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Research on Investment Analysis of Forestry Engineering Project Based on Real Option

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Abstract:

Forestry carbon sequestration plays a crucial role in both addressing and adapting to global climate change. The large investment scale, long recovery period, and uncertain returns associated with forestry carbon sequestration projects have made forestry investment decisions increasingly complex. Traditional valuation methods, such as discounted cash flow analysis, struggle to provide a comprehensive, objective, and accurate assessment of carbon sequestration projects overall. In contrast, the physical option method can fully consider uncertainty factors and quantify them into the form of options, analyzing the time value of cash flows in carbon sequestration projects more realistically, scientifically, and reasonably, thus making a more comprehensive assessment of carbon sequestration projects and addressing the shortcomings of traditional methods.

Based on the research results of China's voluntary forest greenhouse gas emission reduction projects, this study takes the forestry carbon sequestration project in Gaotianyan Ecological Forest Area, Lianhua County, Pingxiang City, Jiangxi Province as an example. The traditional NPV method and the Black-Scholes model are used to evaluate the value of the project. The conclusions drawn are as follows: (1) Under the existing technical support conditions, forestry carbon sequestration projects, such as Chinese fir carbon sequestration afforestation projects, have significant carbon sequestration and emission reduction effects, while also exhibiting characteristics of skewed distribution. (2) The option value of afforestation projects constitutes the main part of the carbon sequestration value based on the project. The purpose of this study is to provide a reference for promoting the healthy development of forestry carbon sequestration projects and scientifically evaluating the value of forestry carbon sequestration projects.

Keywords:

Forestry carbon sequestration projects; Physical option; Binomial tree model; Uncertainty

1.Introduction

Forestry is a vital foundational industry in China. In the process of addressing climate change, forestry carbon sequestration emerges as a primary means to reduce CO2 emissions and mitigate climate change. It also serves as a crucial point for reconciling the contradiction between economic development and low-carbon emissions in our country. In September 2023, the General Office of the Central Committee of the Communist Party of China and the General Office of the State Council issued the "Plan for Deepening the Reform of the

Collective Forest Tenure System," which explicitly supports the development of forestry carbon sequestration projects meeting certain conditions as voluntary greenhouse gas emission reduction projects participating in market transactions. This plan also advocates for the establishment of a sound ecological compensation mechanism that reflects the value of carbon sequestration. Consequently, constructing a scientific valuation system for forestry carbon sequestration projects, exploring valuation analysis methods based on physical options, realizing mechanisms for the value of ecological products, and improving the forestry carbon sequestration measurement and monitoring system play pivotal roles.

2. Literature review

Black and Scholes (1973) laid the foundation for option pricing theory by introducing the Black-Scholes option pricing model, which is based on the theory of option pricing. Stewart and Myers (1977) were the first to propose a pricing theory for physical options, integrating financial option pricing theory into the field of physical investment. Brennan and Schwartz (1985) evaluated the value of energy projects using the physical option approach, marking the first application of the physical option method to the assessment of mineral resources. R.H. Clarke et al. (1989) utilized the physical option method to study the problem of timber harvesting under uncertainty and applied the physical option pricing method to forestry. Duku-Kaakyire et al. (2004) compared the static Faustmann investment model with the physical option method, suggesting that the framework of traditional investment decision models is incomplete, while physical options can accommodate the characteristics of uncertainty and flexibility in forestry financing projects. Johnathan Mun, Ph.D. (2012) analyzed various forms of physical options, elucidating why the physical option method is superior to traditional valuation methods and introducing Monte Carlo simulation methods. Regan (2015) and others, through evaluating agricultural land decisions in South Australia, concluded that considering option value can improve the accuracy of investment decisions using physical option simulation models. Biancardi Marta et al. (2022) used the physical option method to value photovoltaic investment projects, employing compound option methods and considering project risks, randomness, and multi-stages for pricing.

Since 2000, domestic scholars have begun applying the physical option approach in the forestry industry. Currently, the application of the physical option method in research on forestry carbon sequestration projects in China can be categorized into two main aspects: Firstly, regarding investments in forestry carbon sequestration projects: Jun Wei (2006) and others elucidated the inadequacies of traditional evaluation methods and demonstrated the feasibility of evaluating forestry investment projects using the physical option method by analyzing forestry project evaluation and its characteristics. Shanqin Huang (2013) introduced physical options in investment decision-making for forest construction projects and analyzed the types of physical options and compound option characteristics in forest construction investment projects, asserting that the "uncertainty" and "management flexibility" therein enhance investment value. Xiaobo He, Shuo Zhang (2013) were among the first to apply the physical option method to forestry carbon sequestration investment, providing a price judgment for forestry carbon sequestration investment using the physical option method. Xiaoting Zhu, Shaowen Zhang (2018) suggested that forestry investment projects have different stages, and if multiple options occur simultaneously in one stage, the maximum value should be taken as the result of the option price for this stage. Qi Li, Shaowen Zhang (2019) systematically analyzed the value connotations and option characteristics of forestry investment projects using the physical option theory. Xiaobo He, Shuo Zhang, Dongmei Wang, Shihong Zeng (2019) employed the physical option pricing method and utilized NetLogo simulation software to dynamically simulate the investment decision-making process of forestry carbon sequestration projects, suggesting that options enhance investors' initiative and better utilize the carbon sequestration function of trees.

Secondly, regarding the evaluation of forestry carbon sequestration projects: Kaixuan Zhang (2017) and others argued that forestry enterprises possess characteristics of call options, expansion options, and deferment options. They utilized a modified B-S option pricing model to assess enterprise value, demonstrating the stability of evaluation using the physical option pricing model. Anqi Chen (2017) and colleagues discussed methods for determining key parameters of the Black-Scholes option pricing model and compared the practical applications of the physical option method with traditional methods through real-life cases. Di Peng, Hualin Guo (2019) proposed that traditional evaluation methods are not suitable for PPP projects and introduced a model using Geske compound real options applicable to phased investments for assessment. Hua Ding (2020) and others conducted case studies and compared the results of traditional income methods with those of B-S theory, concluding that traditional evaluation methods cannot accurately assess value, whereas the physical option method provides a more scientifically grounded assessment of value. Xianlei Cao (2021) and colleagues, using larch as an example, constructed a carbon sequestration afforestation project value assessment model using the physical option method and analyzed factors influencing carbon sequestration value. Peng Wang (2021) evaluated the value of carbon sequestration afforestation projects using traditional NPV, option pricing models, and binomial tree models, expanding the application scope of the physical option method in forestry carbon sequestration value assessment. Xiaoming Hu et al. (2022) employed a fuzzy physical option model to assess project value, addressing the rigidity in parameter selection of traditional physical option methods, thus applicable to forestry carbon sequestration project value assessment.

In summary, both domestic and international scholars have made significant progress in researching physical options and their application in forestry carbon sequestration projects. The theoretical framework has demonstrated the feasibility of using the physical option method to evaluate forestry carbon sequestration projects. However, in practical case studies, most research has focused on forestry carbon sequestration projects implemented after 2015, which are still in their initial operational stages, leading to some limitations in the validation of assumptions. Therefore, this paper selects a forestry carbon sequestration project implemented in the Gaotianyan Ecological Forest Area of Lianhua County, Pingxiang City, Jiangxi Province, starting in 2005. We construct an analysis model for forestry carbon sequestration projects based on the physical option method, aiming to explore and validate a more scientifically and logically sound framework for analyzing forestry carbon sequestration projects.

3. Theoretical Framework and Research Methods

Forestry projects exhibit characteristics such as income uncertainty, irreversible investment, and management flexibility, rendering forestry investment decisions increasingly complex. In terms of value assessment, traditional valuation methods like discounted cash flow analysis often struggle to provide a comprehensive, scientific, objective, and accurate evaluation of forestry. This study aims to apply the physical option method to value assessment in forestry engineering projects. By thoroughly considering various uncertainties inherent in forestry investment projects, we quantize these elements into specific manifestations of options, analyzing the time value of cash flows within projects. This approach enables a more comprehensive evaluation of forestry projects that is realistic, scientific, and rational, thereby addressing the limitations of traditional methods.

3.1 Theoretical Framework

Starting from the concepts of options and physical options, this research identifies similarities between the pricing methods of physical options and the content of value assessment in forestry carbon sequestration projects. Leveraging the similarity in value assessment between physical options and forestry carbon sequestration projects, we construct a binomial tree model for forestry carbon sequestration projects.

3.1.1 Concepts of Options and Real Options

Options are among the most fundamental financial derivatives. They are specific contractual agreements that come in two basic forms: call options and put options. These contracts grant the holder the right to buy or sell a specific asset at a predetermined price at any time in the future or before a certain date.

Real options follow the core idea of financial options, which is the uncertainty factor affecting investors during strategic investments. Therefore, investments must possess a certain level of flexibility to transform this uncertainty risk into investable directions. A real option represents the potential returns of a project, composed of investment profits that the investment project itself can generate and the determinable investment opportunities in the future . Its initial definition was proposed by Stewart Myers (1977) during his time at MIT. He believed that when the investment goal is a project with high risk, the investment returns derived from the cash flow of the investment project come from the sum of the value of fixed assets currently held by the project and the choice of future investment opportunities. Thus, traditional net present value theory underestimates actual investments. However, it can also be argued that companies have the power to acquire the right to buy or sell real investments or project plans at a certain price in the future, allowing for the evaluation of real asset investments using methods similar to general options [2]. Since the underlying asset is a tangible property, this type of option is called a real option. This is similar to carbon sequestration or timber in forestry investment projects, which are expected tangible assets that can be evaluated using the real options method.

3.1.2 Pricing Methods for Real Options

3.1.2.1 Theoretical Foundations of Real Option Pricing

The foundation of real option pricing methods includes principles such as the absence of arbitrage, risk-neutral pricing, and the theory of complete markets [3]. The absence of an arbitrage pricing method involves utilizing established resources to replicate the future returns of the resources to be priced. Under the absence of arbitrage conditions, the benefits of the priced resources are far less than those of the replicated resource combinations. The most classic absence of arbitrage pricing methods are the Black-Scholes pricing formula and the binomial tree option pricing model, which are the most basic option pricing methods in continuous-time and discrete-time states, respectively. Unlike financial options, it is primarily an investment method used to address uncertainties in other financial assets. Additionally, it possesses characteristics such as concealment, randomness, conditioning, combination, and interaction. Therefore, the binomial tree option pricing model or simulation method is commonly adopted in studying real options. However, the calculation formulas for option pricing vary depending on the different investment objectives. The absence of an arbitrage pricing method replicates the future cash flows of the asset to be priced using a specific-priced asset.

3.1.2.1 Black-Scholes Option Pricing Method

Researchers have proposed the Black-Scholes option pricing model based on option pricing theory, assuming: (1) Stock prices follow geometric Brownian motion, i.e., dS=μSdt+σSdz, with constant parameters; (2) All income can be used for short-selling options; (3) There are no frictions in the market, meaning no transaction costs or taxes, and securities are highly divisible; (4) There are no risk-free arbitrage opportunities; (5) Security trading is continuous; (6) The risk-free interest rate r is constant and the same for all maturity dates. The Black-Scholes formula for pricing European call options is:

$$C = S \times N(d_1) - L_e^{-r(T_n - t)} \times N(d_2)$$

$$d_1 = \frac{\ln\frac{S}{L} + (r + 0.5\cdot\sigma^2)(T-t)}{\sigma\cdot\sqrt{T}}, \quad d_2 = \frac{\ln\frac{S}{L} + (r - 0.5\cdot\sigma^2)(T-t)}{\sigma\cdot\sqrt{T}} = d_1 - \sigma\sqrt{\mathrm{T} - \mathrm{t}}$$

In this formula, C represents the option value; S represents the underlying asset's spot price; L represents the strike price of the underlying asset; r represents the risk-free interest rate; σ is the volatility; N(d1)and N(d2) denotes cumulative probabilities when the variable is less than N(d1)and N(d2) , respectively; T and t are the start and end times of the option.

3.1.2.2 Binomial Tree Option Pricing Method

The use of the binomial tree pricing model to calculate option value was introduced by Cox, Ross, and Rubinstein [5]. Its advantage lies in its simplicity and intuitiveness, requiring minimal theoretical mathematical formulas. The assumptions of this model are as follows: (1) There are no transaction costs in market investment, (2) Investors accept prices uniformly, (3) Short-selling proceeds are allowed, (4) Borrowing or lending proceeds are at a risk-free interest rate, (5) Generally, stock price volatility has only two directions: upward and downward movements, and it is assumed that the probability and magnitude of price movement remain constant throughout the entire period. This paper introduces the single-period binomial tree option pricing formula. Similar methods can be used to derive option pricing formulas for two-period or multi-period binomial tree models. The single-period binomial tree option pricing formula is:

$$\frac{\frac{R-d}{u-d}C_u + (1 - \frac{R-d}{u-d})C_d}{R} = \frac{\frac{RS-Sd}{Su-Sd}C_u + (1 - \frac{SR-Sd}{Su-Sd})C_d}{R}$$

$$C_u = max[S(1+u) - X, 0]$$

$$C_d = max[S(1+d) - X, 0]$$

$$\mathrm{R} = (1+\mathrm{r})^{\mathrm{h}}$$

In this formula, C represents the market value of the option, S represents the current value of the underlying asset and represents the rates of upward and downward movements at expiration, and represents the option value at maturity, while r denotes the risk-free interest rate, and t is the number of compounding years (in the single-period case, h=1).

In the formula, C represents the market value of the option, S represents the current value of the underlying asset, C_u and C_d represent the ratios of value increase or decrease at expiration, and T represents the option value at expiration. r is the risk-free interest rate, and h is the number of years compounded (in the case of a single period, h = 1).

3.2 Method

The value of forestry carbon sequestration projects encompasses two aspects: first, the asset value of the project itself, also known as the static net present value, calculated through traditional income-based methods; second, the value of the investor's option on the asset, referred to as the value of the real option, quantified using the real options method.

Based on the research assumptions and analytical framework outlined above, the model constructed for assessing the carbon sequestration value per unit area of forestry carbon sequestration projects is as follows:

$$E_{NPV} = N_{PV} + O_P \quad (1)$$

$$N_{PV} = \sum_{t=0}^{T} \frac{P_t \times Q_t - C_t}{(1+r)^t}, \ t=1、2、3、...、n \quad (2)$$

$$O_P = S \times N(d_1) - L_e^{-r(T_n - t)} \times N(d_2) \quad (3)$$

In the formula,

$$d_1 = \frac{\ln\frac{S}{L} + (r + 0.5 \cdot \sigma^2)(T-t)}{\sigma \cdot \sqrt{T}} \quad (4)$$

$$d_2 = \frac{\ln\frac{S}{L} + (r - 0.5 \cdot \sigma^2)(T-t)}{\sigma \cdot \sqrt{T}} = d_1 - \sigma\sqrt{T-t} \quad (5)$$

In the formulas provided: E_{NPV} represents the total value of carbon sequestration per unit area, E_{PV} denotes the intrinsic asset value of carbon sequestration, and O_p signifies the call option value of carbon sequestration (in yuan/hm²); T denotes the project's operational period, set at 20 a in this instance; O_t represents the carbon sequestration per unit area in year t (t/hm²); S stands for the current value of the underlying asset (in yuan/hm²); P represents the price of carbon sequestration (in yuan/t), determined based on the average of the past five years' trading data (shown as table2-1), set at 26 yuan/t; C_t represents the transaction cost of carbon sequestration per unit area; and d_1 and d_2 denote the cumulative normal distribution variables. L denotes the strike price of the underlying asset (in yuan/hm²); $N(d_1)$ represents the cumulative normal distribution function value of d_1, and $N(d_2)$ represents the cumulative normal distribution function value of Nd_2; T - t signifies the time to expiration of the carbon sequestration option, set at 20 a; r denotes the risk-free interest rate, set at 2.25% using the five-year deposit rate of commercial banks; and σ symbolizes the volatility of the underlying asset, i.e., the volatility of carbon sequestration transaction prices, assumed to be 20% in this study.

Table 2-1 Summary of Carbon Sequestration Trading in China from 2017 to 2021

Years	Project Location	Transaction Volume (10,000 tons)	Transaction Price (RMB/ton)
2017	Beijing	238.35	49.76
2017	Hubei	1487.01	14.04
2018	Guangdong	987.5	22.15
2018	Tianjin	0.07	12.86
2019	Shanghai	270.46	41.86
2020	Fujian	43.56	17.53
2021	Chongqing	1.43	25.02

4. Data Source and Descriptive Statistics

Take Lianhua County, Jiangxi Province as an example, this county has implemented the CCER project for afforestation for carbon sequestration. Meanwhile, Chinese fir, with its strong adaptability in China, fast growth, good material quality, and strong carbon sequestration capacity, is one of the most important carbon sequestration tree species in southern China. Therefore, against the background of carbon neutrality and peak carbon emissions, analyzing and studying the value of Chinese fir carbon sequestration forestry projects has a certain representativeness and feasibility, which is of great significance to promoting the healthy development of forestry carbon sequestration projects.

4.1 Data Sources

The Gao Tianyan Ecological Forest Farm in Lianhua County, Pingxiang City, Jiangxi Province is located at 113°45'54" -114°9'7" east longitude and 26°27'48"-27°27'56" north latitude. Its scope covers six townships and towns including Fanglou, Liushi, Qinting, Hetang, Gaozhou, and Shenquan, with a total management scale of approximately 184,700 mu, of which the national public welfare forest area is 15,000 mu and the provincial public welfare forest area is 9.69 mu. The proposed afforestation activities for the project began on March 6, 2005, and the accounting period is from March 6, 2005, to March 5, 2025 (including the first and last days), totaling 20 years. The project has been registered on the China Voluntary Emission Reduction Trading Information Platform, and the verified emission reduction volume meets the technical conditions for tradable forestry carbon sequestration, such as additionality.

4.2 Variable Selection

In this study, we adopt the approach proposed by Xianlei Cao et al., considering that the current value of the underlying asset is the expected carbon sequestration income per unit area of Chinese fir afforestation projects, which is equivalent to the present value of the product of carbon sequestration price (P) and the unit area carbon sequestration volume.

Regarding the carbon sequestration volume per unit area, this study mainly follows the accounting methods for forest carbon sequestration volume outlined in the "Methodology for Afforestation and Reforestation Projects (AR-CM-001-V01)." Specifically, the measurement method for total biomass per hectare of Chinese fir is as follows:

$$B_{TREE\_PROJ,t} = V_{TREE\_PROJ,t} \times D_{TREE\_PROJ,t} \times BEF_{TREE\_PROJ,t} \times (1 + R_{TREE\_PROJ,t}) \times N_{TREE\_PROJ,t} \times A_{PROJ} = 0.1877 \times (1 - \mathrm{e}^{-0.1254t})^{5.0485} \times 0.307 \times 1.364 \times (1 + 0.246) \times N_{TREE\_PROJ,t} \times A_{PROJ}$$

$V_{TREE\_PROJ,t} = 0.1877 \times (1 - e^{-0.1254t})^{5.0485}$ (7)

(6)

In Equation (6), $BEF_{TREE\_PROJ,t}$ represents the Chinese fir's biomass per unit area in year t (t/hm²), and $V_{TREE\_PROJ,t}$ represents the Chinese fir's volume in year t (calculated using Equation (7)). According to the "Second National Communication on Climate Change of the People's Republic of China," for land-use change and forestry greenhouse gas inventories, the values for Chinese fir are as follows: $D_{TREE\_PROJ,t}$ = 0.307, $BEF_{TREE\_PROJ,t}$ = 1.634, and $R_{TREE\_PROJ,t}$ = 0.246. Since this study aims to determine the carbon sequestration value per unit area, the carbon area A_{PROJ} is set to 1, and t represents the age of the Chinese fir. $N_{TREE\_PROJ,t}$ is the number of Chinese fir trees per mu (1 mu ≈ 0.067 hectares), which is determined based on the project design document for forestry greenhouse gas emission reduction projects (Afforestation Project at Gaotianyan Ecological Forest Farm in Lianhua County, Pingxiang City, Jiangxi Province), with a value of 2505 trees. Additionally, by multiplying the biomass in year t by the carbon content factor (CF_B) of Chinese fir and then by the ratio of CO2 to C molecular weights (44/12), we can calculate the total carbon stock per unit area of Chinese fir in year t. Assuming linear changes in Chinese fir biomass over a period (from year t_1 to t_2), we can use the consecutive-year-change method to obtain the carbon sequestration volume per unit area. The specific calculation equation is as follows:

$$\Delta C_{TREE\_PROJ,t} = \frac{(44/12)\times[(B_{TREE\_PROJ,t_2}\times CF_B)-(B_{TREE\_PROJ,t_1}\times CF_B)]}{t_2-t_1} \quad (8)$$

$C_{TREE\_PROJ,t}$ represents the annual change in total carbon stock per unit area of Chinese fir in year t, namely the carbon sequestration volume (t). According to the "Second National Communication on Climate Change of the People's Republic of China," Chinese fir is assigned a value of 0.520. t1 and t2 denote the t1 and t2 years after the project begins, with t1 ≤ t ≤ t2. Specific parameter values are detailed in Table 3-1.

Table 3-1 Table of model parameters

Parameter	Value
Basic wood density of Chinese fir $D_{TREE\_PROJ,t}$	0.307
Biomass expansion factor of Chinese fir $BEF_{TREE\_PROJ,t}$	1.634
Ratio of belowground biomass to aboveground biomass of Chinese fir $R_{TREE\_PROJ,t}$	0.246
Number of Chinese fir trees per hectare $N_{TREE\_PROJ,t}$ (trees/hectare)	2505
Carbon content rate of Chinese fir biomass CF_B	0.520
Carbon surface area A_{PROJ}（hm^2)	1

Utilizing the real options investment in Chinese fir afforestation projects for carbon sequestration, the actual operational value of carbon sequestration valuation primarily encompasses the total of all carbon trading costs, including those incurred in the development of the Project Design Document (PDD), project construction review, and all carbon trading costs accrued during emission reduction verification processes. The carbon trading cost per unit of built area is derived by dividing the project-level investment by the built area of the project. In this context, the PDD and project verification tools were developed at the inception of the project in 2005, with specific values set at twenty thousand dollars per item and fifteen thousand dollars per item, respectively. The costs for emission reduction detection and accounting will occur in three detection stages in 2017, 2020, and 2025, with each project incurring a cost of fifteen thousand dollars per item.

4.3 Descriptive Statistics

Utilizing the carbon sequestration price estimation model based on real options and the main parameters calculated, we can analyze the values of the main parameters (see Table 3-2) and the dynamic evaluation results of carbon sequestration physical quantities and economic value for Chinese fir afforestation projects under current conditions (see Table 3-3).

Table 3-2: Carbon Sequestration Value Results of Chinese Fir Management Carbon Sequestration Project in Lianhua County, 1-20a

Age (Years)	Biomass (t/hm^2)	Carbon Reserves (t/hm^2)	Carbon Sequestration (t)	Carbon Price (Yuan)	Carbon Sequestration Value (Yuan /hm²)
1	0.01	0.01	0.01	0.3	-256.6
2	0.15	0.28	0.27	7.0	6.8
3	0.84	1.60	1.33	34.5	32.6
4	2.68	5.11	3.51	91.2	84.1
5	6.21	11.84	6.73	174.9	157.0
6	11.78	22.46	10.62	276.0	241.1
7	19.50	37.18	14.72	382.8	325.5
8	29.28	55.83	18.65	484.9	401.3
9	40.86	77.91	22.08	574.2	462.5
10	53.89	102.76	24.84	646.0	420.2
11	67.98	129.61	26.85	698.2	532.8
12	82.72	157.72	28.11	730.9	542.9
13	97.76	186.40	28.68	745.6	539.0
14	112.78	215.03	28.63	744.5	523.9
15	127.51	243.13	28.09	730.4	424.9
16	141.76	270.28	27.16	706.1	470.7
17	155.36	296.21	25.93	674.1	437.4
18	168.20	320.71	24.49	636.9	402.2
19	180.23	343.64	22.93	596.2	366.5
20	191.40	364.94	21.30	553.9	265.6

Table 3-3: Dynamic Results of Carbon Sequestration Value per Unit Area for Chinese Fir Afforestation Project in Lianhua County

Project	Unit	Annual Amount	Cumulative Amount
Carbon Sequestration from Chinese Fir Afforestation （1~10a）	（t/hm²）	10.28	102.76
Carbon Sequestration from Chinese Fir Afforestation （11~20a）	（t/hm²）	26.22	262.2
Carbon Sequestration from Chinese Fir Afforestation (Project Cycle)	（t/hm²）	18.25	346.94

Execution Price of Underlying Asset (Carbon Cost)	（yuan /hm²）	24.22	484.31
Current Value of Underlying Asset （1~10a）	（yuan /hm²）	187.45	1874.52
Current Value of Underlying Asset （11~20a）	（yuan /hm²）	450.6	4506
Current Value of Underlying Asset （1~20a）	（yuan /hm²）	319.03	6380.53
Call Option Value (Project Cycle)	（yuan /hm²）	305.02	6100.4
Carbon Sequestration Value (Project Cycle)	（yuan /hm²）	599.83	11996.56

5. Results

(1) Under current technological conditions, Chinese fir afforestation projects for carbon sequestration exhibit remarkable carbon fixation and emission reduction effects, characterized by a specific "long tail" dynamic distribution. Based on annual average carbon sequestration and per unit area statistics, the carbon sequestration volume of Chinese fir afforestation projects is sequentially 18.25 t/hm² and 346.94 t/hm². This indicates a significant improvement in carbon fixation, energy conservation, and emission reduction effects of Chinese fir afforestation. During the dynamic change of carbon sequestration, the carbon sequestration volume in the latter 10 a per unit area (26.22t·a-1hm-2, 262.2 t·hm-2) far exceeds that in the former 10 a (10.28t·a-1hm-2, 102.76 t·hm-2). This is closely related to the growth characteristics of Chinese fir in the increment phase of biomass, which determines the skewed distribution of carbon sequestration income prices, namely, the current price of underlying assets. This also reflects the characteristics of a long financing cycle and slow investment recovery speed in carbon sequestration afforestation projects.

(2) Against the backdrop of developing a low-carbon economy, Chinese fir afforestation projects for carbon sequestration have considerable carbon sequestration value. Moreover, their main content includes the selection value of carbon sequestration based on this project. Specifically, the annual average and 20a carbon sequestration values of Chinese fir afforestation projects in China are 599.83 yuan/hm² and 1196.56 yuan/hm², respectively. Among them, the value of call options for carbon sequestration is 305.02 yuan/hm² and 6100.4 yuan/hm², respectively, accounting for 50.88% and 50.85% each. This indicates that the main body of the value of carbon sequestration, based on the project, is the option value. In fact, the value of carbon sequestration options mainly comes from flexible management rather than carbon assets themselves. This suggests that project owners must be keen to capture and flexibly respond to fluctuations in carbon market prices to increase the value of carbon sequestration, enhance carbon revenue, and make scientific decisions in response to changing market conditions.

(3) Forestry carbon sequestration is not only an ecological benefit but also a new investment product, providing a new avenue for China's forestry development. The forest system plays a crucial role in addressing global climate change, and forestry carbon sequestration, as a new type of forest management, has attracted increasing attention worldwide. This also presents a new opportunity for China to develop forestry carbon sequestration projects.

6. Conclusion, Discussion, and Policy Implications

This study takes the Chinese fir afforestation CCER project as an example and establishes a forest afforestation project carbon sequestration benefit evaluation model using the real options value theory, measuring the carbon sequestration benefits of afforestation through modeling and key reference data.

6.1 Conclusion

From the perspective of project owners' investment, the study finds:

(1) Under current technological conditions, Chinese fir afforestation projects for carbon sequestration exhibit remarkable carbon fixation and emission reduction effects, demonstrating a significant "long-tail" distribution characteristic. Specifically, the annual average and cumulative carbon sequestration per unit area are 18.25 t/hm^2 and 346.94 t/hm^2, respectively. However, in terms of dynamic distribution, most of the carbon sequestration of Chinese fir afforestation projects is concentrated in the latter 10a of the project, showing a distinct "long-tail" distribution feature.

(2)Against the backdrop of developing a low-carbon economy, Chinese fir afforestation projects for carbon sequestration have relatively substantial carbon sequestration value. However, the value of carbon sequestration options based on the project constitutes an important part. Specifically, the annual average carbon sequestration value of Chinese fir afforestation projects is 599.83 $yuan/hm^2$, and the cumulative value over 20 years is 11996.56 $yuan/hm^2$. Among them, the annual average value of call options for carbon sequestration is 305.02 $yuan/hm^2$, and the cumulative value over 20 years is 6100.4 $yuan/hm^2$, accounting for 50.85% of the total carbon value. This indicates that the value of carbon sequestration in the project mainly consists of option value, which constitutes the main part of the carbon value based on the project.

6.2 Discussion

This paper takes forest carbon sequestration option value as the project carrier and constructs a carbon sequestration value assessment model for afforestation projects from the perspective of project owners. It quantitatively evaluates the value of forestry carbon sequestration using this model. The research results to some extent reflect the interests of carbon sequestration resource owners in China, which has significant practical and policy implications. However, this study only investigates a single species of Chinese fir and focuses on afforestation carbon sequestration schemes. In addition, China's forestry carbon sequestration plans also involve forestry management carbon sequestration projects. Therefore, in different regions, there are certain geographical limitations on the choice and arrangement of management methods. Further exploration of the value of forestry carbon sequestration in China is needed to provide valuable insights for relevant departments in formulating carbon markets and promoting the development of forestry carbon sequestration projects.

6.3 Policy Implications

In light of the above research findings, there is still a need to actively promote the healthy development of forestry carbon sequestration projects through three main avenues: improving forestry carbon sequestration legislation, encouraging the development of forestry carbon sequestration technical consulting services, and exploring pathways for carbon finance. Based on the conclusions and discussions of this paper, the following policy implications are suggested:

(1)Introducing options in the carbon trading market can not only stimulate investors' enthusiasm but also effectively control CO2 concentration in the atmosphere. When evaluating forestry carbon sequestration projects using the physical option model, investors can implement staged investments based on the market value of forestry investment projects chosen at decision points to mitigate risks.

(2)Addressing the uncertainties, irreversibility, and management flexibility issues in China's forestry investment, this paper proposes a new approach to inspire investors to flexibly choose investment strategies amid changes in market interest rates. In the stock market, investors can opt for expansion, contraction, abandonment, or combination options. When the market outlook is favorable, expansion options can be selected to increase investment scale and profits. Conversely, if project income cannot cover investment costs or profits are too low to meet investors' minimum return requirements, contraction options can be implemented to reduce investment or even abandon it for sale.

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