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The Impact of Forest Quality on Carbon Emission: A Study of China based on Environmental Kuznets Curve

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Abstract: Forest quality has a significant impact on carbon emissions of the economic system. This paper, based on an analysis of the Environmental Kuznets Curve (EKC) of Forest quality and carbon emission of economic systems, explores effective carbon emission reduction paths from the perspective of symbiosis between Forest quality and economic growth system. This paper carries out empirical analysis based on the provincial-level regional data of China and EKC panel data analysis for several major geographic regions in China. The correlation statistical test shows that the model considering Forest quality is more consistent with the test requirements. It is found that the overall EKC curve of China as a whole shows an inverted U-shape. In light of geographic differences, the EKC curve in the northwest also shows an inverted U-shape; it shows a U-shaped curve in North, Northeast, and East China. Meanwhile, in South Central and Southwest China, there is an approximately linear increasing curve. The data simulation of the symbiotic system of Forest quality and economic growth suggests that simultaneously increasing the proportion of forestry output value and the systematic carbon inhibition coefficient is the most effective pathway for carbon emission reduction. Choosing an appropriate carbon reduction pathway can contribute to the sustainable development of Forest quality and economic growth. The main research highlight of this paper is the application of the symbiotic system model to the EKC analysis of carbon emissions from the economic system with Forest quality.

Keywords: forest quality; environmental Kuznets curve; symbiotic system; emission reduction pathway

1. Introduction

Forests, the main body of terrestrial ecosystems, have three major benefits: economic, ecological, and social, and the sum of the benefits is Forest quality [1]. Forest quality is related to national ecological security, and most studies on Forest quality focus on the influence of natural factors [2]. The Forest quality is reflected not only in natural resources but also in economic benefits. As a basic resource of the national economy, the forest has an important role in social development. The development of forest resources is an important part of resources [3,4]. Academics are paying more and more attention to the scarcity of forest resources [5]. The quantitative panel data test of the relationship between forest resources and growth [6,7] has laid a rich foundation for the study of the Forest quality.

Existing studies have explored the relationship of forest land and economic but have not paid enough attention to the quality of forest resources. Existing studies still lack attention to the Forest quality as the improvement of forest ecological function. For a long time, the economic growth model of China's forestry industry has been characterized by a crude approach [8], and some scholars have even observed an inhibitory effect of forest resources on economic growth [9–11].

Currently, the research on environmental and economic growth is mainly based on the environmental Kuznets curve (EKC) hypothesis [12], i.e., the degree of environmental pollution will

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increase with the economic growth in the early stage of economic development and will decrease when the economic growth crosses a certain threshold. That is, the EKC hypothesis is also applicable to the study of the relationship between Forest quality and economic growth in the field of forest ecology specifically. Environmental decline reaches a tipping point as further economic growth exceeds a certain level. At the same time, deforestation is closely linked to carbon dioxide, i.e., carbon dioxide can be mitigated by reforestation and replenishment of forest resources [13].

However, environmental Kuznets curve studies of forest resources are inconclusive. Some studies have found empirical EKC support for forest [14–16], while others have not found any evidence supporting the existence of forest EKC [17]. As the research on forest EKC has progressed, more factors have been added to the forest EKC model. There is a long-term dynamic relationship between forest and economic [18–20].

From the above discussion, it can be seen that EKC on forest land is still controversial, which suggests the need for more empirical research. The research objective of this paper is to develop a suitable extended model to analyze the EKC pattern of Forest quality. The research structure of this paper is arranged as follows: (1) constructing an extended EKC analysis model, (2) conducting empirical analyses using Chinese provincial-level regional data, and (3) optimizing the measurement of regional carbon emission systems. The research highlights of this paper are (1) introducing Forest quality indicators into EKC research, (2) constructing an extended EKC model from a symbiotic perspective, and (3) performing a dynamic optimization analysis of the extended EKC model using the MCGP model.

2. Literature Review

Forest is the most extensively utilized natural heritage by humans, the largest and most widely distributed ecosystem on land, the most complex in texture composition, and the richest in biological and mineral resources. It is the backbone of terrestrial ecosystems. It can provide us with wood and wood based products, and is also the habitat of most animals, playing an unparalleled decisive role in maintaining the balance and stability of terrestrial ecosystems.

2.1. Impact of Forest Land on Economic Development

Forest resources provide heterogeneous service values and economic values for ecosystems, which have a constraining effect on economic growth, and suitable methods are needed to make the resource sustainable. Species diversity of forest land has a significant effect on risk and return [21] and there is a need to improve forest biodiversity [22]. The ecosystem services and economic values derived from forest resources vary widely, and the ecosystem services of forest resources should be assessed holistically, thus helping to inform forest management [23]. Diversification of economic activities such as forestry and ecotourism to conserve forest resources is preferable to direct consumption of forest resources [24].

The influential path of forest resources on economic is reflected in the impact on growth, employment, and labor income. Resource curse also exists in the forest land and economic system, e.g., deforestation in the Solomon Islands which brings about unbalanced economic development [25]. In terms of income and employment, forest resources maintain the level of well-being, food, and human and spiritual values [26]. Forests land play a key role in food security and mitigate climate change risks [27]. Forests also have the function of absorbing particulate matter and providing recreation and entertainment, fully utilizing the environmental functions of forests and educating residents about the environmental functions of forests [28]. In reality, it is difficult to find a generalized management strategy that meets all technical, environmental, social, and cultural constraints while providing forest-based economic development [29].

2.2. Forest Land and Low-Carbon Economic Development

Forest land provide social benefits along with economic growth drivers for social development. The development of sustainable forest resources and environmental policies can be beneficial in

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mitigating the damage caused by climate change [30]. Forestry outputs are often competitive, e.g. monoculture plantations favor intensive timber management while potentially reducing forest biodiversity values [31]. Forest products with different life cycles do not have the same level of impact on the environment [32].Declining industrial production in forests can significantly reduce the climate mitigation benefits of policies concerning forest carbon sinks, and there may also be cross-sectoral carbon leakage, e.g. part of the wood consumption will be shifted to higher-emission fuels [33,34]. Empirical analyses from China suggest that forest dynamics and transitions are driven by natural disasters and economic development [35]. Research on the influential path of low-carbon focuses on the aspects of forest carbon sinks, carbon trading, and economic and ecological benefits brought by forest ecological service systems [36,37].

2.3. Research on EKC

The carbon EKC can be broadly categorized into follow groups: U curve [38–41], U curve [42], other nonlinear shapes [43–46], linear relationship [47–50], weak inverted U curve [51] or there is no relationship [52]. The EKC in specific industrial sectors were conducted [53–56]. High-income countries have a higher percentage of reaching the turning point of carbon emissions [57]. The EKC curves of different countries exhibit heterogeneity [58–60].

In summary, existing studies have found that the EKC curves of forest resources show a diversified trend. The main reasons are: (1) the stages of economic and forest resource development vary in different regions, and relevant studies have found the influence of the life cycle of economic development on the EKC curve. (2) Forest land and economic growth, forest resources and carbon emissions, and economic growth and carbon emissions are all capable of constituting complex systems, and these symbiotic systems are difficult to describe by simple positive or negative relationships. (3) Most of the existing studies use forest area as the main variable in the research model, and the attention to Forest quality needs to be strengthened. To better describe the EKC problem of forest land, this paper is to construct an EKC analysis model based on the symbiotic system of forest resources, economic growth, and carbon emissions.

3. Methods and Materials

In order to understand the impact mechanism of forestry quality factors on EKC in China and explore effective carbon reduction pathways, this paper constructs an EKC model considering forestry quality. The Lotka-Volterra model was introduced into the analysis of the symbiotic mechanism between economic growth and forestry land quality, and the forestry quality EKC and symbiotic mechanism model were used to compensate for the shortcomings of existing research. The research process is shown in Figure 1:

Step	1	2	3	4
Content	Analysis of the Impact of Economic Growth on Carbon Emissions	The impact of forestry quality on carbon emissions	The symbiotic mechanism between economic growth and forest quality	Analysis of Carbon Emission Reduction Pathways
Models and Methods	EKC model (Model 1)	EKC model considering forestry quality (Model 2)	Lotka-Volterra model	Data simulation

Figure 1. Research process and technical roadmap.

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3.1. EKC Modeling of Carbon Emissions under the Perspective of Forest-Economy Symbiosis

This paper refers to the analytical thinking of the Environmental Kuznets Curve [61,62], the basic form of the model is as follows:

$$C_t = \alpha_0 + \alpha_1 G_t + \alpha_2 G_t^2 + \varepsilon_t \quad (1)$$

C_t is the CO^2 emissions in year t; G_t represents the gross domestic product (GDP) in year t; α_i is the coefficient to be estimated; and ε_t is a random error term.

$$C_t = \alpha_0 + \alpha_1 G_t + \alpha_2 G_t^2 + \alpha_3 F_t + \varepsilon_t \quad (2)$$

F_t represents the Forest quality.

There is a complex relationship between economic growth and Forest quality in the EKC framework. This complex relationship is a symbiotic relationship, which cannot be expressed as a simple cooperative or competitive relationship, and is also reflected in the EKC literature [14,19].

Symbiotic relationships between populations in natural ecosystems are mainly expressed by Lotka-Volterra models, which, with the expansion of research, have also been applied to socio-economic symbiotic systems [64], the study of nature-society symbiotic systems [65], and the analysis of symbiosis of industrial populations [66]. The model of the symbiotic relationship between economic growth and forest resources can be expressed by the following Lotka-Volterra model:

$$\begin{cases} \Delta G_t = \lambda_1 G_{t-l} + \gamma_1 G_{t-l}^2 + \beta_{12} G_{t-l} F_{t-l} \\ \Delta F_t = \lambda_2 F_{t-l} + \gamma_2 F_{t-l}^2 + \beta_{21} G_{t-l} F_{t-l} \end{cases}$$

l (l=0,1, 2, …) denotes the time lag period.

$$\begin{cases} G_t - G_{t-1} = \lambda_1 G_{t-1} + \gamma_1 G_{t-1}^2 + \beta_{12} G_{t-1} F_{t-1} \\ F_t - F_{t-1} = \lambda_2 F_{t-1} + \gamma_2 F_{t-1}^2 + \beta_{21} G_{t-1} F_{t-1} \end{cases}$$

$$\Rightarrow \begin{cases} G_t = (\lambda_1 + 1) G_{t-1} + \gamma_1 G_{t-1}^2 + \beta_{12} G_{t-1} F_{t-1} \\ F_t = (\lambda_2 + 1) F_{t-1} + \gamma_2 F_{t-1}^2 + \beta_{21} G_{t-1} F_{t-1} \end{cases}$$

Let$\lambda 1+1= \theta 1$ and$\lambda 2+1= \theta 2$, you will get

$$\begin{cases} G_t = \theta_1 G_{t-1} + \gamma_1 G_{t-1}^2 + \beta_{12} G_{t-1} F_{t-1} \\ F_t = \theta_2 F_{t-1} + \gamma_2 F_{t-1}^2 + \beta_{21} G_{t-1} F_{t-1} \end{cases}$$

The EKC model of the symbiotic system can be obtained by associating the above system of equations with model 2 as follows:

$$\begin{cases} C_t = \alpha_0 + \alpha_1 G_t + \alpha_2 G_t^2 + \alpha_3 F_t + \varepsilon_t \\ G_t = \theta_1 G_{t-1} + \gamma_1 G_{t-1}^2 + \beta_{12} G_{t-1} F_{t-1} \\ F_t = \theta_2 F_{t-1} + \gamma_2 F_{t-1}^2 + \beta_{21} G_{t-1} F_{t-1} \end{cases}$$

3.2. Variables Interpretation and Data Sources

Forest quality, which contains three main factors: ecological, social, and economic factors [1,67], can be evaluated by constructing an indicator system [68]. The main economic indicators of Forest quality are selected to construct the EKC model as a complex indicator system is not suitable for constructing the EKC model. This paper uses the provincial panel data of CO^2 emissions from China Emission Accounts Datasets (CEADs) [70]. Data on forests land in provincial-level regions of China from 2012-2021 were selected from the China Statistical Yearbook.

Table 1. Statistical characteristics of the sample data.

Variable	Description	Unit	Mean	SD
C	CO^2 emissions	ten thousand tons	342	223
G	GDP deflator	billion RMB	14956	11390
F	forestry land output	billion RMB	114	84

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4. Results

4.1. Tests for the Econometric Analysis

The presence of multicollinearity or two correlations between the variables can affect the degree and strength of individual effects; to avoid this, this paper examines the multicollinearity of the variables and chooses the variance inflation factor (VIF) method for the test. The mean value of the variance inflation factor of the variables in the EKC1 model is 10.81, and the mean value of the variance inflation factor of the variables in the EKC2 model is 8.2. Variables in the EKC2 model meet the requirements for the Variance Inflation Factor (VIF) better. To compare the heterogeneity of the EKC1 and EKC2 models, the results of the econometric analysis of the EKC1 model are retained in this study and the results are shown in Table 2.

Table 2. Variance inflation factor (VIF).

Variable	VIF	1/VIF
GDP	10.81	0.092538
GDP^2	10.81	0.092538
Mean VIF	10.81	
GDP	12.02	0.083214
GDP^2	11.38	0.087845
FOREST	1.20	0.836639
Mean VIF	8.2	

When using panel data for regression analysis, Hausman test fixed effects model and random effects model are used. The results of the Hausman test are shown in Table 3.

Table 3. Hausman test results.

EKC Model	area	chi2	Prob>chi2	Fe or Re
EKC 1	Nationwide	0.65	0.4202	RE
	North China	0.52	0.4726	RE
	Northeast China	32.15	0.0000	FE
	East China	0.54	0.4600	RE
	Central-South China	5.04	0.0247	FE
	Southwest China	2.66	0.1026	RE
	Northwest China	19.54	0.0000	FE
EKC 2	Nationwide	7.66	0.0210	FE
	North China	4.35	0.1130	RE
	Northeast China	34.31	0.0000	FE
	East China	9.13	0.0104	FE
	Central-South China	8.24	0.0162	FE
	Southwest China	21.98	0.0000	FE
	Northwest China	24.86	0.0000	FE

The data in Table 3 shows the results of the Hausman test, and the EKC1 and EKC2 models are significantly different. The results of the Hausman test for the EKC1 model for the different regions show that 4 regions are suitable for the random effects model and 3 regions are suitable for the fixed effects model. The results of the Hausman test for the EKC2 model show that 6 regions are suitable for the fixed effects model. EKC2 model is also more suitable for the Hausman test than the EKC1.

4.2. Environmental Kuznets Curve (EKC) Analysis of Carbon Emissions

(1) The Basic EKC Model for Carbon Emissions (fixed effects model)

Observing the data in Table 4, it can be seen that the overall EKC curve of China nationwide shows an inverted U-shaped curve. From the perspective of geographic differences, the EKC curve in the northwest also shows an inverted U shape. The EKC shape indicates that it is possible for China nationwide to achieve carbon peaking when the economy grows. However, the EKC curve in most regions is not optimistic, such as the U-shape in the northeast, and the nearly linear increasing relationship in the eastern region, the south-central region, and the southwestern region. The value of the constant term ($\alpha 0$) of the carbon emission EKC equation is greater in North China, which suggests that the initial value of carbon emission from economic growth in North China is higher, and it is a linear decreasing shape EKC running at a high level. This also explains the air pollution control problems in North China in recent years and its long-term expectation.

Table 4. Regression results of the basic EKC model for Carbon emission.

Area	α_0	α_1	α_2	shape of EKC
North China	541.206 (2.49)***	-8.93×10^{-4} (-4.386)	-4.61×10^{-7} (2.758)	linear decrease
Northeast China	401.864 (8.36)***	-6.40×10^{-3} (-0.82)	4.65×10^{-9} (0.02)	U shape
East China	91.496 (1.20)	0.013 (3.58)***	3.43×10^{-8} (0.60)	linear increase
Central-South China	182.901 (4.49)***	5.80×10^{-3} (1.85)*	5.51×10^{-8} (1.32)	linear increase
Southwest China	161.608 (6.71)***	5.27×10^{-3} (1.58)	9.88×10^{-8} (0.85)	linear increase
Northwest China	-465.630 (-7.25)***	0.19 (9.24)***	-7.20×10^{-6} (-6.82)***	Inverted U shape
Nationwide	106.364 (5.06)***	0.019 (8.118)***	-1.29×10^{-7} (-2.71)***	Inverted U shape

() t value,* p value <0.1, * * p value <0.05, * * * p value <0.01.

The EKC curves of the eastern, south-central, and southwestern regions with an approximately linear increasing relationship show a concerning trend in carbon emissions. In particular, the eastern region encompasses China's most developed industrial region and the Yangtze River Delta Economic Circle, while the eastern regions of Jiangsu, Zhejiang, and Shanghai have more optimized industrial structures and higher levels of innovation. Regions with higher levels of economic growth, science and technology, education, and social development are still not free from carbon constraints. Eastern China is also a region with a high dependence on foreign trade, and the growth in the eastern region confirms the pollution haven hypothesis.

An important assumption premise was set in the early EKC test: different regions are homogeneous when facing the EKC test [71]. The assumption of homogeneity implies that the determinants of environmental quality and development trajectories of different regions are convergent. However, it is difficult for scholars to fulfill this assumption when conducting the EKC test, which is the "Heterogeneity Difficulty" of EKC. The traditional EKC test is generally based on the assumption of homogeneity, which does not take into account the differences in resource endowment and competitive advantages of different sample individuals, and the research conclusions are often fragile and limited. In order to solve the "Heterogeneity Difficulty", make the EKC test more reasonable, and analyze the differences in the shape of EKC between different categories of individuals, it is necessary to effectively divide the research object into regions according to the scientific method for different situations, so as to realize the group test based on a certain division standard. The results of the empirical analysis in this subsection also confirm the existence of environmental EKC heterogeneity characteristics in different regions of China.

(2) Carbon emissions EKC taking into account forestry impacts

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The ultimate goal of studying EKC is to find a harmonious development path between pollution and economic growth. Grossman and Krueger (1991) point out that economic growth affects environmental quality through three different channels (the "three major effects" of EKC): the scale effect, the structure effect, and the technique effect. The scale effect causes pollution to grow with economic growth. The structural effect of the two industrial shifts (from agriculture to industry and from industry to services) results in an "inverted U-shaped" relationship between pollution and economic growth. Technological upgrading improves the efficiency of production and reduces the emission of pollutants due to production. The three effects work together to form an "inverted U-shaped" curve between the environment and the economy.

To avoid the deterioration of carbon emissions in growth, there are two ideas in theoretical analysis: one is to utilize the "three major effects" of EKC to reduce the level of pollution, and the other is to utilize carbon sinks. Carbon sinks occur in forests, croplands, grasslands, green spaces, and other places where plants grow, and forests are the largest carbon reservoir in terrestrial ecosystems. Therefore, model (2) is used in this section to examine the carbon reduction effect of considering Forest quality in economic growth EKC. The results of the analysis are shown in Table 5.

Table 5. Effect of Forest quality on carbon emissions EKC.

Area	α_0	α_1	α_2	α_3	Shape of EKC
North China	603.879 (3.58)***	-0.03 (-1.45)	7.21×10^{-7} (0.89)	1.670 (4.44)***	U shape
Northeast China	388.742 (8.16)***	-9.69×10^{-3} (-1.23)	6.43×10^{-8} (0.23)	0.409 (8.16)	U shape
East China	212.397 (4.74)***	-7.32×10^{-3} (-1.89)*	2.57×10^{-7} (4.89)***	1.47 (7.86)***	U shape
Central-South China	197.158 (4.90)***	2.62×10^{-3} (0.78)	6.42×10^{-8} (1.57)	0.245 (2.21)**	linear increase
Southwest China	158.288 (6.69)***	6.34×10^{-3} (1.54)	3.50×10^{-8} (0.33)	7.951×10^{-3} (0.08)	linear increase
Northwest China	-457.382 (-7.06)***	0.191 (9.28)***	-7.03×10^{-6} (-6.58)***	-0.811 (-1.00)	Inverted U shape
Nationwide	116.919 (5.41)***	0.022 (8.93)***	-1.821×10^{-7} (-3.69)***	-0.358 (-3.36)***	Inverted U shape

() t value,* p value <0.1, * * p value <0.05, * * * p value <0.01.

The data in Table 5 bring out two findings. On the one hand, the inclusion of forestry development quality indicators has the potential to change the shape of the EKC, and on the other hand, the effect of forestry output value indicators on carbon emissions shows regional differences. For example, for the eastern region, the inclusion of the forest land variable changes the EKC curve from an approximately linear increase to a U shape. If the EKC curve in the eastern area can be controlled in the descending section of the U shape, the emission of carbon can be controlled. The overall EKC curve of China nationwide shows an inverted U shape, and the factor of forestry's influence on carbon emissions is negative.

The data in Table 6 provide a feasible way of comparative analysis of carbon emission EKC between regions. It is not suitable to use raw data for direct comparative analysis due to the significant disparities in economic growth and carbon emission scales across different geographical regions. In order to solve the obstacles of data heterogeneity in geographic areas, this paper utilizes simulated data for the comparative analysis of carbon emission differences between regions. The data simulation process will set the initial stage GDP as 10 trillion RMB and keep a growth rate of 3% in each cycle. Meanwhile, the forestry GDP scale is set as 0.3% of the total GDP.

Table 6. Regional comparison of carbon emission modeling data.

Cycle	North China	Northeast China	East China	Central-South China	South-west China	North-west China	G1	Forestry GDP
1	426.1	310.3	355.4	237.1	225.4	725.3	10000	30.0
2	423.0	308.1	360.5	238.5	227.5	739.0	10300	30.9
3	419.9	305.9	365.8	240.0	229.7	751.9	10609	31.8
4	416.9	303.7	371.3	241.5	232.0	763.7	10927	32.8
5	413.9	301.4	377.0	243.1	234.3	774.4	11255	33.8
6	411.1	299.0	382.9	244.7	236.8	783.9	11593	34.8
7	408.3	296.6	389.1	246.4	239.3	791.9	11941	35.8
8	405.6	294.1	395.5	248.1	241.8	798.4	12299	36.9
9	403.0	291.6	402.2	250.0	244.5	803.2	12668	38.0
10	400.6	289.0	409.2	251.9	247.3	806.2	13048	39.1
11	398.3	286.3	416.5	253.8	250.1	807.1	13439	40.3
12	396.1	283.6	424.0	255.9	253.1	805.8	13842	41.5
13	394.1	280.9	431.9	258.0	256.1	802.1	14258	42.8
14	392.4	278.1	440.1	260.3	259.3	795.7	14685	44.1
15	390.8	275.2	448.6	262.6	262.6	786.4	15126	45.4
16	389.5	272.2	457.5	265.0	265.9	774.1	15580	46.7
17	388.5	269.2	466.8	267.5	269.4	758.3	16047	48.1
18	387.8	266.2	476.5	270.1	273.0	738.8	16528	49.6
19	387.4	263.0	486.6	272.9	276.8	715.4	17024	51.1
20	387.4	259.8	497.1	275.7	280.6	687.6	17535	52.6

() t value,* p value <0.1, * * p value <0.05, * * * p value <0.01.

The simulation data show that the Northeast region achieves a gradual reduction in carbon emissions over the simulation cycle and has the best carbon neutralization effect among the geographic regions. The Northwest region has the highest simulated value of carbon emissions, which is related to the higher intensity of carbon emissions per unit in the Northwest region. The Central-South, South-West, and North-East regions are close to each other in terms of carbon emission levels and are all at relatively low levels.

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4.3. Symbiotic Mechanisms of Economic Growth and Forest Quality

There is a complex symbiotic relationship between economic growth and Forest quality, with the most common symbiotic relationships being synergistic, mutually beneficial, and competitive. After the economic system develops well, more resources are invested in the protection and development of forestry resources. A high-quality forestry system will also have higher economic value, thus forming a coordinated development of economic growth and Forest quality. If the resources of the economic system are limited, it will lead to a competitive relationship between the economic system and the forest system, resulting in a contradictory relationship.

The data in Table 7 show that the symbiotic relationship between forestry and overall economic growth in different regions is characterized by heterogeneity. The regression results of the overall national panel data show a synergistic relationship, which indicates a good symbiotic relationship between forestry and overall economic growth in China nationwide. The symbiotic relationship between forestry and overall economic growth in the southwestern area exhibits a competitive relationship, while the symbiotic relationship between forestry and overall economic growth in other regions exhibits a commensalistic relationship. The heterogeneous symbiotic relationship between forestry and overall economic growth also suggests that carbon reduction pathways based on forestry development need to be further analyzed.

Table 7. Symbiotic mechanisms of economic growth and Forest quality.

Area	θ_1	γ_1	β_{12}	θ_2	γ_2	β_{21}	Symbiotic Mechanism
North China	0.033 (1.177)	-9.567×10^{-7} (-0.475)	-1.424×10^{-4} (-0.705)	-0.022 (-0.381)	-7.792×10^{-4} (-1.558)*	9.529×10^{-6} (2.057)**	Commensalism
Northeast China	0.125 (1.923)*	4.945×10^{-7} (0.152)	-0.001 (-2.631)**	0.052 (0.501)	-7.883×10^{-4} (-1.159)	3.574×10^{-6} (0.678)	Commensalism
East China	0.043 (2.374)**	-6.314×10^{-7} (-1.735)*	7.404×10^{-6} (0.096)	0.160 (3.269)***	-4.576×10^{-4} (-2.728)***	-2.274 (-2.347)**	Commensalism
Central-South China	0.037 (3.561)***	-1.812×10^{-7} (-0.651)	-2.902×10^{-5} (-0.497)	0.015 (0.480)	1.369×10^{-5} (0.100)	5.686×10^{-7} (1.081)	Commensalism
Southwest China	0.071 (4.255)***	-1.790×10^{-6} (-1.701)*	-1.520×10^{-5} (-0.196)	0.232 (3.897)***	-8.393×10^{-4} (-3.577)***	-3.029×10^{-8} (-0.012)	Competition
Northwest China	0.053 (3.075)***	6.666×10^{-6} (1.678)*	-0.001 (-2.286)**	0.067 (1.493)*	-0.006 (-3.374)***	3.166×10^{-5} (2.884)***	Commensalism
Nationwide	0.023 (4.182)***	-2.041×10^{-7} (-1.341)	3.053×10^{-5} (1.082)	0.047 (3.104)***	-1.179×10^{-4} (-1.803)*	3.300×10^{-7} (0.906)	Synergy

() t value,* p value <0.1, * * p value <0.05, * * * p value <0.01.

Based on the perspective of forestry and economic symbiosis systems, this paper designs a variety of carbon emission reduction paths and compares the emission reduction effects of different paths. The results of the comparison of emission reduction paths are shown in Table 8.

Table 8. Carbon emissions.

			Carbon emission (Ct)				
Cycle	GDP (G1)	Forestry GDP	Basic Model	2 times the carbon emission inhibition coefficient	4 times the carbon emission inhibition coefficient	2 times the forestry proportion	2 times the forestry proportion and 4 times the carbon emission inhibition coefficient

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1	10000.0	30.0	308.0	279.0	221.1	297.2	178.2
2	10228.7	31.4	311.6	281.3	220.7	300.4	175.7
3	10462.6	32.9	315.4	283.7	220.2	303.6	173.1
4	10701.9	34.5	319.2	286.0	219.6	306.8	170.2
5	10946.6	36.1	323.0	288.3	218.8	310.1	167.1
6	11196.9	37.8	326.9	290.5	217.8	313.4	163.7
7	11452.9	39.6	330.8	292.8	216.7	316.7	160.0
8	11714.8	41.4	334.8	295.0	215.4	320.0	156.1
9	11982.7	43.3	338.9	297.2	213.9	323.4	151.8
10	12256.8	45.4	343.0	299.4	212.2	326.7	147.2
11	12537.2	47.5	347.1	301.5	210.3	330.1	142.3
12	12824.2	49.7	351.3	303.6	208.1	333.5	137.0
13	13117.8	52.0	355.6	305.6	205.8	337.0	131.4
14	13418.3	54.3	359.9	307.6	203.2	340.4	125.3
15	13725.8	56.8	364.2	309.6	200.3	343.9	118.9
16	14040.5	59.4	368.6	311.5	197.1	347.4	112.1
17	14362.7	62.1	373.1	313.3	193.7	350.9	104.8
18	14692.5	64.9	377.6	315.1	190.0	354.4	97.0
19	15030.1	67.8	382.2	316.8	185.9	357.9	88.8
20	15375.8	70.8	386.8	318.4	181.5	361.4	80.1

() t value,* p value <0.1, * * p value <0.05, * * * p value <0.01.

The simulated data in Table 8 show the disparities between different measures. Simultaneously increasing the share of forestry (by 2 times) and the carbon emission inhibition coefficient are the most effective mitigation measures. Increasing the proportion of forestry output in GDP is favorable to reducing carbon emissions. Increasing the carbon emission inhibition coefficient also helps reduce carbon emissions. Simultaneously increasing the proportion of forestry output value and carbon emission inhibition coefficient has the best carbon emission reduction effect.

4.4. Robustness Analysis of EKC Model

In order to meet the data requirements of EKC model and symbiotic model, this article uses raw data for regression analysis. Considering the differences in data scale between different regions and to further validate the stability of the model, this section will use model (2) and the logarithmic form of the original data to examine the carbon emission reduction effect of forestry quality in economic growth EKC. The analysis results are shown in Table 9.

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Table 9. Robustness analysis of EKC model (Logarithmic Data Regression).

Area	α_0	α_1	α_2	α_3	Shape of EKC
North China	164.919 (2.132)**	-33.787 (-2.048)**	1.770 (2.014)**	0.488 (6.532)***	U shape
Northeast China	30.175 (1.238)	-6.151 (-1.162)	0.374 (1.314)	0.085 (0.731)	U shape
East China	22.531 (2.206)**	-4.450 (-2.177)**	0.272 (2.667)***	0.124 (5.961)***	U shape
Central-South China	-19.056 (-16.663)***	4.551 (17.956)***	-0.196 (-14.233)***	-0.165 (-5.465)***	Inverted U shape
Southwest China	55.652 (7.354)***	-11.261 (-6.883)***	0.619 (7.039)***	0.163 (5.081)***	U shape
Northwest China	-22.869 (-3.088)***	6.211 (3.523)***	-0.351 (-3.479)***	0.288 (1.346)	Inverted U shape
Nationwide	-3.671 (-1.730)*	1.368 (2.904)***	-0.041 (-1.596)*	0.027 (1.087)	Inverted U shape

() t value,* p value <0.1, * * p value <0.05, * * * p value <0.01.

The data in Table 9 shows that the regression performance of EKC model 2 based on logarithmic data is good, which confirms the adaptability of EKC model considering forestry quality factors to different data types. In the logarithmic regression results of EKC model 2, the shape of the EKC curve in most regions did not change. Among the seven regions, only the EKC curves in the central southern and southwestern parts changed from monotonically rising to inverted U-shape and U-shape, indicating that the stability of the model is relatively good.

4.5. Discussion

This study has some similar conclusions to the existing studies. The study in this paper reproduces the different shapes of EKC curves, such as inverted U-shape [38–41], U-shape [42], and nearly linear curves [47–50] in the existing studies on EKC curves. The heterogeneous characterization of EKC curves in different regions is verified. The heterogeneity of EKC curves in different regions lies in the fact that economic growth is at different stages. Economic growth and carbon emissions have diverse manifestations, which depend on the stage difference of economic growth. The economic growth of different regions in China is in different stages of development, which can better reflect the heterogeneity characteristics of the EKC model.

Some of the existing studies have put the influence factors of forestry on the left side of the equation [18,36], which will take forestry as the dependent variable in the EKC curve. In this paper, the influence factors of forestry are placed on the right side of the equation, and forestry is used as the independent variable factor in the EKC curve. Since the symbiotic relationship between economic growth and forest resources is also reflected in the EKC literature [14,19], this paper introduces the LV model into the symbiosis analysis and carbon emission reduction pathway research. The LV model can effectively and specifically express the ecological symbiotic relationship. In this paper, it is found that pure symbiosis cannot necessarily lead to carbon emission reduction.

4.6. Policy Implications

It is clear that China can realize economic growth and emission reduction after experiencing a stage of growth. Currently, due to issues related to industrial structure and energy consumption, carbon emissions are increasing. To reach the carbon emission inflection point, it is essential to reduce carbon intensity and increase carbon productivity. This requires optimizing the industrial structure and energy consumption framework, establishing a low-carbon industrial development model and low-carbon energy bases, and guiding China's economy toward a path of coordinated economic growth and carbon emissions that is both rapid and sustainable. This will enhance China's ecological

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civilization and its capacity to address climate change. In turn, it will provide a favorable international development environment foundation for China's low-carbon transformation.

Appropriate regional policies that coordinate economic growth and carbon emissions based on the heterogeneous characteristics of economic development in different regions should be formulated. The Northeast, North, East, Central South, Southwest, and Northwest regions of China have different economic development bases and initial conditions. Moreover, the relationship between growth and carbon emissions varies among these regions. Therefore, it is important to consider the heterogeneity of different areas based on the varying relationships between per capita GDP and per capita carbon emissions in each region. Overall, there is an inverted U-shaped curve in China nationwide and in the northwestern part of the country, which means that measures have to be formulated so that the inflection point of per capita carbon emissions comes earlier. In the eastern, northeastern, and northern regions, there is a positive U-shaped curve in the relationship between economic growth and carbon emissions. Therefore, efforts should be made to achieve a relative decoupling of economic growth from carbon emissions in these areas. The eastern region has a strong foundation for economic development and a large consumption of carbon-based energy. During the period of "rapid development", the eastern region should adjust its economic system, and regions with the conditions can first pilot the program to explore the mode and path of developing a green economy. The eastern region should endeavor to innovate its economic development model and select a path of internal development with low energy consumption, low material consumption, low emissions, and low pollution.

The formulation of policies and measures for a low-carbon economy in China and its regions should take into account the stage of economic development. Currently, there is an inverted U-shaped EKC curve for carbon emissions in China nationwide and in its northwestern region and a positive U-shaped curve in the eastern, northeastern, and northern regions. Policy research should focus on identifying when the carbon emission inflection point will occur, striving to enter a "win-win" phase where economic growth happens alongside a gradual reduction in carbon emissions. At different stages, policy measures need to take into account the characteristics of the EKCs.

Sustainable development of forestry requires the sustainable use of forest land. Forest land is the material basis of forestry production, and careful management and adoption of appropriate management models are crucial. In practice, different management measures are formulated for different levels of Forest quality, scientifically utilizing forest land and fully tapping into its productivity, promoting the transformation of forest land utilization from extensive and inefficient to intensive and efficient. The water and heat conditions are very good, suitable for the growth of various tree species, and the forest has great production potential, making it suitable for intensive management. Fully tap into its production potential, improve productivity per unit area, focus on enhancing forest carbon sequestration capacity, and increase social and ecological benefits. For forests with thin soil layers, slightly insufficient soil fertility, and poor water and heat conditions, these forests are mostly located in areas with frequent natural disasters and important ecological locations, and are suitable for the development of public welfare forests that focus on soil and water conservation and water conservation. Mainly strengthen the construction of disaster prevention, mitigation, and mitigation capabilities in forest ecosystems, build regional ecological barriers, and provide guarantees for regional socio-economic development.

5. Conclusions

Based on analyzing the EKC of carbon emissions from Forest quality and economic systems, this paper explores effective carbon emission reduction paths from the perspective of symbiosis between Forest quality and economic systems. The empirical analysis is based on the provincial-level regional data of China as a sample, and the EKC panel data are analyzed for several major geographic regions in China. The related statistical test shows that the model considering Forest quality is more consistent with the test requirements. It is found that the overall EKC curve of China nationwide shows an inverted U shape. From the perspective of geographic differences, the EKC curve in the northwest also shows an inverted U shape, North, Northeast, and East China are U-shaped, and

South Central and Southwest China show an approximately linear increasing curve. The data simulation of the symbiotic system of Forest quality and economic growth suggests that simultaneously increasing the proportion of forestry output value and the systematic carbon inhibition coefficient is the most effective carbon emission pathway. The application of the symbiotic system model to the analysis of carbon emission EKC with Forest quality on economic systems is the leading research highlight of this paper. Yet this study lacks the dynamic analysis of the EKC curve, and the difference between long-term and short-term EKC will be considered in future research.

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