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Coupling and Coordination Relationship between Economic and Ecologic-Environmental Developments in China's Key State-Owned Forest Areas

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Abstract: China's key state-owned forest areas are important ecological conservation areas and its forest management belongs to several forest industry groups. Therefore, the ecological improvement and economic development of the key state-owned forest areas should be balanced. This study developed an integrated evaluation model of coupling and coordination, by employing the data of the key forest areas from 2001 to 2019, to investigate the coupling and coordination relationship between the efficiency of economic development and the level of ecological development, using the DEA model. The results suggest that the indices of ecological development in the key state-owned forest areas increased from 2001 to 2019, and especially in 2015, to a better status, due to the policy of completely stopping logging. The other finding was that the coupling degree between the efficiency of economic development and the level of ecological development was in an antagonistic stage, which showed a slow upward trend of the coupling degree and coupling coordination degree and then evolved to a medium and high coordination coupling situation. The reason was that, with the implementation of the ecological protection policy and the industrial transformation of the forest industry group, the ecological environment improved and the development of enterprises was further optimized. Moreover, this study further identified the main factors that affect the coupling and coordination degree of the key state-owned forest areas, including the proportion of tertiary industry, economic growth rate, forest park area, and investment in wildlife and plant protection and natural resource conservation areas. The factors were divided into three principal components. The most significant impact on the economic and ecological coupling coordination of the key state-owned forest areas was the first principal component, meaning that ecological improvement was the most important factor. The second principal component was mainly social coupling coordination, while the third principal component had little effect on economic and ecological coupling coordination.

Keywords: entropy weight method; principal components analysis; ecological environment; economic development

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1. Introduction

The formation history of state-owned forest areas and forest farms determines their special social characteristics. In the early days of China's founding, the state adopted the method of national investment to conduct large-scale development of state-owned barren mountains and wastelands in order to meet the demand of national economic construction for wood and other forest resources. A total of 138 state-owned forestry bureaus were established in nine provinces and regions in the northeast, southwest and northwest [1], most of which were located on the banks of rivers, around reservoirs, and in front of sandstorms. These state-owned forestry bureaus were forest industry enterprises specializing in wood cutting and processing. Later, state-owned forest areas were formed with these forest industry enterprises as the main body. Among them, 87 state-owned forestry bureaus, distributed in Heilongjiang Province, Jilin Province and Inner Mongolia Autonomous Region, constituted the key state-owned forest areas, which were managed by five forest industry groups. According to the establishment and development history of the key state-owned forest areas, the key state-owned forest areas actually had the characteristics of "first forest areas, then society". A social region formed with special economic characteristics. This paper took these industry groups as samples for research and analysis.

The key state-owned forest areas have made significant contributions to safeguarding national ecological security, timber security, species security, food security, and the promotion of national economic construction for a long time [2]. The existing forest area in China is 208 million hm^2, and the forest stock is 15.137 billion m^3. The minable area accounts for only 13% of the existing timber forests, and the minable stock accounts for only 23%. There are few available resources, less large diameter timber trees and precious timber trees. The structural contradiction between supply and demand of timber is very prominent. In 2014, China's dependence on foreign timber reached 47.94% [3]. The forest resources in the key state-owned forest areas are an important base for providing trees and forest by-products. The key state-owned forest areas are a water conservation area for important rivers, such as the Helong River and the Songhua River. They are also the ecological barrier for food and animal husbandry bases in Sanjiang Plain, Songnen Plain, and Hulunbeir Grassland.

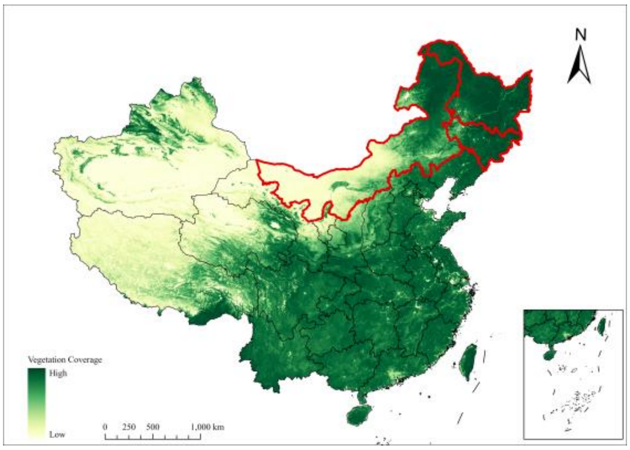
The key state-owned forest areas have dual responsibilities of forest protection and exploitation. However, due to insufficient public financial support, the Forest Industry Group has maintained a balance of income and expenditure for disorderly exploitation and development of forest resources for a long time, and lacks investment in forest resources protection and cultivation. The key state-owned forest areas were caught in the dilemma of a sharp decline in recoverable forest resources, which brought difficulties for forest workers' lives [4]. To solve the crisis of forest resources and the difficulties of employees' lives in state-owned forest areas, the state has implemented a series of natural forest protection projects in the key state-owned forest areas since the late 1990s. In 2011, the state launched the second phase of the natural protection project. Compared with the first phase, the second phase of the project focused on improving people's livelihoods [5]. In the implementation process, the state's investment and policy support were significantly increased, resulting in improved forest management, more public welfare forest construction, and social insurance subsidies. In addition, this project accelerated the industrial transformation and upgrading of forest areas, not only continuously improving the forest area infrastructure and the development level of forest areas' social undertakings, but also continuously innovating the forest area management system and providing new opportunities for the transformation of the key state-owned forest areas [6]. In 2014, implementing the complete cessation of commercial logging of natural forest resources (abbreviated as complete cessation of logging) further strengthened the function for ecological security and forest resource cultivation in state-owned forest areas. In 2015, the Central Committee of the Communist Party of China and the State Council issued the "Guiding Opinions on Reform of State-owned Forest Areas," which promoted the integration of the economic and social development of state-owned forest areas into the local area, and the basic living conditions of employees in the key state-owned forest areas were effectively guaranteed [7]. On the one hand, the implementation of a series of measures highlighted the ecological status of the key state-owned forest areas, making their ecological functions the leading function. On the other hand, it promoted the economic transformation of the key state-owned forest areas. Under the constraint of ecological requirements, the economic development mode of the key state-owned forest areas would be completely transformed. The efficiency of economic development would no longer simply be a pursuit for growth of quantity but would pay more attention to connotative development and comprehensively improve the quality of economic development.

By 2020, the forest policy reform and economic transformation was basically completed. It is very important to evaluate the coupling and coordination relationship of economic efficiency and ecological development in the key state-owned forest areas and to study the influencing factors, as this can be helpful to provide policy-makers with countermeasures and suggestions for promoting the comprehensive and sustainable development of these areas. At the household and individual level, studies have been carried out on the impact of comprehensive logging cessation on the welfare of forest industry group employees and their families [8–11]. From the regional level, there is literature researching the implementation effect of forestry protection policies in the key state-owned forest areas [12], and the coordination effect of human resource allocation and industrial structure [13]. The existing literature mostly focuses on the study of coupling degrees in the city scope [14–16]. Few studies set the key state-owned forest areas as an economic unit and research the coupling relationship between economy and ecology and between economic development efficiency and ecological improvement in these areas. The key state-owned forest areas are the core areas with great potential in China's forestry economic development pattern. Deeply studying the coupling of process and evolutionary trend of efficiency in economic development and ecological improvement helps to put forward benign coupling countermeasures and suggestions. This paper provides a theoretical and practical basis for selecting the economic development model for such areas in the future.

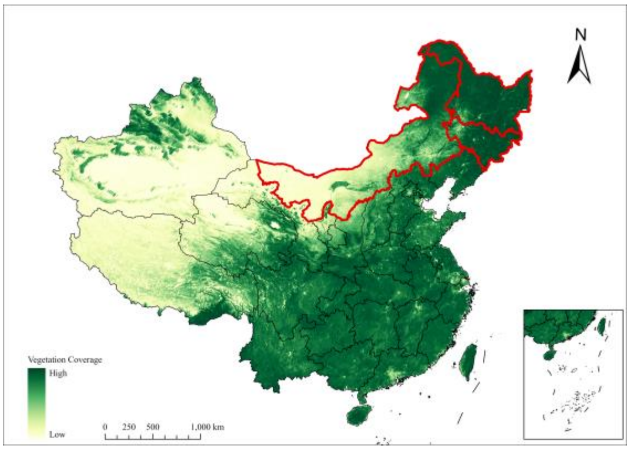
2. Overview of the Study Area and Data Sources

2.1. The Study Area

The key state-owned forest areas are important areas for national ecological development. The key state-owned forest areas cover Heilongjiang, Jilin, and Inner Mongolia (autonomous region). They are the regions with relatively concentrated forest resources in China and have strong forestry industry development potential. The key state-owned forest areas are jointly managed by five forest industry groups, namely the Daxing'anling Forest Industry Group, the Jilin Forest Industry Group, the Inner Mongolia Forest Industry Group, the Longjiang Forest Industry Group, and the Changbai Mountain Forest Industry Group. This paper takes these industry groups as samples for research and analysis. The study area is shown in Figure 1. During the research period, the vegetation coverage of the key state-owned forest areas increased, especially in Inner Mongolia (autonomous region).

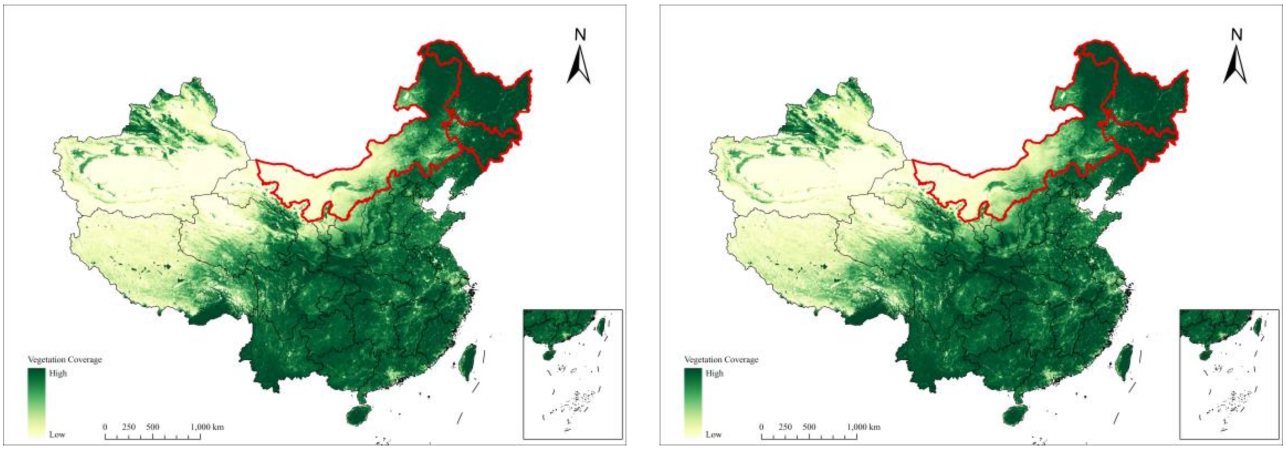


(**a**)



(**b**)

Figure 1. *Cont.*



(**c**) (**d**)

Figure 1. Changes of vegetation coverage in the key state-owned areas in (**a**) 2005, (**b**) 2010, (**c**) 2015 and (**d**) 2019. Note: Area within the red margins indicates the survey area.

2.2. The Forest Industry Groups

The Longjiang Forest Industry Group is one of the most important state-owned forest areas and the largest timber production base in China, which has the forefront quantity of forest area, total forest stock, and timber output. Natural forest resources are the main forest resources. The construction area of the Jilin Forest Industry Group is located in the Changbai Mountain District, Jilin Province, which is known as the "Changbai Forest Sea" and is an important national commercial timber production base. The Jilin Forest Industry Group is based on the management of forest resources. The Inner Mongolia Autonomous Region is located in the northern frontier of China, having the first-ranked grassland area and rich forest resources of the country. The Daxing'anling Mountains are located here and have a large timber stock. The whole autonomous region has a temperate continental monsoon climate. Due to the wide geographical scope, different regions have different climatic features. Most regions have four distinct seasons, with a short summer and long, dry, extremely cold winter. The forest land area owned by the Inner Mongolia Forest Industry Group ranks first among the four state-owned forest regions in China, as well as the forest stock. This is the largest centralized and contiguous state-owned forest area and an important timber production base in China. The total business area of Daxing'anling Forestry Group is 8.03 million hectares, accounting for 96.10% of the total forest area. The forestry management area is 7.91 million hectares, accounting for 98.57% of the total area. The above five forest industry groups manage the largest forest areas in China. Their sustainable development is significant for China's ecological and forestry economic development.

2.3. Data Sources

This paper took the key state-owned forest areas as the basic unit conducting a time series study from 2001 to 2019. The data were collected from the *China Forestry and Grassland Statistical Yearbook* of forestry social, and economic development from 2001 to 2019, the *China Statistical Yearbook* and the *China Statistical Yearbook on Environment* of the environment from 2001 to 2020. The statistics analysis is in Table 1.

In Table 1, most of the indicators' median and average values have little difference, meaning that the distribution of data is relatively flat, and the maximum and minimum values have little impact on the overall data. The indicators of investment in wild animals and plants protection and nature reserves and forest management and protection area changed the most over time, inferring that the investment of forest industry enterprises in ecological protection changed greatly. For the indicator of forestry economic growth rate, it was from below zero to over 50%, indicating that the development of the forestry industry experienced shock in some years of the research period.

Table 1. Statistics analysis of the key state-owned forest areas.

Indicator	Max	Min	Median	Average
Number of people on duty at the end of the year (person)	493,487.00	257,815.00	371,742.00	384,088.00
Forestry area (10,000 hectares)	7462.48	6542.68	7235.68	7169.16
Total output value of forestry (10,000 yuan)	33,203,570.00	3,294,207.00	12,996,879.00	14,493,647.53
Average annual salary of on-the-job employees (1000 yuan/year)	4.71	0.45	1.22	1.35
Sulfur dioxide emission (10,000 tons)	280.80	120.31	228.69	217.83
Smoke (powder) emission (10,000 tons)	245.10	69.90	169.70	165.00
Output of industrial solid waste (10,000 tons)	391,717.97	318,079.80	329,768.75	344,422.07
Wastewater discharge (10,000 tons)	384,522.00	244,718.00	274,333.00	299,057.50
The proportion of the tertiary industry to the total output value of forestry (%)	46.65	18.98	25.63	28.15
Investment of fixed assets (10,000 yuan)	2,412,567.00	783,355.00	978,743.00	1,223,542.27
Forestry economic growth rate (%)	53.56	−4.67	9.12	11.91
The enterprise employment index (%)	68.03	59.52	62.02	63.42
Forest management and protection area (10,000 hectares)	3852.82	108.52	3442.91	3201.45
Forest parks area (10,000 hectares)	589.06	310.00	558.82	526.51
Investment in wild animals and plants protection and nature reserves (10,000 yuan)	19,833.00	1397.00	8316.00	10,023.67

Note: Data source from China Forestry and Grassland Statistical Yearbook 2000–2019 and China Statistical Yearbook 2000–2019.

3. Index System, Model and Method

3.1. Entropy Value Method to Determine Indicator Weight

3.1.1. Data Standardization

As each indicator unit was different, it was necessary to standardize each indicator. The standardization formula of positive indicators is Equation (1), and that of negative indicators is Equation (2) [17,18].

$$X_{ij} = \frac{x_{ij} - \min(x_{1j,2j\ldots nj})}{\max(x_{1j,2j\ldots nj}) - \min(x_{1j,2j\ldots nj})} \quad i = 1,2\ldots n, j = 1,2\ldots m \tag{1}$$

$$X_{ij} = \frac{\min(x_{1j,2j\ldots nj}) - x_{ij}}{\max(x_{1j,2j\ldots nj}) - \min(x_{1j,2j\ldots nj})} \quad i = 1,2\ldots n, j = 1,2\ldots m \tag{2}$$

In the above formula: $i = 1, 2, 3, \ldots, n$, $j = 1, 2, 3, \ldots, m$; X_{ij} is the total index value of the five forest industry groups in terms of the time dimension and space dimension; X_{ij} is the standard value.

3.1.2. Determine the Weight of Each Indicator

First, to quantify each indicator, the calculation formula of the spatial dimension is displayed in Equation (3); x_{ij} is the standard value.

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} i = 1,2,3\ldots n, j = 1,2,3\ldots m \tag{3}$$

Next, to calculate the information entropy of each index item, where n is the year of the time dimension and the forest industry group of the spatial dimension, the calculation formula of information entropy is shown in Equation (4).

$$e_j = -k\sum_{i=1}^{n} P_{ij}\ln(P_{ij})(k = 1/\ln(n), k > 0, e_j \geq 0) \tag{4}$$

Finally, to calculate the weight of each index, the calculation formula is Equation (5).

$$W_j = \frac{1 - e_j}{\sum_{j=1}^{m}(1 - e_j)} \quad (5)$$

3.2. DEA Model for Measuring Economic Development Efficiency

DEA (Data Envelopment Analysis) is a linear programming model. The model assumes there are n decision-making units, $j = 1, 2, \ldots, n$; x_j, y_j, θ represent the input variable, output variable, and relative efficiency values of the jth decision-making unit, respectively. According to the CCR model, obtained by assuming the decision-making unit is constant returns to scale (CRS), the linear programming is:

$$\begin{cases} Min\theta \\ s.t. \sum_{j \in n} x_j \lambda_j + \theta x_0 \geq 0 \\ \sum_{j \in n} y_j \lambda_j + \theta x_0 \geq y_0 \\ \lambda_j \geq 0, j \in n \end{cases} \quad (6)$$

where $Min\theta$ is the objective function; $s.t.$ represents the restrictive condition; λ_j is the weight variable of a certain index of the sample region; x_0 and y_0 represent the original input and output values of the decision-making unit respectively. The value θ is the integrated efficiency of the decision-making unit, which is calculated by the CCR model, including technical efficiency and scale efficiency. If the constraint condition $\Sigma\lambda_j = 1$ is added to Equation (1), the CCR model becomes the BCC model:

$$\begin{cases} Min\theta \\ s.t. \sum_{j \in n} x_j \lambda_j \leq \theta x_0 \\ \sum \lambda_j y_i \geq y_0 \\ \sum \lambda_j = 1 \\ \lambda_j \geq 0, i = 1, 2, \ldots, n \end{cases} \quad (7)$$

where the value of θ is the technical efficiency value of the decision-making unit.

3.3. Integrated Evaluation Model: Calculate the Integrated Evaluation Index of Ecological Development Level of the Key State-Owned Forest Areas

According to previous studies, such as those of Liao (1999) [19] and Liu (2011) [20], this paper established the integrated evaluation index of ecological development level. The formula is:

$$g(y) = \sum_{i=1}^{m} b_i y_i \quad (8)$$

where y_i represents the standard value of each element; b_i represents the weight of each element; m represents the number of elements [21,22].

3.4. Coupling Degree Model: Measuring the Coupling Relationship between Economic Development Efficiency and Ecological Development Level of the Key State-Owned Forest Areas

In this paper, the coupling coefficient method was used to calculate the coupling degree between economic development efficiency and ecological development level in the key state-owned forest areas. We modified and improved the coupling coefficient (degree) model, which was referred to in previous research [21,23,24].

The following coupling coefficient (degree) model was established by referring to previous research and through modification and improvement.

$$C = \{(f(x) \times g(y) / [(f(x) + g(y)) \times (f(x) + g(y))]\}^{1/n} \quad (9)$$

where C is the coupling coefficient of economic development efficiency and ecological development level, between 0 to 1. The greater the value of C, the more coordinated the coupling relationship between economic development efficiency and ecological improvement is, and vice versa. The value $f(x)$ is the integrated efficiency index of economic development; $g(y)$ is the integrated evaluation index of ecological development level; n is the adjustment coefficient, and generally $2 \leq n \leq 5$. Since this paper measured the coupling degree model composed of two subsystems, economic development efficiency and ecological improvement, the value of n was 2. This model could not judge whether the coupling between the two systems was benign, that is, when the integrated development level of both systems was low, a high degree of coupling could still be obtained, although this coupling was not in an ideal state. To avoid this deficiency, this study introduced a coupling coordination degree model to objectively reflect the coupling coordination development state of the efficiency of economic development and level of ecological development of the key state-owned forest areas [25,26]. The model expression is as follows:

$$D = \sqrt{C \times T}, T = \alpha f(x) + \beta g(y) \tag{10}$$

where D is coupling coordination degree; T is the integrated evaluation index of economic development efficiency and ecological development level, which reflects the overall benefit or level of economic development efficiency and ecological development level. The values α and β are the weight to be determined. We considered the efficiency of economic development and the level of ecological improvement to be of equal importance in the process of coupling and coordinated development of the two systems. The values α and β were set as 0.5 [21].

There was no consistent standard for the division of coupling degree and coupling coordination degree in the previous literature [17,27–29]. We chose to set both coupling degree and coupling coordination degree into 4 levels, shown in Table 2.

Table 2. Classification criteria for coupling degree and coupling coordination degree.

	Value Range	Stage of Coupling
Coupling degree C	$0 < C \leq 0.3$	Low-level coupling stage
	$0.3 < C \leq 0.5$	Antagonistic stage
	$0.5 < C \leq 0.8$	Running in stage
	$0.8 < C \leq 1$	High level coupling stage
Coupling coordination degree D	$0 < D \leq 0.3$	Low coordination coupling
	$0.3 < D \leq 0.5$	Medium coordinated coupling
	$0.5 < D \leq 0.8$	Highly coordinated coupling
	$0.8 < D \leq 1$	Extremely coordinated coupling

Note: The antagonistic stage is the stage where the economic and social transformation and development are on a par with the ecological improvement capacity, and they compete with each other [20].

3.5. Index System Set

3.5.1. Integrated Evaluation Index System of Economic Development Efficiency of the Key State-Owned Forest Areas

According to the requirements of the DEA, we took the key state-owned forest areas as the decision-making units to evaluate the efficiency of their economic development. On the basis of the principles of representativeness, authenticity, and availability of indicator selection, the input and output indicator system of economic development efficiency was determined, as shown in Table 3, referring to the relevant research [14–16]. The evaluation indicators of the level of ecological development were established on the basis of two aspects: condition of ecological elements and condition of ecological pressure (Table 4).

Table 3. Integrated evaluation system of economic development efficiency in the key state-owned forest areas.

Indicator Category	Index	Index Meaning
Input system	Investment in fixed assets (10,000 yuan)	Capital input
	Number of people on duty at the end of the year (person)	Labor input
	Forestry area (10,000 hectares)	Land input
Output system	Total output value of forestry (10,000 yuan)	Economic development benefits
	Average annual salary of on-the-job employees (1000 yuan/year)	Economic development benefits

Table 4. Integrated evaluation index and weight of ecological development level in the key state-owned forest areas.

Indicator Category	Index	Weight
Condition of ecological factor	Forest Park Area (ha)	0.0337
	Wildlife and plant protection and nature reserves (10,000 yuan)	0.0377
	Total volume of standing trees (m^3/10,000 hectares)	0.0336
	Actual forest management and protection area at the end of the year (10,000 hectares)	0.1159
Condition of ecological pressure	Sulfur dioxide emission (10,000 tons)	0.0411
	Smoke (powder) emission (10,000 tons)	0.0297
	Output of industrial solid waste (10,000 tons)	0.1143
	Wastewater discharge (10,000 tons)	0.5940

Note: Sulfur dioxide emissions, smoke (dust) emissions, and wastewater emissions include industrial emissions and domestic emissions. The amount of industrial solid waste includes the amount of general industrial solid waste and the amount of hazardous solid waste.

3.5.2. Integrated Evaluation Index of Ecological Development Level of the Key State-Owned Forest Areas

In this paper, we based the establishment of the evaluation system of level of ecological development on existing research [30,31] and environmental development indicators. Meanwhile, this paper used the entropy weight method to calculate the weight of ecological development level evaluation indicators. The results are shown in Table 4.

4. Results and Analysis

4.1. Ecological Level and Economic Development Efficiency of the Key State-Owned Forest Areas

Based on Equations (6) and (7), we used the DEA model to calculate the scale returns of the key state-owned forest areas from 2001 to 2019 and obtained the efficiency of each decision-making unit (Table 5). If the comprehensive efficiency value was 1, it meant that the input and output levels were efficient, that is, the number of inputs was exactly the number of outputs in the year of output. If the scale efficiency equaled 1 and the pure technical efficiency was less than 1, it meant that, although the scale economy of investment was achieved, the best technical level was not achieved. If the pure technical efficiency was equal to 1 and the scale efficiency was less than 1, it meant that, even with a good level of technological progress, economies of scale were not achieved [32–34].

According to the calculation results of Table 5, the integrated evaluation index of ecological development level in the key state-owned forest areas basically presented an upward trend for the period 2001–2019. Over the same period, the integrated efficiency of economic development increased year by year, reaching its best in 2019. The pure technical efficiency and scale efficiency both equaled 1 in 2008, 2011 and 2015, indicating that increasing investment level became the main way to improve the efficiency of economic development of state-owned forest areas during the research period.

Table 5. Integrated evaluation index of ecological development level and economic development efficiency in the key state-owned forest areas.

Year	Integrated Evaluation Index of Ecological Development Level	Economic Development Efficiency			
		Integrated Efficiency	Pure Technical Efficiency	Scale Efficiency	Scale Return
2001	0.0140	0.848	1	0.367	Irs
2002	0.0059	0.671	1	0.671	Irs
2003	0.0731	0.835	1	0.835	Irs
2004	0.0893	0.855	0.855	0.883	Irs
2005	0.1025	0.968	1	0.968	Irs
2006	0.1249	0.927	0.98	0.946	Irs
2007	0.1360	0.89	0.957	0.930	Irs
2008	0.1208	1	1	1.000	-
2009	0.1474	0.787	0.995	0.791	Irs
2010	0.1584	0.76	0.916	0.830	Irs
2011	0.1518	1	1	1.000	-
2012	0.1615	0.776	0.961	0.807	Irs
2013	0.1740	0.858	0.985	0.872	Irs
2014	0.2155	0.884	0.945	0.936	Irs
2015	0.2231	0.891	0.981	0.908	Irs
2016	0.2312	0.734	0.855	0.628	Irs
2017	0.2432	0.793	0.889	0.705	Irs
2018	0.2497	0.823	0.912	0.751	Irs
2019	0.2532	0.886	1	0.886	Irs

Note: Integrated efficiency = Pure technical efficiency × Scale efficiency; "drs" means diminishing returns to scale; "-" means that the scale reward remains unchanged; "irs" means increasing returns to scale. If the scale returns increased, it indicated that the input level should be increased. If the scale returns decreased, it indicated that the input level should be reduced.

4.2. Coupling Type of Economic Development Efficiency and Ecological Development Level of the Key State-Owned Forest Areas

First, according to the data in Table 5, the coupling degree and coupling coordination of economic development efficiency and ecological improvement were calculated by using Equations (8) and (9), (Table 6). The higher the value was, the more coordinated the economic development efficiency and ecological development level were, otherwise the opposite was true [35,36]. Then, comparing with the standards in Table 2, we obtained the specific classification of the status.

The coupling degree was in the low-level coupling stage over the period 2001–2005, and in the antagonistic stage over the period 2006–2019. The coefficient of coupling coordination degree of economic development efficiency and ecological development level increased year by year, and was in the low coordinated coupling stage in 2001–2002 and in the medium coordinated coupling stage in 2003–2019. The content of Table 6 is shown in Figure 2, which further characterizes the trend of coupling degree and coupling coordinated degree between economic development efficiency and ecological development level.

The coupling degree between economic development efficiency and ecological development level basically rose over the period 2001–2019, as did the coordinated coupling degree. The coefficients of both indices fluctuated in 2002, 2011, and 2016. The plausible explanation was that Tianbao Project was implemented in 2000, which made the ecological strategy in the first place. The key state-owned forest areas began to pay attention to ecological development. The year 2011 was one year after the implementation of Phase 2 of the Tianbao Project. The degree of coupling and coordinated coupling between economic development efficiency and ecological improvement had not yet adapted to the further increasement of ecological protection, inducing fluctuation. The year 2016 was the next year after the full cessation of logging. There was clear demonstration that the full cessation of logging impacted the coupling degree and coordinated degree of economic development efficiency and ecological development level in the key state-owned forest areas.

Table 6. The state of coupling degree and coupling coordination degree between economic development efficiency and ecological development level of the key state-owned forest areas.

Year	Coupling Degree		Coupling Coordination Degree	
2001	0.1263	Low-level coupling stage	0.2333	Low coordination coupling
2002	0.0932	Low-level coupling stage	0.1776	Low coordination coupling
2003	0.2720	Low-level coupling stage	0.3514	Medium coordinated coupling
2004	0.2927	Low-level coupling stage	0.3717	Medium coordinated coupling
2005	0.2942	Low-level coupling stage	0.3968	Medium coordinated coupling
2006	0.3234	Antagonistic stage	0.4124	Medium coordinated coupling
2007	0.3391	Antagonistic stage	0.4171	Medium coordinated coupling
2008	0.3101	Antagonistic stage	0.4168	Medium coordinated coupling
2009	0.3645	Antagonistic stage	0.4127	Medium coordinated coupling
2010	0.3778	Antagonistic stage	0.4165	Medium coordinated coupling
2011	0.3383	Antagonistic stage	0.4414	Medium coordinated coupling
2012	0.2940	Antagonistic stage	0.3551	Medium coordinated coupling
2013	0.3744	Antagonistic stage	0.4396	Medium coordinated coupling
2014	0.3970	Antagonistic stage	0.4672	Medium coordinated coupling
2015	0.4002	Antagonistic stage	0.4721	Medium coordinated coupling
2016	0.4268	Antagonistic stage	0.4538	Medium coordinated coupling
2017	0.4238	Antagonistic stage	0.4686	Medium coordinated coupling
2018	0.4226	Antagonistic stage	0.4761	Medium coordinated coupling
2019	0.4158	Antagonistic stage	0.4866	Medium coordinated coupling

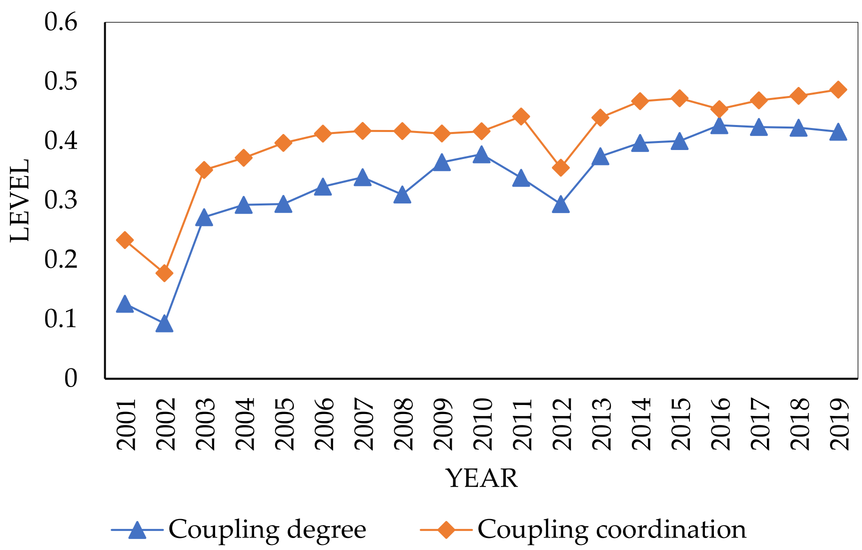


Figure 2. Trend of coupling degree and coupling coordination between economic development efficiency and ecological development level of the key state-owned forest areas.

4.3. Selection of Factors Affecting Coupling Coordination

Based on the coupling coordination indicators of the key state-owned forest areas, the selection of factors that affected the coupling coordination of the key state-owned forest areas was constructed from economic, social, and ecological levels, and included 9 indicators: (1) The proportion of the tertiary industry to the total output value of forestry ($x1$), reflecting the degree of industrialization transformation of the forest area; (2) Investment of fixed assets ($x2$), reflecting the relationship between the scale, speed and proportion of fixed asset investment in the forest area; (3) Forestry economic growth rate ($x3$), a dynamic indicator reflecting the degree of change in the economic development level of a forest area in a certain period, and reflecting also the basic indicator of whether a forest area's economy was vigorous; (4) The enterprise employment index ($x4$), reflecting the level of employment in the forest area and the degree of social stability in the forest area; (5) The level of social security expressed in terms of the number of pension insurance participants

($x5$), related to the stable development of the forest community; (6) The level of social welfare expressed in terms of forestry education investment ($x6$), both reflecting the level of social education and development of the forest area, and having an important impact on the future social transformation of the forest area; (7) Forest management and protection area at the end of the year ($x7$), reflecting the degree of protection and management of forest resources in the forest area; (8) Forest parks area ($x8$), reflecting the degree of maintenance and development of the forest landscape in the forest area; (9) Investment in wild animals and plants protection and nature reserves ($x9$), reflecting biodiversity protection in forest areas.

4.4. Influencing Factors of Coupling Coordination

4.4.1. Data Processing and Inspection

The data was standardized as above, and, on this basis, it was verified whether the indicators of the established influencing factors were suitable for principal component analysis. This study used common methods, like KMO and Bartlett sphere tests, to test the correlation between the standardized data. The results are shown in Table 7.

Table 7. KMO test and Bartlett spherical test of the results.

Kaiser-Meyer-Olkin		0.6190
Bartlett	Approximately chi-square	98.1360
	Df	36.0000
	Significance	0.0000

According to the results of the KMO test and Bartlett spherical test, the KMO value was greater than 0.6, which indicated that the original data was suitable for principal component analysis. The associated probability (Sig.) in the Bartlett test was less than 0.05, which indicated that the original data was suitable for principal component analysis.

4.4.2. Principal Component Extraction

On the premise of determining that the original variable data was suitable for principal component analysis, the eigenvalues of the matrix variables and the cumulative variance contribution rate, shown in Table 8, were obtained with the help of software tools. Based on the principle that the eigenvalue was greater than 1, 3 principal component variables were selected. The cumulative variance contribution rate reached 85.080%, indicating that the 3 principal components selected could fully explain the total variance of the original influencing variables and ensured, as much as possible, the original variables of all the information. The result of the principal component factor extraction was ideal. The factor load levels of different variables constituting the principal component were further calculated according to the extracted principal component factors. The larger the absolute value of the factor load, the greater the influence and effect on the corresponding principal component. On the one hand, by clearly extracting the effects of the internal variables of the three principal components on the principal components, it was possible to carry out subsequent analysis of the impact of various factor variables, based on the composition of different principal components on the coupling coordination of the key state-owned forest areas. According to the different principal components variables, three principal components to give new economic, social and ecological significance were identified, which provides new ideas for existing related research on the factors affecting the coupling coordination of the key state-owned forest areas.

Table 8. Eigenvalues and the variance contribution rate of the correlation matrix.

Explained Total Variance								
Element	**Eigenvalue**			**Extract the Sum of Squared Loadings**			**Rotation Sums of Squared Loadings**	
	Total	**Variance %**	**Accumulate %**	**Total**	**Variance %**	**Accumulate %**	**Total**	**Variance %**
1	4.366	48.509	48.509	4.366	48.509	48.509	2.835	31.502
2	2.164	24.040	72.549	2.164	24.040	72.549	2.774	30.824
3	1.128	12.530	85.080	1.128	12.530	85.080	2.048	22.754
4	0.593	6.584	91.663					
5	0.256	2.845	94.508					
6	0.234	2.601	97.109					
7	0.135	1.495	98.603					
8	0.094	1.041	99.645					
9	0.032	0.355	100.000					

According to the calculation result of the rotation factor load matrix, the constituent factors of the first principal component F_1 and the absolute value of the factor load were: forest park area ($x8$) (0.941); investment in wildlife plant protection and nature reserve ($x9$) (0.888); economic growth rate ($x3$) (0.692); the proportion of the tertiary industry to the total output value of forestry ($x1$) (0.642). The composition of the second principal component F_2 and the absolute value of its factor load were: the level of social welfare ($x6$) (0.918); level of social security ($x5$) (0.870); forest management and protection area ($x7$) (0.694). The absolute value of the third principal component F_3 and its factor load were: investment of fixed assets ($x2$) (0.932); enterprise employment index ($x4$) (0.881). Utilizing SPSS software, the score coefficient matrix of each principal component was obtained. Finally, the principal component expressions of the key state-owned forest areas' coupling coordination influencing factors, with each principal component Fi as the dependent variable and different variable factors as independent variables, were obtained:

$$F_1 = 0.123X_1 - 0.174X_2 + 0.253X_3 + 0.227X_4 - 0.124X_5 + 0.018X_6 - 0.033X_7 + 0.457X_8 + 0.367X_9 \quad (11)$$

$$F_2 = 0.144X_1 + 0.036X_2 + 0.145X_3 - 0.398X_4 + 0.019X_5 - 0.346X_6 + 0.232X_7 - 0.191X_8 - 0.060X_9 \quad (12)$$

$$F_3 = 0.125X_1 + 0.562X_2 - 0.146X_3 + 0.012X_4 + 0.498X_5 + 0.063X_6 + 0.112X_7 - 0.137X_8 - 0.078X_9 \quad (13)$$

The cumulative variance contribution rate of the first principal component F_1 reached 48.509%. The reduced F_1 could represent a large amount of original variable information, and its impact on the coupling coordination of the key state-owned forest areas was also the most prominent. To further analyze the composition of $F_1{}'$s variables, the common characteristics of the five factors were: forest park area, investment in wildlife plant protection and natural resource protection, area investment, economic growth rate, and the proportion of tertiary industry, reflected in its ability to transform the economy and ecology of the key state-owned forest areas and, also, the active factor that promotes and accelerates the economic and ecological coupling coordination of the forest area. Taking the proportion of the tertiary industry as an example, the key state-owned forest areas have been actively developing the tertiary industry since 2000 in response to timber reduction and ecological improvement. As of 2019, the output value of the tertiary industry (2001–2019) has been increasing, from (about) 14% to (about) 30%. The rapid development of the tertiary industry is conducive to the optimization of the industrial structure of the forest area, and an ecologically-led industrial system is gradually being formed, which is objectively conducive to accelerating the economic transformation of the forest area and promoting ecological development.

According to the above analysis, it was considered that F1 was a large-scale indicator that had the most significant impact on the economic coupling coordination of the key state-owned forest areas and the ecological coupling coordination. Active factors could improve the forest area's coupling coordination and provide reference and incentives for strengthening coupling coordination. Differing from the first principal component F_1, the second principal component F_2 was mainly an important driving factor for the social coupling coordination of the key state-owned forest areas. In addition to major changes in forest resources, major state-owned forest areas have undergone major reforms. The separation of enterprises made the functions of the key state-owned forest areas clearer, especially in terms of social functions. The change in social functions strengthened the social coupling coordination of forest areas. The third principal component F_3 had little effect on the key state-owned forest areas' economic and ecological coupling coordination.

4.4.3. Principal Component Regression Analysis

According to the extraction of three principal components that had significant effects on the coupling coordination of the key state-owned forest areas, the three principal components that could cover the information of the original variables were used as new independent variables. The total forestry output value of the key state-owned forest areas was the dependent variable (the total output value was considered the most intuitive reference indicator to reflect the forest area's coupling coordination). A multiple linear regression equation was constructed as follows:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 \quad (14)$$

Y is the explanatory variable, that is, the dependent variable. The term B_0 is a constant term, X_i (i = 1, 2) is an independent variable replaced by a different principal component, and the normalized original variable data expressed its value according to the respective principal component expression. It turned out that B_i (i = 1, 2, 3) was the independent variable coefficient.

In the principal component regression, it was necessary to separately perform equation fitting degree determination, equation significance test, and collinearity test on the regression model. Here, the corresponding test results were obtained by using SPSS software. The test results are shown in Tables 9–11:

Table 9. Determination of Fitness of Principal Component Regression Equation.

R	R Squared	Adjusted R Squared	Standard Skewness Error	Durbin-Watson
0.951	0.904	0.8880	0.1140	2.435

Table 10. Analysis of variance of the principal component regression equation.

	Sum of Square	df	Mean Squared	*F*	Significance
Regression	1.471	3	0.490	37.729	0.000
Residual	0.156	12	0.013		
Total	1.627	15			

Table 11. Principal component regression collinearity test and coefficients.

		T	Significance	Collinearity Statistics	
	Coefficient			Tolerance	Bright
(constant)		12.765	0.000		
F1	0.676	7.567	0.000	1.000	1.000
F2	0.663	7.420	0.000	1.000	1.000
F3	0.083	6.799	0.000	1.000	1.000

Tables 9–11 show the following: (1) In the test of the fitness of the regression equation, the fitness index was R2 = 0.904, indicating that the independent variable caused 88.8% of the dependent variable change. The regression equation fit the data very well. In addition, the Durbin–Watson value was 2.435, which was in the standard interval of $0 < D < 4$, indicating that the residual variables were independent of each other; (2) In the significance test of the regression equation, the significance level Sig was approximately 0, rejecting the assumption that the regression coefficients were all zero. It proved a significant linear correlation between the independent and dependent variables in the regression model, and the regression equation was meaningful; (3) In the collinearity test of the independent variables of the regression model, the collinearity was tested by referring to the tolerance and variance inflation factor (VIF), VIF = 1 met the basic requirement of VIF < 10, which indicated that there was no collinearity between the independent variables problem. In summary, the principal component regression model had a good fitting effect; (4) The coefficients of the independent variables of the regression model were 0.676, 0.663, and 0.083, and the regression equations for the factors affecting the development and transformation of the key state-owned forest areas, based on the principal component independent variables, were established as follows:

$$Y = 0.676X_1 + 0.663X_2 + 0.083X_3 \tag{15}$$

The above regression equations were further combined with the principal component expressions of $F1$, $F2$, and $F3$. Finally, the regression equations of the factors affecting the coupling coordination of the key state-owned forest areas were obtained:

$$Y = 0.1890X_1 - 0.0948X_2 + 0.2550X_3 - 0.1094X_4 - 0.0299X_5 - 0.2120X_6 + 0.1408X_7 + 0.1709X_8 + 0.2018X_9 \tag{16}$$

According to the principal component regression equation of the key state-owned forest areas' coupling coordination influencing factors, two perspectives were identified for discussion of the independent variable coefficients: one perspective focused on the positive and negative, and the second perspective focused on the magnitude. First, taking the positive and negative characteristics of the independent variable coefficients as a breakthrough point, investment of fixed assets ($x2$), enterprise employment index ($x4$), the level of social security ($x5$), and the level of social welfare ($x6$) weakened the coupling coordination of the forest area. The main operating entity of the key state-owned forest area is the Forest Industry Group. The Forest Industry Group created a management model that integrates management of timber production, government–enterprise, resource cultivation, timber production, forestry industry, and community services. However, the shortcomings of this management model are gradually appearing in China's socialist market economy. Therefore, the reform of "separating government and enterprise", stripping off the social functions of enterprises and improving people's livelihood is imminent. However, forest area reform is a long-term process. The research period was from 2000 to 2019, and, during this period, the key state-owned forest areas were in the early stage of exploration in forest area reform. Many social and corporate functions were not divided, which caused a long-term game between the forest industry group and the local government. For the key state-owned forest areas, under the effect of comprehensive suspension of logging, the economic transformation and system reforms, with "diversified development and separation of government and enterprise" as the core, continued to deepen. Investment of fixed assets ($x2$), enterprise employment index ($x4$), the level of social security ($x5$), and the level of social welfare ($x6$) would gradually reduce the negative impact of the coupling coordination of the forest area. The proportion of the tertiary industry to the total output value of forestry ($x1$), economic growth rate ($x3$), forest park area ($x8$), investment of wildlife plant protection, and nature reserve areas ($x9$) positively affected the coupling coordination of the key state-owned forest areas, and the above-mentioned negative effects would be further weakened.

Second, the positive independent coefficients were the following: the proportion of the tertiary industry to the total output value of forestry ($x1$), economic growth rate ($x3$), forest park area ($x8$), investment of wildlife plant protection, and nature reserve ($x9$); negative dependent coefficients are: investment of fixed assets($x2$), enterprise employment index ($x4$), the level of social security ($x5$), and the level of social welfare ($x6$). The absolute value of the independent coefficient (set to B) size characteristics was the following: (1) B > 0.3, none; (2) 0.3 > B > 0.1: the proportion of the tertiary industry to the total output value of forestry ($x1$), economic growth rate ($x3$), enterprise employment index ($x4$), the level of social welfare ($x6$), forest management and protection area ($x7$); forest park area ($x8$), investment of wildlife plant protection and nature reserve ($x9$), the level of social security ($x5$). The results showed that there was no independent variable of the first type. The influence of each factor in the second type of independent variables on the coupling coordination of the key state-owned forest areas was second only to the first type of independent variables. A unit change of 1% of each factor could cause the dependent variable to change by about 0.2%. However, a single factor affecting forest areas' transformation and development capability was not as good as the first independent variable. Still, in practice, if resources are rationally allocated, and different driving factors that positively affect transformation and reform were considered, huge practical effects would eventually be achieved. The third type of independent variable had little contribution and impact on the coupling coordination of the key state-owned forest areas.

5. Conclusions and Implications

This study focused on the key state-owned forest areas and analyzed the coupling and coordination relationship between economic development efficiency and ecological development level, from an empirical perspective, for the period 2001–2019. The results showed that the integrated evaluation index of ecological development level in the key state-owned forest areas basically exhibited an upward trend, which was the same for the economic development efficiency. Our results were consistent with previous literature. Li et al. [37] studied the ecological vulnerability of the key state-owned forest areas in Heilongjiang Province, indicating that, with the implementation of China's ecological protection policies and the economic transformation of the key state-owned forest areas, the forest resources were gradually enriched, and ecological vulnerability gradually reduced from 2004 to 2014. The comprehensive evaluation index of the ecological improvement of the forest industry groups increased overall. The comprehensive efficiency of ecological development of the key state-owned forest areas and five forest industry groups increased year by year, and became much better since 2015. The comprehensive efficiency of economic development shows fluctuating trends, closely related to the logging policies. Yang et al. [38] demonstrated that, after 2015, the industrial agglomeration of the state-owned key forest areas in the Greater and Smaller Khingan Mountains showed the characteristics of alternate evolution. The coupling degree between the efficiency of economic development and the level of ecological improvement was basically in an antagonistic stage. The coupling degree and coupling coordination degree increased slowly and would evolve to the stage of medium and high coordination coupling in the future. This related to relevant reform measures of recent years, such as vigorously strengthening ecological improvement and promoting economic transformation and development in the key state-owned forest areas.

The ultimate goal of ecological development in the key state-owned forest areas is to achieve efficiently coordinated development of the economy and ecology. From the sustainable perspective, the economic transformation and development of state-owned forest areas and ecological improvement have a practical basis for coupling, that is, the consistency of goals. There are some other factors that have significant impact on the coordinated development of forest economy and ecology. For example, the influence of nontimber forest products on the coordinated economic and ecological development has received considerable attention, and the results are mixed [39–41]. Due to space consideration, this paper did not discuss this factor in detail. In the future, this factor could be discussed separately.

Considering the specific coupling and coordination state of ecological improvement and socio-economic development, this study provides a suitable and optimal specific mode of socio-economic transformation and development for the key state-owned forest areas. Therefore, in the process of future transformation and development, the key state-owned forest areas should closely combine ecological improvement with economic transformation and development, putting the development of ecology and economy in an equally important position.

On the basis of fully implementing the national forestry policies, the key state-owned forest areas could make full use of their own forest resources to increase the development of diversified management by means of the following: (1) Using the key state-owned forest areas' own resource advantages to develop green industries, extending the traditional industrial chain and increasing the development of emerging alternative industries; (2) Gradually replacing the original extensive industrial model with the ecological industrial development model to increase its material capital stock. These measures would enable the forest region to promote rapid and efficient economic development of the forest region on the premise of maintaining the ecological leading function of the forest region unchanged.

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