia. It is precisely the low quality of economic development resulting in extensive development of natural resources, such as oil, natural gas, and rain forests, as well as the substantial imbalance issues between

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ecological environment and development (Sherman, Peterson, Damar, & Wagey, 2019). Therefore, the rapid development of economic speed and the low economic quality of tropical and subtropical regions in Asia, as well as the resulting ecological and environmental problems, have become important concerns of this study.

In practice, the ecological and environmental problems caused by excessive pursuit of economic growth have become an important resistance to the socioeconomic development of tropical and subtropical regions of Asia (L. Li & Liu, 2019; Y. Li, Li, Wu, Zhang, & De, 2018). Theoretically, these are typical phenomena of the environmental Kuznets inverted U-shaped curve, showing that with the further increase of per capita income, the seriousness of the ecological environment caused by environmental pollution will also change from low to high. After the critical point, the ecological environment will gradually decline. The tropical and subtropical regions of Asia basically cover Asian emerging markets and developing economies, most of which are in transition phases of extensive growth or from extensive growth to high quality growth (Nepal & Paija, 2019; Zaidi, Zafar, Shahbaz, & Hou, 2019). Under the background that the global climate is gradually warming and environmental issues have become a basic global consensus, how to promote the coordinated development of the environment and the economy to achieve a win–win situation is essential for the socioeconomic development of tropical and subtropical regions of Asia. Hence, it is of great practical significance to study the coordination coupling degree between economic development and ecological environment in Asia.

Traditional Environment Kuznets Curve (EKC) theory believes that environmental pollution not only has scale effect, technical effect, and structural effect but also has strong spatial spillover effect (Du et al., 2019; Xie, Xu, & Liu, 2019). However, the traditional spatial econometric model can only observe the overall effect between samples, and it is difficult to observe the individual heterogeneity of sample space effects. Fortunately, the Geographically and Temporally Weighted Regression (GTWR) model can overcome these deficiencies (Huang, Wu, & Barry, 2010). In this sense, this article uses the GTWR model to analyze the spatiotemporal heterogeneity of the coordination coupling degree of ecology and economy in tropical and subtropical regions of Asia. Besides, from a theoretical and practical point of view, it is very significant to study on this topic. On the one hand, from the perspective of the promotion of relevant theories, the advancement of the relationship between the whole and the parts is a reference for further study; on the other hand, we can get the spatiotemporal heterogeneity characteristics of each country from the application of GTWR.

This article is structured as follows: The upcoming section is a literature review regarding the coordination of economic development and ecological environment, which is followed by a section that describes the coupling coordination degree measurement method and GTWR model. A further section explores the spatiotemporal disparities of the coordination coupling degree of economic development and ecological environment, which is followed by a section that describes the difference of spatiotemporal heterogeneity of the relationship between economic development and ecological environment. The final section presents the conclusion and recommendations.

Literature Review

The relationship between economic development and the ecological environment has always been the focus of academic discussions and an important basis for government decision-making and residents' physical, social, and psychological well-being. Governments have been formulating and implementing policies to mitigate environmental deterioration in cities (Wan, Shen, & Choi, 2017).

In ecological economics, on the one hand, the important determining factors of environment are scale, composition, and technology (Song, Fisher, & Kwoh, 2019; Yao, Huang, & Song, 2019); on the other hand, the increases in the generation of wastes and the use of materials and energy (showing in scale) have generally been related in economic growth (Yao et al., 2019). These concepts are associated with the environmental Kuznets curve (Victor, 2010).

There are some evidences of the relationship between economic development and ecological environment from different perspectives. Such as examining the road-induced tradeoffs among biodiversity loss, deforestation, and economic growth, since roads are vital for the economic development from the perspective of ability of bringing significant economic benefits (Damania, Russ, Wheeler, & Barra, 2018); considering poverty among environment, economy, and social in development economics (Haider, Boonstra, Peterson, & Schlüter, 2018); and concerning the alleviation of climate change and deforestation under ecological economic conditions (Bakaki & Bernauer, 2018).

Some have similar and direct evidences. Many investigate the relationship between economic growth and CO_2 emissions associated with both consumption and production behavior (Fernández-Amador, Francois, Oberdabernig, & Tomberger, 2017; Rezai, Taylor, & Foley, 2018) and believe that there is a bidirectional causal relationship between economic growth and carbon emissions (Belke, Dobnik, & Dreger, 2011; Wang, Zhou, Zhou, & Wang, 2011). The expansion is that besides economic growth and carbon emission, bidirectional causality also exists between energy consumption and carbon emissions (Wang et al., 2011). And the tradeoffs appear again.

Climate change lowers profitability and reduces investment probability and resulting in cutting output in the short and long runs: On the one hand, deficient demand brings employment falling in short run; on the other hand, productivity growth becomes slower, such lowering the potential income in the long run (Rezai et al., 2018). In many countries, such as in China, reducing carbon emissions is quite difficulty since it will handicap China's economic growth, and will not decrease carbon emissions in a long period (Wang et al., 2011); while for 14 Asian countries, the natural environment will become a victim of increased economic growth (Uddin, Alam, & Gow, 2019). Despite that, not many of them have taken adequate measures to increase their capacity of bioproductive or to reduce their energy inefficient until now (Uddin et al., 2019); however, efficiency is crucial and many scholars estimate energy efficiency (Song & Li, 2019); similarly, during the period of 1995–2013, for the 12 transition economies with high income, the economic growth has increased the energy consumption, while for the countries with low income, the former has reduced the latter (Pablo-Romero, Sánchez-Braza, & Anna, 2019); even some scholars have also assessed the cost of ecological losses: The economic losses of ecological cost is \$2,076/person in South Korean during 1980–2000 (Lee & Kim, 2018). We should realize that we must pay attention to the use of ecological characteristics, which are completely different from those of artificial resources, if we expect the quality of life to be sustained.

In contrast, there are also some related but different opinions. Some scholars hold that there is no a long run causal relationship between income and emissions, and it is not necessary to abandon economic growth to reduce carbon emissions (Soytas & Sari, 2009). The growth of the national economy has been accompanied by changes in industrial and environmental policies, which have promoted the improvement of water quality. The turning point in improving water quality occurs in the later stage of economic development of industrial pollution, rather than biological pollution (Choi, Hearne, Lee, & Roberts, 2015). In addition to these empirical results, survey data show that in developed countries, most respondents believe that environmental protection and economic growth can be achieved simultaneously (Drews & van den Bergh, 2017; Drews, Antal, & van den Bergh, 2018), especially when the GDP growth rate exceeds 3% (Drews & van den Bergh, 2016). In addition, Yu et al. (2017) find the evidence that in the context of rapid economic growth, environmental pressure is not related to economic growth in Chongqing of China, among which technological change was the dominate factor.

In addition to the positive or negative correlation between the economic growth and ecological environment, there is a large amount of evidences of nonlinear relationships, which is consistent with the EKC hypothesis (Charfeddine, 2017; Zhou, Zhang, Shao, & Wang, 2019).

In summary, some literature has suggested that there may be a tradeoff relationship or mutual promotion relationship between economic development and the ecological environment, which is related to the different stages of economic development and the specific conditions of the ecological environment. It can be seen that the degree of coordination between economic development and ecological environment is a topic worthy of study. This article discusses the relationship between the two in the Asian region to assess whether they are coordinate or not and can also propose some targeted policy recommendations.

Methods

The Coordination Coupling Degree Measurement of Economic Development and Ecological Environment

Zhang, Shang, and Xiong (2019) introduced information entropy to describe the uncertainty of the signals from the signal source. In information theory, the entropy value method determines the weighting coefficient, and the entropy value reflects the degree of disorder of information, which can be used to measure the size of information. The more information an indicator carries, the greater its effect on decision making, indicating that the greater the impact of this indicator on decision-making. Therefore, this article first uses the entropy method to measure the comprehensive levels of economic development and ecological environment in the sample area and then employs the coupling coordination method to measure the coupling coordination coefficient between economic development and ecological environment.

First, based on the extreme value method, x_{ij} represents the value of indicator j in the sample region i ($i=1,\ldots, n$, $j=1,\ldots, m$) and is standardized as follows:

$$x_{ij}^{+} = \frac{x_{ij} - \min\{x_{1j}, \ldots, x_{nj}\}}{\max\{x_{1j}, \ldots, x_{nj}\} - \min\{x_{1j}, \ldots, x_{nj}\}} \tag{1}$$

In Equation (1), x_{ij}^{+} represents the positive indicator (if it is the negative, the denominator can be kept unchanged, and the numerator can be changed to $\max\{x_{1j}, \ldots, x_{nj}\} - x_{ij}$). $\max\{x_{1j}, \ldots, x_{nj}\}$ and $\min\{x_{1j}, \ldots, x_{nj}\}$ represent the maximum and the minimum values of the indicator, respectively. To avoid the case that the indicator x_{ij}^{+} (or x_{ij}^{-}) may be equal to 0 after the logarithm, we add with 1 to the indicator and get $(x_{ij}^{+}+1)$ or $(x_{ij}^{-}+1)$.

Second, we calculate the entropy value e_j of indicator x_{ij}:

$$e_j = -k\sum_{i=1}^{n} p_{ij} \times \ln(p_{ij}) \tag{2}$$

where $p_{ij} = (1 + x_{ij}^{+}) / \sum_{i=1}^{n} (1 + x_{ij}^{+})$ (or $p_{ij} = (1 + x_{ij}^{-}) / \sum_{i=1}^{n} (1 + x_{ij}^{-})$), $k = 1/\ln(n)$ satisfies the condition $e_j \geq 0$.

Third, we calculate the comprehensive evaluation index S_i of the sample area i:

$$S_i = \sum_{j=1}^{m} w_j \times x_{ij}^{+} \quad \text{or } S_i = \sum_{j=1}^{m} w_j \times x_{ij}^{-} \qquad (3)$$

In Equation (3), the information entropy value of the indicator j is $w_j = d_j / \sum_{j=1}^{m} d_j$, where $d_j = 1 - e_j$. According to the abovementioned steps, the comprehensive evaluation indexes of economic development and ecological environment are calculated separately and set to $S_{ENY,i}$ and $S_{ECG,i}$.

Fourth, the coupling coefficient C_i of the comprehensive evaluation indexes of economic development and ecological environment is calculated as follows:

$$C_i = \left\{ \frac{S_{ENY,i} \times S_{ECG,i}}{\left(\frac{S_{ENY,i} + S_{ECG,i}}{2} \right)^2} \right\}^k, \quad (k \geq 2) \qquad (4)$$

In Equation (4), we take $k = 2$ since only the comprehensive evaluation indexes of economic development and ecological environment are considered. And at the same time, the larger the C_i, the higher the degree of coupling between the two. Furthermore, to better reflect the systemization and coordination between the two indicators, there is the coupling coordination coefficient D_i, shown as follows:

$$D_i = \sqrt{C_i \times T_i}, \quad T_j = \alpha S_{ENY,i} + \beta S_{ECG,i} \qquad (5)$$

In Equation (5), α and β represent the important weight indicators of economic development and ecological environment, respectively. Considering the importance of each country to the environment, we set $\alpha = \beta = 0.5$ to avoid the deviation of cognition between economic development and ecological environment. We divide the actual types of economic development and ecological environment in the sample countries according to: $\gamma_i = S_{ENY,i} / S_{ECG,i}$; when $\gamma_i > 1$, the sample countries belong to ecological lag type; when $\gamma_i < 1$, they belong to economic lag type; when $\gamma_i = 1$, an economic-ecological synchronization type is formed. Furthermore, in order to better demonstrate the heterogeneous characteristics between economic development and ecological environment in tropical and subtropical sample countries of Asia, this article divides the coupling coordination level evaluation system of the two by drawing from the extant research results, as shown in Table 1.

Relationship Between Economic Development and Ecological Environment

Furthermore, we analyze the relationship between economic development and ecological environment in the

Table 1. Coupling Coordination Grade Evaluation Criteria of Economic Development and Ecological Environment.

Coordination coupling degree D	Grade	Effects compared	Type
$0.8 < d_j \leq 1$	Good coordination (v1)	$S_{ED} < S_{EL}$	Economic development lag
		$S_{ED} \approx S_{EL}$	Economic-ecological synchronization
		$S_{ED} > S_{EL}$	Ecological development lag
$0.6 < d_j \leq 0.8$	Intermediate coordination (v2)	$S_{ED} < S_{EL}$	Economic development lag
		$S_{ED} \approx S_{EL}$	Economic-ecological synchronization
		$S_{ED} > S_{EL}$	Ecological development lag
$0.5 < d_j \leq 0.6$	Primary coordination (v3)	$S_{ED} < S_{EL}$	Economic development lag
		$S_{ED} \approx S_{EL}$	Economic-ecological synchronization
		$S_{ED} > S_{EL}$	Ecological development lag
$0.4 < d_j \leq 0.5$	Primary imbalance (v4)	$S_{ED} < S_{EL}$	Economic development lag
		$S_{ED} \approx S_{EL}$	Economic-ecological synchronization
		$S_{ED} > S_{EL}$	Ecological development lag
$0.2 < d_j \leq 0.4$	Intermediate imbalance (v5)	$S_{ED} < S_{EL}$	Economic development lag
		$S_{ED} \approx S_{EL}$	Economic-ecological synchronization
		$S_{ED} > S_{EL}$	Ecological development lag
$0 < d_j \leq 0.2$	Extreme imbalance (v6)	$S_{ED} < S_{EL}$	Economic development lag
		$S_{ED} \approx S_{EL}$	Economic-ecological synchronization
		$S_{ED} > S_{EL}$	Ecological development lag

Note. $S_{ED} \approx S_{EL}$ refers to $|S_{ED} - S_{EL}| \leq 0.1$.

tropical and subtropical sample countries of Asia. Compared with the traditional spatial econometric model, the GTWR model can better reflect the individual heterogeneity of the spatiotemporal relationship between variables, which is highlighted by the changes of variable coefficients of each sample at each time. Using the GTWR model, Cheng, Dai, and Ye (2016) analyzed the spatiotemporal difference of industrial pollution in China. And based on their model, we analyze the interrelationship between economic development and ecological environment in the tropical and subtropical sample countries of Asia. The model is as follows:

$$S_{ENY,i} = \beta_0(m_i, n_i, s_i) + \sum_{i=1}^{k} \beta_i(m_i, n_i, s_i) S_{ECG,i} + \delta_i \quad (6)$$

In Equation (6), (m_i, n_i, s_i) represents the spatial coordinates of the *i*-th country, δ_i indicates random elements. The spatiotemporal distance of data point (m_0, n_0, z_0) from any point (m_i, n_i, t_i) in the sample country is measured by d. The spatiotemporal distance can be expressed as a linear combination of the time distance d^T and the spatial distance d^S: $d = \lambda d^T + \gamma d^S$. The spatiotemporal weight is determined by the Gaussian function, where $w_{ij} = e^{-\left(\frac{d_{ij}}{b}\right)^2}$. d_{ik} is the distance between the sample point i and k, b is the bandwidth, which is obtained when $cv = \min\left(\sum_{i=1}^{n} [y_i - \hat{y}_i(b)]^2\right)$ takes the minimum value, and $\hat{y}_i(b)$ is the fitting value of y_i.

Variable Selection and Research Scope Definition

Variable selection. Considering the availability of data in tropical and subtropical countries in Asia, this article develops the comprehensive evaluation index system of economic development and ecological environment in combination with the design of existing scholars' indicators. Among them, the evaluation indicators for economic development comprise economic development scale, structure, and level, while those for ecological environment consist of environmental level and environmental pollution, as shown in Table 2.

Economic development evaluation indicators. Generally speaking, the economic development scale indicators are mainly represented by total economic development. The commonly used indicator is GDP. The larger the value of GDP is, the larger the economic development scale is. In practice, the developed economies of the world are generally the countries with a high degree of industrial and service development. The higher the degree of development of secondary and tertiary industries, the more the economic development promoted. To this end, the structural indicators of economic development are mainly expressed by the ratios of them. The indicator of economic development level is represented by variable per capita GDP, the urbanization rate, and the proportion of taxation to GDP ratio. Among them, the higher the per capita GDP level indicates that a country has a higher standard of living and stronger the purchasing power, which is conducive to consumption-driven economic development; the higher the urbanization rate, the more favorable the aggregation effect of population, land, and other factors released, thus pushing economic development; the higher the proportion of taxation to GDP, the worse the tax environment of economic development level, thereby being not conducive to economic development.

Ecological environment evaluation indicators. The ecological development environment level is represented by the variable PM_{10} (national level) emissions and per unit GDP energy consumption. Wherein the lower the PM_{10} emissions, the better the regional ecological environment, especially the better the air quality, showing a direct evidence of good ecological environment development; per unit GDP energy consumption manifests the clean and

Table 2. Evaluation Indicator System of Economic Development and Ecological Environment.

First class indicator	Second class indicator	Third class indicator	Attributes of indicator
Economic development	Scale of economic development	GDP (hundred million dollars)	+
	Economic structure	Percentage of added value of industry in GDP (%)	+
		Percentage of added value of service industry in GDP (%)	+
	Economic development level	Per capita GDP (dollars)	+
		Urbanization rate (%)	+
		Percentage of tax in GDP (%)	−
Ecological environment	Ecological environment level	PM_{10} discharge (micrograms per cubic meter)	−
		The amount of energy used per unit of GDP (purchasing power parity dollar/kilogram petroleum equivalent)	−
	Ecological environment pollution	Industrial sulfur dioxide emissions (ten thousand tons)	−

Note. GDP = gross domestic product.

green of the economic development of a country. The lower the level is, the stronger the greening ability of economic development in the country, and the more favorable the healthy development of the regional ecological environment. Sulfur dioxide is the main emission of regional ecological pollution, including automobile exhaust and industrial emissions. The higher the emissions are, the more unfavorable the regional ecological environment. Therefore, the emission of sulfur dioxide reflects the degree of ecological pollution in the region. Table 3 shows the descriptive statistics for the aforementioned variables.

Research scope. The definition of tropical and subtropical regions of Asia bases on Corlett (2013). The provinces and cities located at the tropical areas in Asia include Bangladesh, Cambodia, India, Indonesia, Malaysia, the Philippines, Sri Lanka, Thailand, and Vietnam. The subtropical regions comprise Iran, Iraq, Japan, Jordan, Pakistan, Qatar, China, and Japan. As the statistics database of World Bank lacks of data with regard to the economic development and ecological environment of some of the above regions, only 14 countries or regions such as China, Malaysia, Thailand, Indonesia, Philippines, Vietnam, Cambodia, Myanmar, India, Sri Lanka, Pakistan, Bangladesh, Nepal, and Singapore were selected as our samples. At the same time, combined with the availability of sample data, the interval of inspection time was from 2003 to 2016. The data used in this article come from the statistics database (2003–2016) of World Bank unless otherwise specified.

Results

Analysis of Temporal and Spatial Characteristics of Coupling Coordination Degree in Sample Areas

Analysis of temporal difference of regional coupling coordination degree. Figure 1 displays the coupling coordination degree and the trend of each level between 2003 and 2016. First, the coupling coordination coupling degree in the sample Asian countries has steadily increased. Since 2003, the coordination coupling degree of economic development and ecological environment in tropical and subtropical regions of Asia has remained above 0.59, mainly in primary coordination and intermediate coordination. Among them, the coordination coupling value is between 0.5 and 0.6 from 2003 to 2007, belonging to the primary coordination stage; the coupling coordination value is between 0.6 and 0.63 from 2007 to 2016, which is in the intermediate coordination stage. It is worth noting that before 2005, the coordination coupling degree of economic development and ecological environment in the sample countries has gradually decreased. In contrast, the value has steadily increased after 2005. The reason is that in 2005, the countries, represented by China and India, issued some environmental protection policies, which made environmental protection stricter and results better. Among them, China released 104 environmental protection standards and 7 laws and regulations such as the "Law of the People's Republic of China on the Prevention and Control of Solid Waste Pollution" in 2005. It is the year when China's national environmental protection standards have issued the most, significantly enhancing the protection of ecological environment. Not coincidentally, India issued the draft of "National Environmental Protection Policy (2006)" to promote environmental protection from a legislative perspective in 2006. Second, most Asian tropical and subtropical sample countries have the coupling coordination levels that are at the intermediate level or above. In Figure 1, the proportion of countries with the coordination coupling degrees at the intermediate level and above has increased steadily from 57.14% in 2003 to 71.43% in 2016; the number of sample areas in primary coordination has steadily declined from the highest level of 21.43% between 2008 and 2013 to the lowest value of 7.14% in 2016; the number of sample areas with basic imbalance level decreased steadily, from 35.71% in 2003 to 21.43% in 2016; the number of sample areas in quality coordination is relatively small and the ratio is stable, keeping

Table 3. Descriptive Statistics of Variables.

Variables	Mean	Standard deviation	Min	Max	Observations
GDP	6,971.19	18,211.09	46.58	111,991.00	196
Percentage of secondary industry	31.92	8.75	14.26	48.53	196
Percentage of tertiary industry	50.08	8.98	35.12	75.20	196
Per capita GDP	5,300.62	11,203.68	219.78	56,336.07	196
Urbanization rate	40.77	21.78	14.56	100.00	196
Percentage of taxation to GDP	11.88	3.98	2.21	22.40	196
PM_{10} emissions	79.82	41.10	24.53	218.39	196
SO_2 emissions	81,726.79	219,980.10	237.99	1,134,685.00	196
Per unit GDP energy consumption	9.36	3.89	3.51	23.84	196

Note. GDP = gross domestic product.

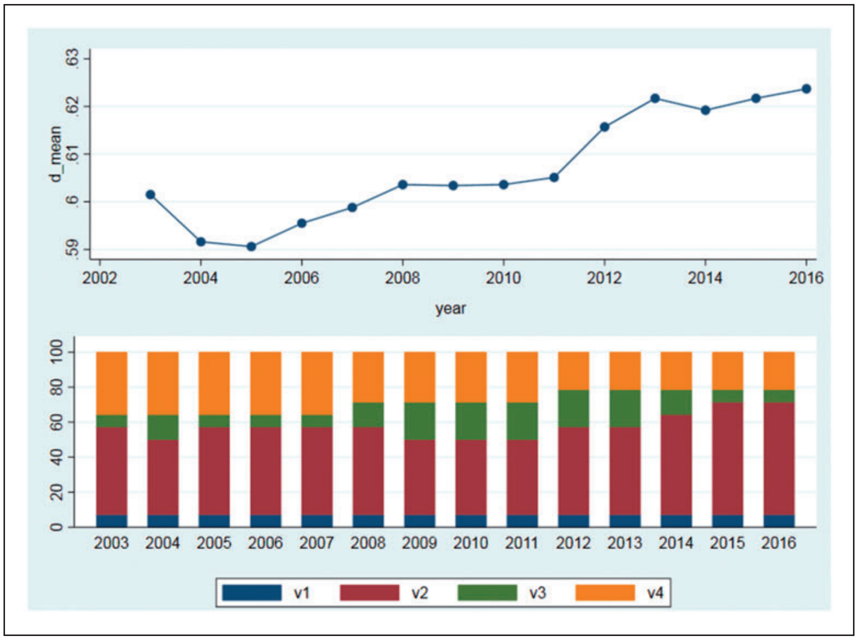

Figure 1. The coupling coordination degree and percentage trend of tropical and subtropical sample countries in Asia during 2003–2016.

around 7.14%. There are no sample countries with moderate and extreme imbalance levels. In summary, it is believed that economic development and ecological environment in the tropical and subtropical sample countries of Asia are gradually becoming more coordinated.

Analysis of spatial characteristics of coupling coordination degree. Figure 2 reports the spatial distribution of coupling coordination degrees in the tropical and subtropical sample countries of Asia in 2003, 2007, 2011, and 2016, respectively. In general, the coupling coordination degree of tropical and subtropical regions in Asia shows a spatial distribution pattern decreasing from the east to the west. First, there are few high-quality coordination countries, and only China is in this type during the sample period. Second, there are many countries belonging to intermediate coordination stage and are concentrated in Southeast Asia such as Singapore and Malaysia. Third, there are fewer countries at the primary coordination stage and are distributed centrally in South Asia such as India, Vietnam, and Myanmar. Fourth, there are few countries at the primary coordination stage and are distributed centrally in South Asia such as Pakistan and Nepal.

Coupling coordination degree types in sample countries. Furthermore, the coupling coordination degree of economic development and ecological environment is divided into three types: ecological development lag type, economic-ecological synchronization type, and economic development lag type. The division results are shown in Table 4. First, the number of countries with economic development lag type has gradually increased. In 2003, there were 11 countries or regions belonging to this type, while in 2010 and 2016, the number rose directly to 13. That is to say, except for Singapore, where the coupling coordination grade is ecological development lag type, the rest of the Asian tropical and subtropical sample countries were subject to the economic development lag type, indicating that there was still a room for improvement in the economic development level to meet the ecological balance. Meanwhile, when the coupling coordination grade is economic development lag type, except China, the rest of the countries mainly belonged to intermediate coordination, which is relatively low. Second, the number of regions of ecological development lag type has been reduced. In 2003, Singapore, Malaysia, and Pakistan all belonged to ecological development lag type, while in 2010, this type only included Singapore, and since then only Singapore has been in this type. Simultaneously, Singapore was at the intermediate coupling coordination level. As a result, it is believed that during the inspection period, economic development and ecological environment of the sample countries were not coordinated, mainly dominated by the economic development lag type, but the ecological development lag type was relatively less.

Spatiotemporal Disparities of Mutual Influence Between Economic Development and Ecological Environment

Estimation of the relationship between economic development and ecological environment in sample countries. To simplify the analysis, this article focuses on the interrelationship

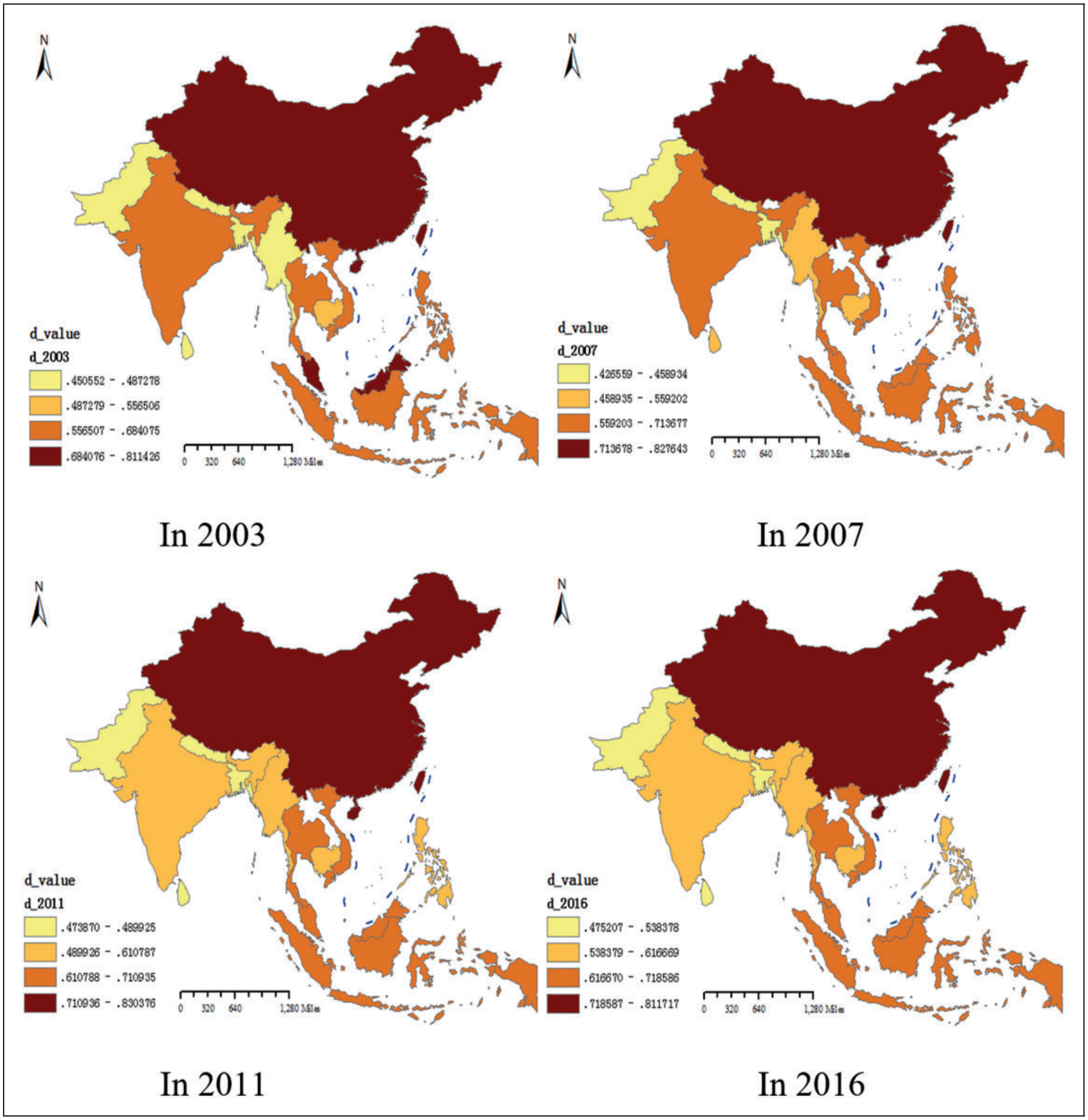

Figure 2. Spatial distribution of regional coupling coordination degrees in 2003, 2007, 2011, and 2016.

between ecological environment and economic development in the sample countries and uses the GTWR model to estimate the models of both as dependent variables and independent variables. In the estimated results, the goodness of fit, Akaike's information criterion value, and Spatiotemporal Distance Ratio value are 0.9112, −1,108.5567, and 1.9210, respectively, when the dependent variable is economic development comprehensive evaluation index; while these values are 0.9218, 1.9210, and 1.9210, respectively, when the dependent variable is ecological environment comprehensive evaluation index. It indicates that the estimation results of the two models are statistically significant. Figure 3 presents the kernel density distribution of the estimated parameters of the two models. The results show that (a) the ecological environment coefficients are concentrated between −0.8 and 1.21, and there are more coefficients greater than 0 when the dependent variable is economic development comprehensive evaluation index. (b) The economic development coefficients are concentrated between −1 and 1.8, and there are more coefficients greater than 0 when the dependent variable is ecological

Table 4. Major Types of Regional Coupling Coordination in 2003, 2010, and 2016.

Type	2003	2010	2016
Ecological development lag	Singapore, Malaysia, and Pakistan	Singapore	Singapore
Economic-ecological synchronization	None	None	None
Economic development lag	China, Thailand, Indonesia, Philippines, Vietnam, Cambodia, Myanmar, India, Sri Lanka, Bangladesh, and Nepal	China, Malaysia, Thailand, Indonesia, Philippines, Vietnam, Cambodia, Myanmar, India, Sri Lanka, Pakistan, Bangladesh, and Nepal	China, Malaysia, Thailand, Indonesia, Philippines, Vietnam, Cambodia, Myanmar, India, Sri Lanka, Pakistan, Bangladesh, and Nepal

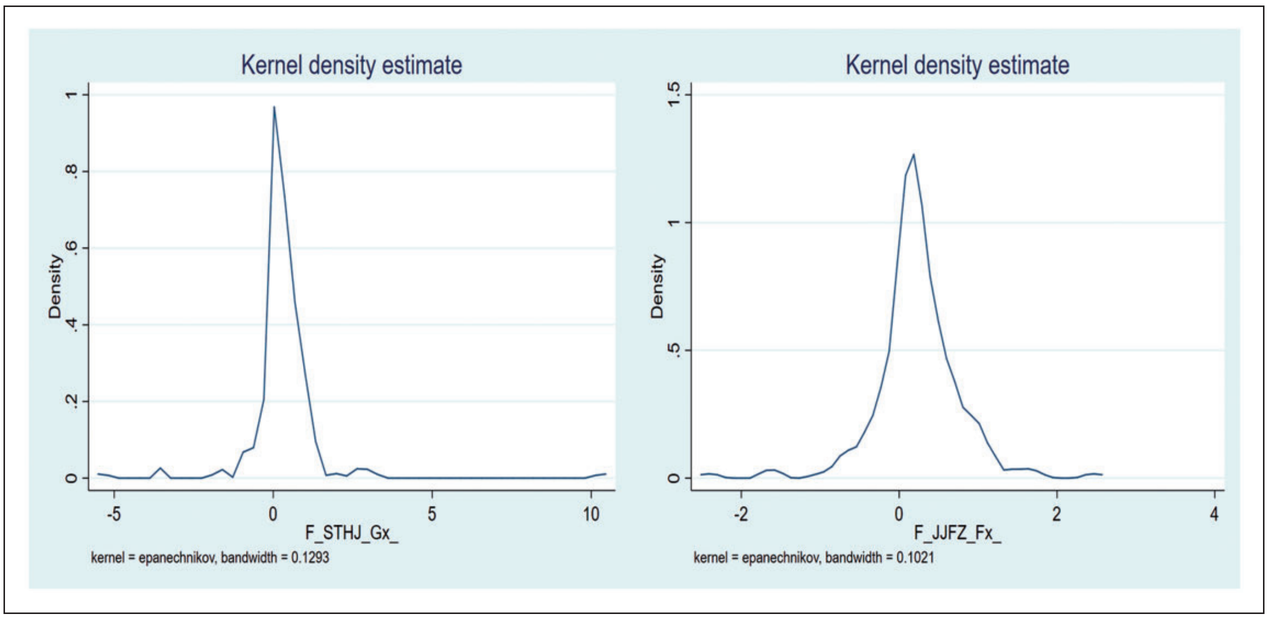

Figure 3. Kernel density distribution of variable coefficients.

environment comprehensive evaluation index. These imply that (a) there is a positive correlation between economic development and ecological environment in most Asian tropical and subtropical sample countries during 2003–2016 and (b) economic development is conducive to the improvement of ecological environment, and vice versa.

The spatiotemporal disparities in the relationship between economic development and the ecological environment. Figure 4 shows the spatiotemporal disparities in the impact of ecological environment on economic development in the sample countries. In general, from 2003 to 2016, there were more countries where ecological environment had a positive impact on economic development than those countries where ecological environment had a negative impact in tropical and subtropical regions of Asia. Among them, the impact coefficients of eight sample countries tend to be positive, spatially distributed in the northern regions, such as China, India, Indonesia, Nepal, Bangladesh, Cambodia, Myanmar, and Malaysia; the coefficients of the six sample countries tend to be negative, spatially distributed in the southern regions, namely, Pakistan, Sri Lanka, Singapore, the Philippines, Vietnam, and Thailand. It indicates that the positive effect that ecological environment plays on economic development in the northern tropical and subtropical region of Asia is better than that in the southern.

It is worth noting that as environmental protection supervision by emerging economies such as China is strengthened, some labor-intensive and extensive enterprises have gradually shifted to Southeast Asia, such as Vietnam, Thailand, the Philippines, Pakistan, and Indonesia. Meanwhile, the development of the tertiary industry represented by tourism has also aggravated the development of primitive ecological environment in countries such as Sri Lanka. In these countries, the development of the tertiary industry on the one hand drove the rapid economic

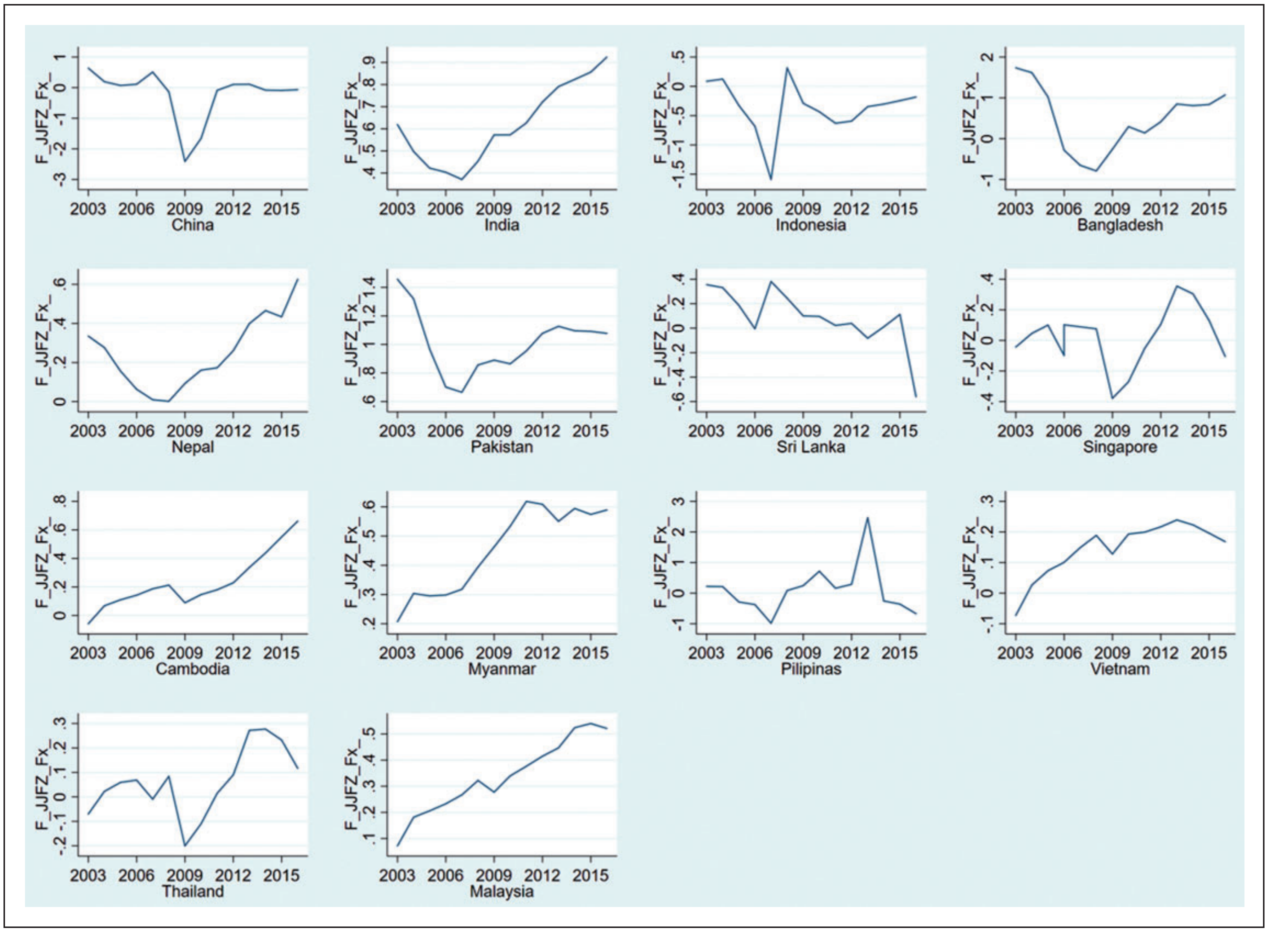

Figure 4. The trend of the impact of ecological environment on economic development in tropical and subtropical countries of Asia during 2003–2016.

development, but on the other hand increased the difficulty of environmental protection to some extent, which made the ecological environment show negative feedback on economic development. In addition, similar to the developed economies such as Singapore, due to the intensive emissions of national shipping, the per unit GDP energy consumption is higher, resulting in the exacerbated difficulty of environmental governance.

Figure 5 presents the spatiotemporal disparities in the impact of economic development on ecological environment in the sample countries. In general, from 2003 to 2016, the number of the tropical and subtropical sample countries of Asia where the impact of economic development on ecological environment tends to be positive was larger than these with negative impact. Among them, the countries where economic development had a positive impact on ecological environment are those with rapid economic development, such as China, the Philippines, Vietnam, and Thailand. Compared to this, the countries where economic development tends to have a negative impact on ecological environment include India, Indonesia, Bangladesh, Cambodia, Nepal, Pakistan, Sri Lanka, Singapore, Myanmar, and Malaysia, which have relatively slow economic development. It indicates that the positive impact of economic development on ecological environment in faster economic development sample countries is better than that in the slower ones. The rapid economic development, on the one hand, is able to provide the local government with sufficient fiscal revenues and environmental governance capacity, such as the Philippines and Vietnam. On the other hand, it provides relatively strong ability to adjust industrial structure to achieve the governance of ecological environment, such as China.

Discussion

Based on the data of 14 tropical and subtropical sample countries of Asia from 2003 to 2016, this article uses the entropy method to analyze the coupling coordination degree between economic development and ecological environment and employs the GTWR model to analyze the impact of spatiotemporal heterogeneity between

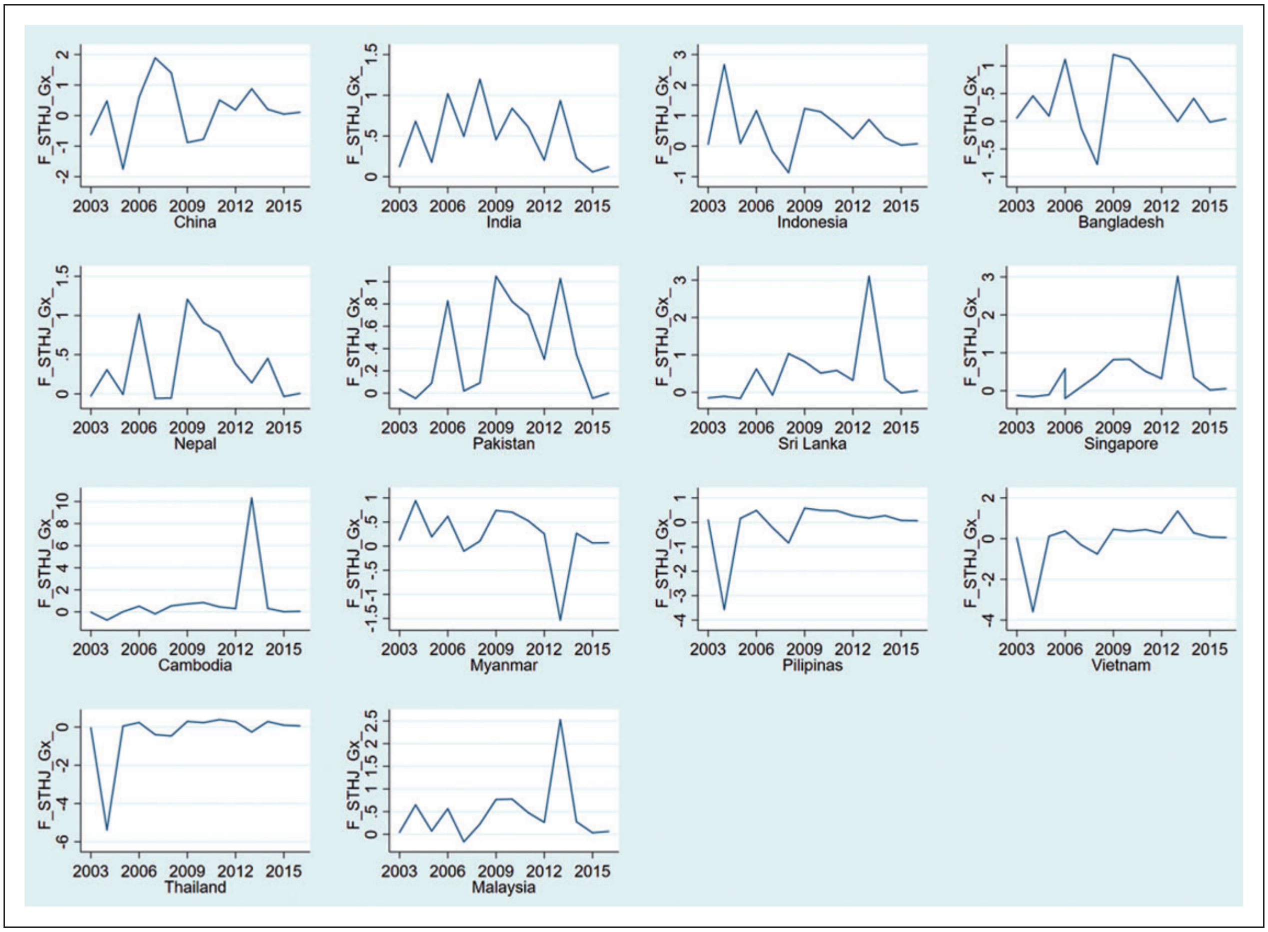

Figure 5. The trend of the impact of economic development on ecological environment in tropical and subtropical countries of Asia during 2003–2016.

economic development and ecological environment. The results show that:

1. In general, from 2003 to 2016, economic development and ecological environment of tropical and subtropical countries of Asia are at the intermediate coordination coupling level, dominated by economic development lag type, followed by ecological development lag type, with no country of economic-ecological synchronization type; spatially, the ecological development lag type is mainly distributed in the developed countries, such as Singapore, and the economic development lag type in most areas of the sample. From this point of view, vigorous development of the economy is still a top priority rather than the ecological environment for most tropical and subtropical countries in Asia. According to the experience of a few developed countries in Asia, in the process of development, the developing countries should make full use of the benefits of circular economy (de Oliveira, Machado, Jabbour, & de Sousa Jabbour, 2019), introduce technology and support from developed countries, and strengthen cooperation so as to balance the ecological environment.
2. At the same time, there is a significantly positive effect between economic development and ecological environment in most sample countries; however, spatiotemporal heterogeneity is strong. In this sense, the positive effect of ecological environment on economic development in the north of the tropical and subtropical countries of Asia is better than that in the south, and more countries tend to have positive effects; the positive effect of economic development on ecological environment in the faster economic development areas is better than that in the slower economic development areas, and more areas tend to play negative effects. Accordingly, full consideration should be given to the spatiotemporal linkages between different countries, so as to promote the backward development with advanced ones, the exchange of economic development experience and the good interaction of the ecological environment, and the harmonious and friendly economic development of tropical and subtropical regions of Asian with high quality.

3. Finally, the coupling coordination degree of China is higher than the other tropical and subtropical countries in Asia, while the major type of coupling coordination is still the economic development lag as for the most countries in research period and means that the higher coupling coordination degree of China is a lower quality degree. From this view, the economic development for China should be enhanced, but to emphasize the ecology development in the current stage will be of more importance.

Implications

On March 13, 2019, the United Nations released Global Environment Outlook 6, which was the most comprehensive and rigorous assessment of the state of the global environment over a 5-year period. The report pointed out that the earth has been extremely seriously damaged. If no urgent and more intense actions are taken to protect the environment, the earth's ecosystem and human sustainable development will increasingly be threatened more seriously. And put forward that to achieve the vision of "healthy earth, healthy human beings," we need to open up a new way of thinking, that is completely abandon the development mode of "only paying attention to immediate interests, regardless of the future," and transform to an economic model of almost zero-waste by 2050.

1. The first is to deeply integrate the green development concept into economic development to fully understand the prominent role of green development in the global economic development pattern, especially in tropical and subtropical developing countries of Asia. The concept of green development can be integrated into the whole process of economic development, emphasizing the development and application of green technologies (Jin, Peng, & Song, 2019), and adjust the economic development structure, especially reducing the high polluted industry of mining, thermal power generation, and so on, and develop the third industry, such as tourism for the rich natural resource. It thus gradually releases economic value and social value of green development, in the hope of promoting healthy and sustainable economic development.
2. The second is to strengthen the protection of ecological environment in the process of economic development. On the one hand, it needs to continuously improve the utilization efficiency of energy resources such as water, oil, natural gas, and electric energy, as well as reduce the economic energy consumption. On the other hand, it continues to increase the upgrading of energy-saving and emission-reducing equipment to reduce the emissions and toxic content of waste gas, waste water, and solid waste, especially in tropical and subtropical regions of Asia which have high levels of economic development, as these areas need more energy to make use of their advantages to strengthen the protective effect of biotechnology innovation on ecological environment. In addition, it can also increase the development of renewable energy such as nuclear energy, solar energy, and tidal energy, and gradually uses renewable energy to replace nonrenewable energy resources such as oil (Chen, Wu, Xu, Song, & Liu, 2019).
3. The third is to promote the harmonious development of economy and ecology adapting to local conditions. For countries of economic development lag type, it should continue to increase the economic development and improve the economic support on ecological environmental protection, such as strengthening the fiscal and financial support, especially for China. For the countries of ecological development lag type, it should strengthen the protection of ecological environment to steadily release the positive effects of ecological environment on economic development.

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Reference

Bakaki, Z., & Bernauer, T. (2018). Do economic conditions affect public support for environmental policy? *Journal of Cleaner Production*, *195*, 66–78. doi:10.1016/j.jclepro.2018.05.162
Belke, A., Dobnik, F., & Dreger, C. (2011). Energy consumption and economic growth: New insights into the cointegration relationship. *Energy Economics*, *33*(5), 782–789. doi:10.1016/j.eneco.2011.02.005
Charfeddine, L. (2017). The impact of energy consumption and economic development on ecological footprint and CO_2

emissions: Evidence from a Markov switching equilibrium correction model. *Energy Economics*, *65*, 355–374. doi:10.1016/j.eneco.2017.05.009

Chen, J., Wu, Y., Xu, C., Song, M., & Liu, X. (2019). Global non-fossil fuel consumption: Driving factors, disparities, and trends. *Management Decision*, *57*(4), 791–810. doi:10.1108/MD-04-2018-0409

Cheng, J., Dai, S., & Ye, X. (2016). Spatiotemporal heterogeneity of industrial pollution in China. *China Economic Review*, *40*, 179–191. doi:10.1016/j.chieco.2016.07.001

Choi, J., Hearne, R., Lee, K., & Roberts, D. (2015). The relation between water pollution and economic growth using the environmental Kuznets curve: A case study in South Korea. *Water International*, *40*(3), 499–512. doi:10.1080/02508060.2015.1036387

Corlett, R. T. (2013). Where are the subtropics? *Biotropica*, *45*(3), 273–275. doi:10.1111/btp.12028

Damania, R., Russ, J., Wheeler, D., & Barra, A. F. (2018). The road to growth: Measuring the tradeoffs between economic growth and ecological destruction. *World Development*, *101*, 351–376. doi:10.1016/j.worlddev.2017.06.001

de Oliveira, M. C. C., Machado, M. C., Jabbour, C. J. C., & de Sousa Jabbour, A. B. L. (2019). Paving the way for the circular economy and more sustainable supply chains. *Management of Environmental Quality: An International Journal*, *30*(5), 1095–1113. doi:10.1108/MEQ-01-2019-0005

Drews, S., Antal, M., & van den Bergh, J. C. J. M. (2018). Challenges in assessing public opinion on economic growth versus environment: Considering European and US Data. *Ecological Economics*, *146*(April 2017), 265–272. doi:10.1016/j.ecolecon.2017.11.006

Drews, S., & van den Bergh, J. C. J. M. (2016). Public views on economic growth, the environment and prosperity: Results of a questionnaire survey. *Global Environmental Change*, *39*, 1–14. doi:10.1016/j.gloenvcha.2016.04.001

Drews, S., & van den Bergh, J. C. J. M. (2017). Scientists' views on economic growth versus the environment: A questionnaire survey among economists and non-economists. *Global Environmental Change*, *46*(8), 88–103. doi:10.1016/j.gloenvcha.2017.08.007

Du, Y., Wan, Q., Liu, H., Liu, H., Kapsar, K., & Peng, J. (2019). How does urbanization influence PM 2.5 concentrations? Perspective of spillover effect of multi-dimensional urbanization impact. *Journal of Cleaner Production*, *220*, 974–983. doi:10.1016/j.jclepro.2019.02.222

Fernández-Amador, O., Francois, J. F., Oberdabernig, D. A., & Tomberger, P. (2017). Carbon dioxide emissions and economic growth: An assessment based on production and consumption emission inventories. *Ecological Economics*, *135*, 269–279. doi:10.1016/j.ecolecon.2017.01.004

Haider, L. J., Boonstra, W. J., Peterson, G. D., & Schlüter, M. (2018). Traps and sustainable development in rural areas: A review. *World Development*, *101*, 311–321. doi:10.1016/j.worlddev.2017.05.038

Huang, B., Wu, B., & Barry, M. (2010). Geographically and temporally weighted regression for modeling spatio-temporal variation in house prices. *International Journal of Geographical Information Science*, *24*(3), 383–401. doi:10.1080/13658810802672469

International Monetary Fund Report. (2018). Asia is at theforefront: Growth challenges for the next decade andbeyond. (in Chinese)

Jin, P., Peng, C., & Song, M. (2019). Macroeconomic uncertainty, high-level innovation, and urban green development performance in China. *China Economic Review*, *55*(October 2018), 1–18. doi:10.1016/j.chieco.2019.02.008

Lee, H. K., & Kim, H. Y. (2018). Economic growth for ecological conversions: South Korean case. *Environmental Sciences Europe*, *30*(1), 21. doi:10.1186/s12302-018-0149-x

Li, L., & Liu, X. (2019). Allocation of regional emission permits in China: Based on the technology of energy conservation and emission reduction. *Tropical Conservation Science*, *12*, 194008291985719. doi:10.1177/1940082919857191

Li, Y., Li, Z., Wu, M., Zhang, F., & De, G. (2018). Regional-level allocation of CO2 emission permits in China: Evidence from the Boltzmann distribution method. *Sustainability (Switzerland)*, *10*(8), doi:10.3390/su10082612

Nepal, R., & Paija, N. (2019). Energy security, electricity, population and economic growth: The case of a developing South Asian resource-rich economy. *Energy Policy*, *132*(July 2018), 771–781. doi:10.1016/j.enpol.2019.05.054

Pablo-Romero, M., del, P., Sánchez-Braza, A., & Anna, G. (2019). Relationship between economic growth and residential energy use in transition economies. *Climate and Development*, *11*(4), 338–354. doi:10.1080/17565529.2018.1442789

Rezai, A., Taylor, L., & Foley, D. (2018). Economic growth, income distribution, and climate change. *Ecological Economics*, *146*(August 2017), 164–172. doi:10.1016/j.ecolecon.2017.10.020

Sherman, K., Peterson, B., Damar, A., & Wagey, T. (2019). Towards sustainable development of Asian Large Marine Ecosystems. *Deep-Sea Research Part II: Topical Studies in Oceanography*, *163*, 1–5. doi:10.1016/j.dsr2.2019.06.008

Song, M., Fisher, R., & Kwoh, Y. (2019). Technological challenges of green innovation and sustainable resource management with large scale data. *Technological Forecasting and Social Change*, *144*(July 2018), 361–368. doi:10.1016/j.techfore.2018.07.055

Song, M., & Li, H. (2019). Estimating the efficiency of a sustainable Chinese tourism industry using bootstrap technology rectification. *Technological Forecasting and Social Change*, *143*(February), 45–54. doi:10.1016/j.techfore.2019.03.008

Soytas, U., & Sari, R. (2009). Energy consumption, economic growth, and carbon emissions: Challenges faced by an EU candidate member. *Ecological Economics*, *68*(6), 1667–1675. doi:10.1016/j.ecolecon.2007.06.014

Uddin, G. A., Alam, K., & Gow, J. (2019). Ecological and economic growth interdependency in the Asian economies: An empirical analysis. *Environmental Science and Pollution Research*, *26*(13), 13159–13172. doi:10.1007/s11356-019-04791-1

Victor, P. A. (2010). Ecological economics and economic growth. *Annals of the New York Academy of Sciences*, *1185*, 237–245. doi:10.1057/9780230280823_3

Wan, C., Shen, G. Q., & Choi, S. (2017). A review on political factors influencing public support for urban environmental policy. *Environmental Science and Policy*, *75*(June), 70–80. doi:10.1016/j.envsci.2017.05.005

Wang, S. S., Zhou, D. Q., Zhou, P., & Wang, Q. W. (2011). CO2 emissions, energy consumption and economic growth in China: A panel data analysis. *Energy Policy*, *39*(9), 4870–4875. doi:10.1016/j.enpol.2011.06.032

Xie, Q., Xu, X., & Liu, X. (2019). Is there an EKC between economic growth and smog pollution in China? New evidence from semiparametric spatial autoregressive models. *Journal of Cleaner Production*, *220*, 873–883. doi:10.1016/j.jclepro.2019.02.166

Yao, X., Huang, R., & Song, M. (2019). How to reduce carbon emissions of small and medium enterprises (SMEs) by knowledge sharing in China. *Production Planning & Control*, *30*(10–12), 881–892. doi:10.1080/09537287.2019.1582096

Yu, Y., Zhou, L., Zhou, W., Ren, H., Kharrazi, A., Ma, T., & Zhu, B. (2017). Decoupling environmental pressure from economic growth on city level: The case study of Chongqing in China. *Ecological Indicators*, *75*, 27–35. doi:10.1016/j.ecolind.2016.12.027

Zaidi, S. A. H., Zafar, M. W., Shahbaz, M., & Hou, F. (2019). Dynamic linkages between globalization, financial development and carbon emissions: Evidence from Asia Pacific Economic Cooperation countries. *Journal of Cleaner Production*, *228*, 533–543. doi:10.1016/j.jclepro.2019.04.210

Zhang, Y., Shang, P., & Xiong, H. (2019). Multivariate generalized information entropy of financial time series. *Physica A: Statistical Mechanics and Its Applications*, *525*, 1212–1223. doi:10.1016/j.physa.2019.04.029

Zhou, Q., Zhang, X., Shao, Q., & Wang, X. (2019). The nonlinear effect of environmental regulation on haze pollution: Empirical evidence for 277 Chinese cities during 2002–2010. *Journal of Environmental Management*, *248*(April), 109274. doi:10.1016/j.jenvman.2019.109274