Practical evaluation and prediction based on carbon sequestration forest decision model

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Abstract. A decision model for understanding forest use is developed and the model is applied to selected forests and evaluated in practice.To make a decision model for using forests, we use a meta-analysis method to look at how forest ecosystem services are worth and rank their value impacts. To figure out whether or not the forest can be left uncut and when it should be cut down, we look at carbon sequestration benefits, which is a significant factor in the operator's decision.We applied the forestry model to several forestry sites. We used it to the Sekhangba forest in China and forestry sites throughout New Zealand to predict the amount of CO_2 absorbed in 100 years and give the corresponding forest management plan. We answered using the optimal rotation period given in the previous round for the transition strategy.

Keywords: Decision model, Meta model, carbon sequestration benefits, optimal rotation period.

1. Introduction

1.1. Background

It is widely recognized that the increase of greenhouse gases in the atmosphere, especially CO_2, is the most critical driver of global climate change. CO_2 concentration in the atmosphere has increased from 280 ml-m^3 before the industrial revolution to 370 ml*m^3 in 2001 and is growing at a rate of 1~1.5 ml*m^3 per year [31.5s]. [1]In contrast, the annual average temperature of the Earth's surface has risen by 0.6 °C over more than a century [2] to reduce the adverse effects of global climate change and to slow down the increasing trend of greenhouse gases, especially the atmospheric concentration of CO.

As the mainstay of terrestrial ecosystems, Forests are an essential part of the Earth's biosphere. Although the global forest area only accounts for 27% of the land area, the above-ground vegetation carbon pool stores about 80% of the global above-ground carbon stock. The forest soil carbon pool stores about 40% of the global soil carbon stock. [3]The annual carbon exchange between forest photosynthesis and respiration and the atmosphere is up to 90% of the yearly carbon exchange in terrestrial ecosystems and therefore plays an essential role in regulating global climate and maintaining global carbon balance. [4]

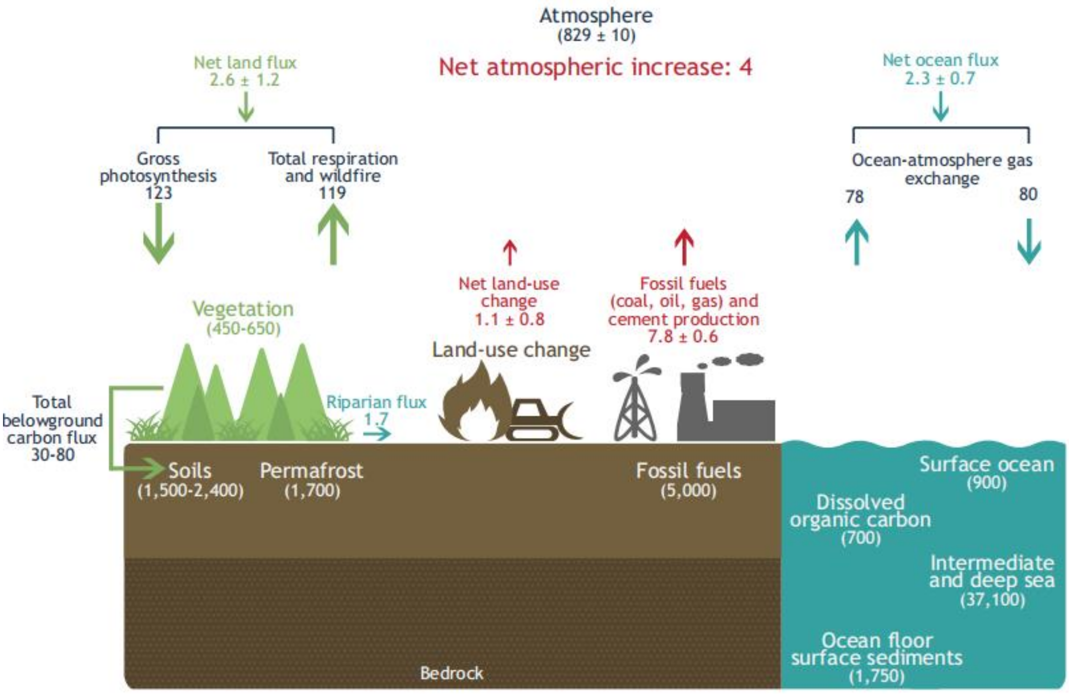

Figure 1. Global carbon cycle. Carbon (Gt C) stocks are denoted in parentheses and shown in gigatons. Fluxes (Gt C per year) are associated with arrows and shown in gigatons per year.

1.2. Our Work

Task 1: Develop a decision model to inform forest managers of the best use of a forest.

To address these issues, this paper aims to investigate the value transfer pattern of forest ecosystem services in China based on a modified model form using meta-analysis. On this basis, we calculate the value change of the forest ecosystem from 2010 to 2100. As for deforestation, as mentioned in the original title, many studies have also shown that a lengthy rotation period is generated for even-aged forests when carbon sequestration benefits are considered. Sohngen B et al.3 explored the potential carbon sequestration costs and sequestration over an extended rotation period using softwood forests in the western and southern United States as an example. The increased costs of 324 softwood species were calculated by bringing the value of carbon into the optimal rotation period model at a given carbon price. The results showed that in 12 states, 15 million t of CO^2 could be sequestered at the cost of \$7/t, which is very cost-effective for a carbon price of \$55-\$209/t. In addition, the study found that the price of forest trees had a significant impact on the marginal cost of carbon sequestration, followed by site quality, at a carbon price of \$55/t. At a carbon price of \$55/t, 100 hm^2 of softwood forest would be retained [5] We express the uncertainty of stand price and carbon price by developing a choice model, which is further discussed under two scenarios with or without carbon sequestration benefits, and find that the optimal rotation period varies with the type of price, the way carbon benefits are priced, and the discount rate.

Task 2: Apply your models to various forests. Identify a forest that your decision model would suggest the inclusion of harvesting in its management plan.

In this paper, we use the global 1 km land cover change dataset from 2010 to 2100 constructed by Xia Li et al. This dataset is based on the IMAGE and cellular automata models. The evolution of different land-use types from 2010 to 2100 is simulated according to four scenarios, A1B, A2, B1, and B2 in the IPCC SRES, where the baseline scenario is 2010. After that, we extracted the Chinese forest dataset and used a meta-regression model to calculate the changes of ecosystem service values under different scenarios.

1.3. Abbreviation and Defifinitions

We begin by defining a list of nomenclature (symbols) used in this article, cf. Table 1.

Table 1. Nomenclature.

Variable Name	Meaning/Unit
Plaque edge density (DE)	Complexity of the perimeter shape of patches in the landscape
Maximum plaque index (Ip)	Proportion of the largest patch area in the landscape to the total area
Plaque density index (Ipp)	Number of patches per square kilometer
Aggregation Index (Ix)	The degree of randomness or aggregation of different patch types in the landscape
Aroma uniformity index (IsHE)	Measure the uniformity of the distribution of landscape patches in terms of area
Value	Trillion
Area	billion h m^2
Carbon sink	pg cyr-1

2. The GAME Model

Now, we are to state our model in detail.

Model Assumptions

Based on now, the data information we collected may have errors with the actual, assuming availability and reference in the ideal state. It is assumed that unforeseen large-scale man-made environmental damage is not considered.Assume that each region has a complete ecological civilization system. It is assumed that the resources will not be used up in the short term. There are no influential human activities.

2.1. Data collection and analysis

The research area of this paper is China (data from Hong Kong, Macao, and Taiwan are not available), and the source of literature is CNKI. All literature on the valuation of forest ecosystem services in China published since 1990 was searched using the subject terms "forest" and "valuation." In the process of literature selection, those with any of the following conditions were excluded:

(1) The object of assessment is the forest within a particular administrative region: In this paper, the original empirical studies were chosen to focus on the independence, integrity, and continuity of forest ecosystems, such as nature reserves, forest parks, and forest farms; when the object of study is the forest within a particular administrative region, it may be suspected of artificially dividing the boundary;

(2) The assessment object is planted forest: In this paper, when selecting the independent variables of the model, we mainly consider the geographical location of the forest ecosystem, the surrounding environmental conditions, and other natural or human factors that affect the growth and distribution of the forest, while the planted forest is mainly operated and constructed according to human requirements or purposes, which may affect the representativeness of the sample points;

(3) Assessing the value of non-ecosystem services: The object of this paper is the value of forest ecosystem services, and some literature focuses on the economic or social benefits provided by ecosystems, so it is not considered here;

(4) Use of energy value analysis for value assessment: Most of the current research work on value assessment is based on object quality analysis, so the literature using energy value analysis is excluded;

(5) Value assessment using the value transfer method: Since this paper adopts the value transfer method for value assessment, the literature using the value transfer method is excluded.

Forest ecosystem has the functions of supplying forest and fruit products, water connotation, carbon sequestration and oxygen release, air purification, soil conservation, nutrient accumulation, forest protection: biodiversity conservation, forest recreation, scientific research and education, and other types of services. In the reviewed literature, only a few studies have assessed the forest protection value and scientific research and educational value of forest ecosystems, so they are not included in this paper.

2.2. Model Description

The most widely used class of meta-regression models is the least squares-based multiple linear regression:

$$\ln\ y_{ij} = \alpha + \beta^e X^t + \beta^c X^c + \beta^e X^e + \beta^s X^s + u_{ij} \tag{1}$$

Where y is the value of forest ecosystem services; α is the constant term; X is the matrix of independent variables, where X represents the type of ecosystem services, X represents the characteristics of the study area (i.e., vegetation zoning and forest area), X" represents the surrounding environment (i.e., forest abundance and railroad length), and X represents socioeconomic conditions (i.e., population size and GDP per capita); β is the corresponding coefficient matrix; and u is the random error term.

The underlying assumption of the least squares method is that different observations are not correlated with each other. In the Meta-analysis database established in this paper, the maximum number of value observations provided by one literature was 8 and the minimum was 1. 96% of the literature provided multiple value observations. Since the observations from the same literature are not independent and may be correlated among studies, it is necessary to take this into account in the model construction process. Some studies use weighted least squares with the reciprocal of the number of observations as the weight, which reduces the effect of sample correlation to some extent [160-18].

The weighted least squares method corrected for heteroskedasticity in the model. Still, it did not consider the hierarchical structure of the data set and the differences in randomness across studies. The panel data regression model explicitly considered the heterogeneity among different studies, weakened the effect of covariance of variables, and improved the model's validity. Its specific form is as follows:

$$\ln y_{ij} = \alpha + \beta^c X^t + \beta^c X^c + \beta^e X^e + \beta^s X^s + w_{ij} \tag{2}$$

Where u is the error term, which can be decomposed into two components, s and u.The former represents the error component of the i-th study, and the latter represents the random observation error. Since different studies do not provide exactly the same number of value observations, this is an unbalanced panel. The panel data regression models include mixed least squares model, fixed effects model and random effects model. In this paper, the Breusch-Pagan Lagrange multiplier test (LM test) is used to determine the existence of individual random effects, and the Hausman test is used to determine the merits of the fixed effects model and the random effects model [6].

3. **Results**

Meta regression model results. In order to select the appropriate model for this dataset, the regression results of the three models were calculated separately in this paper. For the panel data regression model, the results of the LM test indicated that there was a random effect between studies (P=0.0839), so the mixed model was not applicable; the results of the Hausman test indicated that the original hypothesis that the random effect was independent of the explanatory variables (P=0.5859) could be accepted, and the random effect model was preferred in this case. In the model construction process, observations with standardized residuals greater than 1.5 were excluded. Comparing the results of different regression methods, it can be seen that the panel data regression model has the best overall fit, so the random-effects model in the panel data regression method is used to construct the Meta regression equation.

The transfer error is used to test the consistency between model predictions and value observations, and is equivalent to MeanAbsolute Percentage Error (MAPE), which is defined as:

$$TE = \frac{|\text{value}_{est} - \text{value}_{obs}|}{\text{value}_{obs}} \tag{3}$$

Where, TE is the Transfer Error, value. Is the predicted value of the model, and value is the observed value of the value. Generally speaking, the smaller the transfer error, the higher the validity of the value transfer model. In this paper, we adopt the Leave-One-Out Cross Validation, i.e., we select each observation in turn as the test set and the rest as the training set, and calculate the transfer error of the corresponding observation in the test set respectively. Compared with the common k-fold crossvalidation (k>1), the leave-one-out method is the most tedious, but has the highest sample utilization rate, which can not only evaluate the overall model error more accurately, but also facilitate the analysis of the variation characteristics of the error with the observation values.

Table 2. Results of meta regression model.

Variables	Coefficients		
	OLS	WLS	RE
constent	13.21 *** (1.45)	13.55 *** (1.44)	12.86 *** (1.79)
Biodiversity conservation	2.41 *** (0.21)	2.38 *** (0.20)	2.46 *** (0.20)
Forest products	1.34 *** (0.22)	1.32 *** (0.22)	1.43 *** (0.21)
Waler conservation	3.46 *** (0.23)	3.45 *** (0.21)	3.46 *** (0.21)
Soil conservation	1.68 *** (0.20)	1.71 *** (0.19)	1.74 *** (0.19)
Carbon fixation and oxygen production	2.34 *** (0.19)	2.34 *** (0.19)	2.40 *** (0.18)
Forest recreation	1.17 *** (0.22)	1.08 *** (0.20)	1.24 *** (0.21)
Air purifcation	1.54 *** (0.21)	1.47 *** (0.20)	1.63 *** (0.20)
Cold temperate deciducus needleleaf forest	0.17(0.52)	0.14(0.47)	0.20(0.67)
Temperate mized needleleaf and broadleaf forest region	−0.69 *** (0.20)	−0.69 *** (0.20)	−0.69 *** (0.25)
War temperate deciduous broadleaf forest	−0.37 ** (0.14)	−0.42 ** (0.13)	−0.36 ** (0.18)
Tropical monsoon rain forest and rain foresl region	−0.74 *** (0.22)	−0.92 *** (0.23)	−0.65 ** (0.27)
Temperate steppe region	−0.79 ** (0.24)	−0.82 *** (0.24)	−0.77 *** (0.29)
Temperate desert region	−1.44 *** (0.27)	−1.48 *** (0.25)	−1.42 *** (0.36)
Plateau hich-cold region	−0.96 *** (0.29)	−1.01 *** (0.29)	−0.92 *** (0.36)
Forest area	−0.17 *** (0.04)	−0.17 *** (0.04)	−0.17 *** (0.05)
Forest abundance	−0.06 ** (0.02)	−0.06 ** (0.02)	−0.06 ** (0.03)
Railway length	−0.07 * (0.03)	−0.07 * (0.03)	−0.06 * (0.04)
Number of population	−0.09(0.06)	−0.09(0.06)	−0.09(0.08)
GDP Per capita GDP	−0.29 ** (0.11)	−0.32 ** (0.10)	−0.27 ** (0.13)
Number df obcervations	495	495	495
Adjusted R^2	0.43	0.47	0.48
P	0.00	0.00	0.00

According to the results of the meta-regression model, the magnitude of the value of each ecosystem service type was water retention > biodiversity conservation > carbon sequestration and oxygen release > soil conservation > air purification > forest fruit products > forest recreation > nutrient accumulation.

4. Discussion

The model established in this paper, taking into account several factors and data, has undergone systematic theoretical analysis, and the algorithm is stable and the calculation results are more accurate. The accuracy of the model developed in this paper will be significantly reduced when there are large changes in national policies and force majeure such as natural disasters, therefore, the model can be optimized by considering national policies and natural disasters. Due to the time and financial constraints, we have not yet obtained the data related to soil carbon sequestration, especially the dynamic data processing, which needs further study.

The forestry model we give in this paper, the specific assessment scheme, etc., when put into use in real life, together with the comprehensive consideration of other factors in reality, can provide a good reference for urban management and national environmental management, and can be extended to more regions to help solve ecological and environmental problem.

4.1. Optimal rotation period of forests based on carbon sequestration benefits

For the question of whether there are trees that can be left uncut and their transition points, here we briefly describe foreign research on optimal rotation periods based on carbon sequestration benefits. Numerous studies have shown that when considering the carbon sequestration benefits of plantation forests, the rotation period length is affected and varies with the carbon price and discount rate, and this variation is usually sensitive.[7] The general model of carbon sequestration benefits was derived by summarizing the domestic research on forest carbon sequestration benefits, and introduced into the Faust Mann optimal rotation period model to compile the optimal rotation period model based on carbon sequestration benefits.

4.2. Expression of carbon sequestration benefits

Based on the forest stock and carbon tax method. The expression of forest carbon sequestration benefit (F (t)) was derived based on the calculation methods of forest stock and carbon tax method:

$$F(t) = pM(t) = p\int_0 \quad aQ(t)dt \tag{4}$$

Where: M (t) is the forest carbon sequestration site; Q (t) is the forest stock; a is the coefficient (a>0); p is the carbon price.

According to a large number of theoretical and empirical studies, the amount of carbon sequestered at a certain time is positively and linearly correlated with the amount of forest stock (the effect of soil sequestration is not considered here). [8]The carbon price (p) can be determined by carbon tax method, afforestation cost method, willingness to pay method, etc.

4.3. Expression of multiple rotation periods

According to Faustmann's multiple rotation period model, the following assumptions are made for multiple rotation periods: (1) the market is free and competitive; (2) forest operators can operate forever and expect to maximize net present value; (3) stands are planted at the same time and all stands are in the same growth period; (4) timber value is obtained after the forest is cut, while the forest has carbon sequestration when it is not cut. (4) The forest gains timber value after cutting, and the forest has carbon sequestration benefits when it is not cut [9].

According to Faustmann's rotation period model, the timber benefit is the same at the end of all rotation periods, and the timber benefit can be expressed as [p,Q(T)-c], where c is the cost of planting the forest, and the discounted net present value of the timber value is:

$$V_c = [p_1Q(T) - c]e^{-rT}(1 + e^{-rT} + e^{-2rT}) \tag{5}$$

4.4. Application to Chinese forests

Country-based study of forestry resource changes. In this paper, we use the global 1 km land cover change dataset from 2010 to 2100 constructed by Li Xia et al. This dataset is based on the IMAGE model and cellular automata model, and the evolution of different land use types during 2010-2100 is simulated according to four scenarios in IPCC SRES - A1B, A2, B1, B2 [5], where the baseline scenario is 2010. A1B is a sub-case of A1 scenario with balanced development of various energy sources.

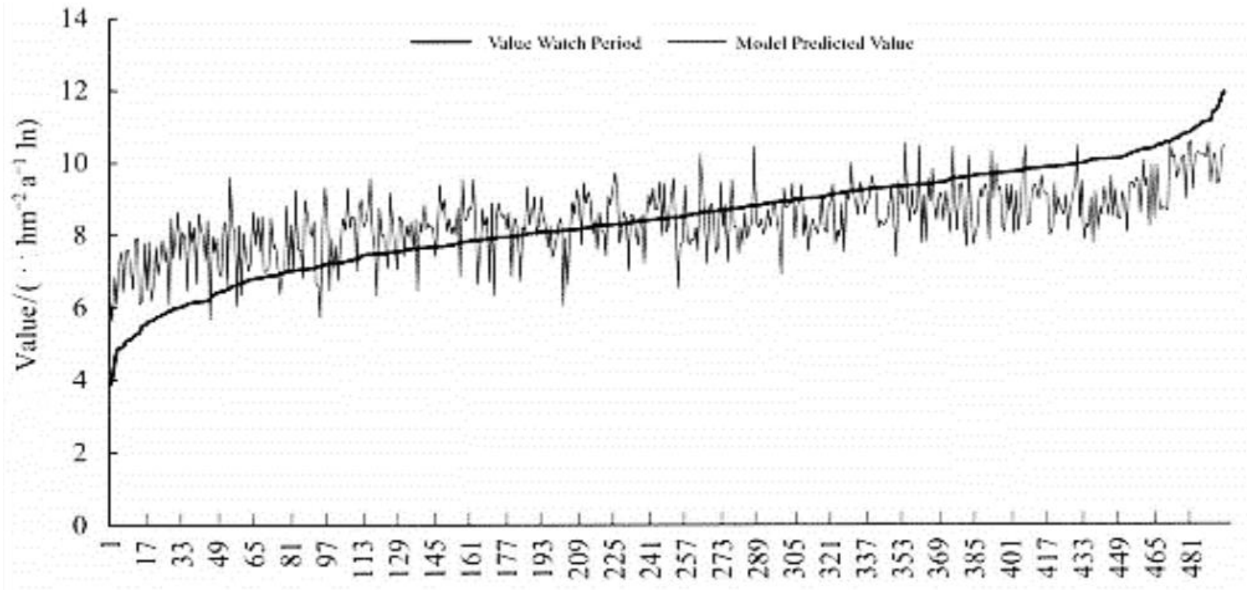

Fig 2. Value.

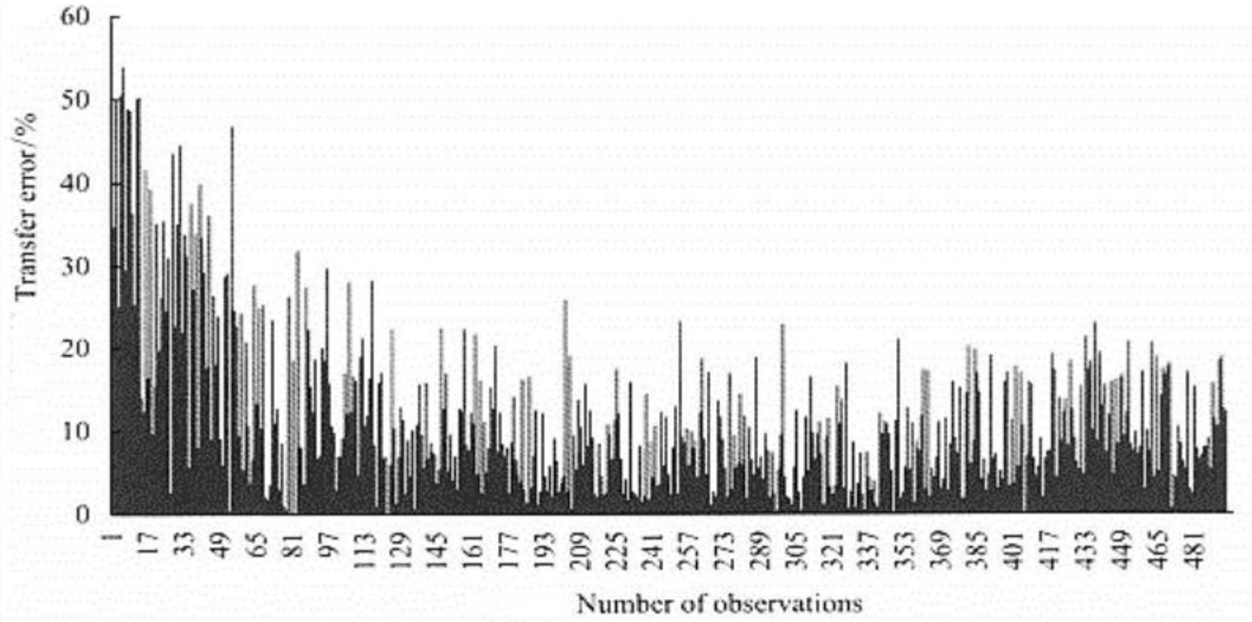

Fig 3. Observations.

In this paper, we extracted the Chinese forest dataset and calculated the changes of ecosystem service values under different scenarios using a meta-regression model, and the results are shown in Table 5.

The total value of ecosystem services was 26.26 trillion yuan in 2010. [10]For the four scenarios, the changes of forest area and total value of ecosystem services over time showed the same trend. [11]Under scenarios AlB and B1, the total value of forest area and ecosystem services continues to increase, reaching 41.06 trillion yuan and 41.58 trillion yuan, respectively, by 2100. Under scenario A2, the total value of forest area and ecosystem services continues to decline, with an average annual decrease of $6.785 billion from 2010 to 2050 and $7.551 billion from 2050 to 2100. Under scenario B2, the total value of forest area and ecosystem services decreases first, under scenario B2, the total value of forest area and ecosystem services first increases and then decreases, and the total value of forests in 2100 is only 22.97 trillion yuan. Overall, scenario B1 is the optimal development path for China's forest ecosystems, while scenario B has the largest loss of total ecosystem service value.

Regression result of transfer error on vegetation zoning

Table 3. Regression result of transfer error on vegetation zoning.

Variable	Coefficient	Standard deviation
Subtropical evergreen broadleaf forest region	0.106***	0.006
Cold temperate deciduous needleleaf forest	0.159***	0.040
Temperate mixed needleleaf and broadleaf forest region	0.140***	0.016
War temperate deciduous broadleaf forest	0.117***	0.010
Tropical monsoon rain forest and rain forest region	0.109***	0.018
Temperate steppe region	0.115***	0.016
Temperate steppe region	0.144***	0.020
Plateau high-cold region	0.137***	0.019

Table 4. Change in forest area and value in China under different scenarios.

Scenarios	Year	Area	Value
Baseline scenario	2010	1.66	26.26
A1B	2050	2.02	30.85
Scenario A1B	2100	3.16	41.06
A2	2050	1.55	25.98
Scenario A2	2100	1.17	23.58
B1	2050	2.26	33.53
Scenario B1	2100	3.29	41.58
B2	2050	1.75	27.41
Scenario B2	2100	1.50	22.97

5. Conclusion

Rotation period is an important decision basis for forestry operators, and it determines the risk of forestry investment. At present, in the process of plantation forest management, due to the incomplete carbon market and lack of awareness, operators basically do not consider the benefits of forest carbon sequestration; however, in larger forest areas, there have been many studies on the benefits of forest carbon sequestration, and people gradually realize the huge benefits of forest carbon sequestration. If only the stumpage value of timber is considered, operators tend to cut down trees earlier, which makes the rotation period shorter. In addition, forests not only have carbon sequestration benefits, but also have many ecological services such as water conservation, wind and sand control, and biodiversity maintenance, and many studies have shown that their environmental value has far exceeded their stand value. It is evident that forest trees require a rotation period and no conditions exist to keep them from being cut down.

By arranging the value observations in ascending order, it is noted that the model predictions gradually transition from overestimation to underestimation as the observations increase, and the transfer error tends to decrease. This result is consistent with the results of Chaikumbung (wetland ecosystem), Salem (mangrove ecosystem), and Brander (wetland ecosystem) studies. There is no reasonable explanation for this phenomenon, but it can be used as a reference in the value transfer process. For example, according to the regression results of transfer errors on ecosystem service types and vegetation zones, when using meta-regression models to assess the value of forests in subtropical evergreen broad-leaved forests or the value of water retention, the transfer errors are smaller and the estimation results are more accurate; while when assessing the value of forests in temperate desert areas or the value of nutrient accumulation and forest recreation, the transfer errors are larger and the estimation results should be treated with more caution. The results should be treated with more caution. Both emission reduction and sink increase are equally important for promoting carbon neutrality goals. Based on the preferred land model of the ecological reserve developed in this problem, it is possible to use the ecosystem to reach the carbon balance faster and achieve the carbon neutrality goal.

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