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Black–Scholes Infrastructure Model Based Plantation Carbon Sink Option Value Assessment and Sensitivity Analysis

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Abstract: As China holds talks with the United States of America (USA) on climate change, the issue of ecology and the environment has come to the fore again. Faced with the emergence of problems such as the destruction of the ecological environment and the obstruction of sustainable ecological development, carbon sinks and carbon sink trading markets have emerged as a necessity. The vigorous development of carbon sink trading markets can improve the control of environmental pollution to a certain extent and relieve the pressure of emission reduction of carbon emission enterprises. Therefore, the reliable measurement and economic evaluation of carbon sinks are of great significance to promote the development of carbon sink market trading. However, there is no reliable and unified method to evaluate carbon sinks. Considering that carbon sink value is affected by many factors and carbon sink trading has particular option characteristics, carbon sink trading can be regarded as a special form of option trading. Based on the option pricing theory, this paper applies the Black–Scholes (B-S) model to the calculation of the carbon sink value of forests and proposes a set of measurement methods for calculating the economic value of carbon sinks. By proposing the basic assumptions of the option pricing theory, the value of the carbon sink option of the plantation forest in Guangdong Province in 2013–2032 was calculated by using Excel and MATLAB R2020b software, and the relevant sensitive factors were analysed. Results showed that: (1) For 2013–2032, the option value was positive, 4 714.755 48 million yuan. It showed that it is feasible to introduce option pricing into carbon sink trading of plantations when market conditions and other factors are satisfied. (2) Sensitivity analysis showed that carbon sink price, risk-free rate and option price had a positive impact, while carbon sequestration cost, discount rate and option price had a negative impact, and the sensitivity coefficient of carbon sink price was the highest. It was concluded that the B-S option pricing model could not only improve the accuracy of evaluation, but also improve decision flexibility compared with traditional value measurement. It was more comprehensive, scientific, and reasonable, and simultaneously provided a novel method of investment decision for carbon sink traders and investors.

Keywords: Plantation carbon sink; B-S option pricing model; Carbon sink value
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1. INTRODUCTION

For the natural environment in which we live, the sustainable use of resources is a topic that requires constant study. This seems to follow the "law of conservation of energy", but in fact, it encourages people to actively seek alternative energy objects and methods based on the premises of energy conservation and emission reduction. The improvement of the environment is closely linked to the development of the economy [16], therefore, currently, the functional form of the carbon sink economy is not only limited to protecting the ecology, purifying the environment, and curbing climate change, but also plays a major role in disaster prevention and mitigation and protection of biodiversity. Playing an important role in sustainable development, forestry carbon sinks consider the dual functions of climate change mitigation and adaptation [8], and have received extensive attention.

China is entering a stage of high-quality development as a responsible major country, and the green economy is a very important part of high-quality development. Protecting the existing green vegetation and increasing afforestation efforts can not only improve the ecological environment, but also achieve the purpose of reducing greenhouse gas emissions and alleviating global warming. First, reduce CO2 emissions at the source and second, increase carbon sinks by reducing energy consumption, improving energy efficiency and seeking energy alternatives. The main methods are reducing energy consumption, improving energy efficiency and seeking energy alternatives. Increasing afforestation area can effectively increase the absorption of carbon dioxide, thereby neutralizing greenhouse gas emissions. Finally, in addition to accumulating carbon sinks, it is also necessary to improve the stability, adaptability and overall service functions of forest ecosystems, promote biodiversity and ecological protection, and promote community development and other forest benefits [9]. At present, the development of forestry carbon sinks is internationally recognised as economically feasible and an effective measure to cope with climate change. Forestry carbon sinks have not only ecological but also economic value [6][13][27], and comprehensive and accurate value assessment can make them more attractive for investment [10]. The launch of the forestry carbon sink trading market not only provides an effective market channel for the realisation of "turning green waters and lush mountains into golden and silver mountains", but also sets milestones for establishing a new ecological financing mechanism and promoting the marketing of ecological services.

2. LITERATURE REVIEW

The effective measurement of the value of carbon sinks has positive significance in mobilising the enthusiasm of the supply and demand side of carbon sink trading, and reasonable measurement has a positive effect on the trading and construction of carbon sink markets, while the traditional net present value method ignores the characteristics of forestry carbon sink projects themselves, resulting in underestimation of the value and decision-making bias[3].Therefore, it is necessary to study and discuss carbon sink options, as a financial derivative product, which can be used to avoid price risks while achieving emission reduction targets[28]. Some scholars believe that when the carbon trading market is constructed and improved upon in the future, options and futures trading should be promoted in a timely manner, legislation and protection of carbon sink revenue rights should be introduced as soon as possible, and multiple measures should be taken to reduce the transaction costs of forestry carbon sinks [1]. Due to the long cycle of forest carbon sink projects and the time lag of project returns, they show certain option characteristics, and some traditional value measurement methods cannot fully consider other factors that have a more obvious impact on the value of carbon sink projects besides the time value of costs and benefits, so it is feasible to use common option pricing methods to calculate the value of carbon sink projects [5]. Some scholars believe that taking the Black–Scholes or Black–Scholes–Merton (B-S) option pricing model as a research method, measuring risk change by the probability of actual value change and risk-free rate of return, not only considers the time value of funds, but also enhances the flexibility of decision-making, so that evaluation results are closer to the actual value [23]. Some scholars believe that the B-S option pricing model can accurately calculate the operating costs and benefits during the project cycle by considering the uncertain factors of carbon sink prices in carbon sink trading, to assist in making optimal decisions [30][17].

According to current literature research results, the use of the B-S option pricing model is a form of compensation for the accounting of carbon sink value compared with traditional value assessment methods, which can consider the changes of more uncertain factors, such as ecosystem value. Taking uncertainties into consideration will make the calculations more accurate and promote sound operation of the carbon trading market. Therefore, this study analyses the sensitivity of carbon sequestration cost and discount rate to the carbon sink value of plantations using this model.

3. RESEARCH BACKGROUND AND METHODS

3.1 Research Background

With General Secretary Xi Jinping's proposal of China attaining carbon peak by 2030 and carbon neutrality by 2060, Guangdong Province, an important province for the development of the carbon sink economy, attaches great importance to ecological development construction with forestry as the main focus, and in recent years has actively developed the reform and construction of ecological public welfare forests and state-owned forest farms, vigorously invested manpower and funds, and continues to improve compensation standards for ecological public welfare forests. For the carbon sink economy to develop well and rapidly, it is inseparable from the coordinated development of the carbon sink economy in multiple fields, for example, development of new energy technology, establishment of the options trading market and other new energy field development and innovation. With the existing technology industry for support, we need to vigorously promote new neighbourhoods, research and develop new technologies, explore more paths, propose more novel and diversified solutions to choose from, accelerate the process of ecological civilization construction, implement energy conservation and emission reduction plans, and achieve a win-win situation for the economy and ecology.

With the support of government, various policies on carbon sink afforestation have been introduced, which has led to a positive development of forest resources and related aspects such as land use and greenhouse gas sequestration in forestry [18]. In addition, relevant carbon emission allowance management and trading measures have been established, including more than 20 relevant management measures such as trading systems and information disclosure and constraint mechanisms. Since carbon sink trading can be traded at a specific time in the future after signing the contract, Guangzhou Carbon regards carbon sink trading as a forward transaction, with Guangzhou Carbon as the trading medium, buyer and seller sign the contract and submit it to Guangzhou Carbon for filing, and Guangzhou Carbon will issue a clearing and delivery reminder to the buyer and seller three trading days before the delivery date for final performance, as shown in Figure 1. The B-S option pricing model was proposed by American scholars Black and Scholes [4], and after continuous exploration, the research boundary was moderately relaxed, to facilitate its use in evaluating natural resources. Combining the characteristics of options with the inherent characteristics of carbon trading, it focuses more on the right of the counterparty to decide whether to buy or sell, which this study believes can be regarded as an option transaction.

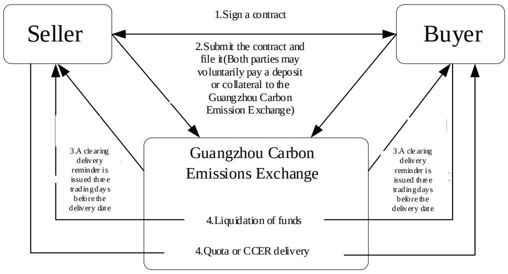

Figure 1: Trading flowchart of Guangzhou Carbon Emissions Exchange (Image source: Guangzhou Carbon Emissions Exchange).

Considering carbon trading as a trading option requires the following characteristics: (1) Volatility of the transaction price. Due to dynamic changes in supply and demand in the process of carbon sink trading in plantations, coupled with the continuous adjustment of national policies and requirements in environmental protection, and the long cycle of carbon sink projects in plantations, there will be certain fluctuations in transaction prices. (2) Flexibility in trading decisions. In the process of trading options, trading is only required on the expiration date, and it is agreed that the purchaser of the option can decide whether to exercise the option on the expiration date or abandon the exercise. Therefore, the purchaser of the trading option has the discretion to decide whether to exercise the option or not. (3) Uncertainty of risks and benefits. The purchaser of an option transaction is required to pay an option fee, which is a sunk cost and cannot be recovered regardless of whether the buyer will exercise the option in the future. In the future, if the market price of the option meets the expectations of the enterprise compared with the strike price, a large profit can be obtained, and the enterprise can choose to exercise the option. If the market price of the option is not aligned with the company's expectation compared with the strike price, exercise of the option on schedule may cause losses to the enterprise, and the enterprise can choose to lose the option premium to minimise the loss and abandon the exercise.

3.2 Research Methods

As a mathematical model for pricing financial derivatives such as options or warrants, the Black–Scholes (B-S) model does not apply variables that reflect investors' risk appetite when used to measure the value of carbon sink options, but only needs to use observable variables to calculate the value. Excluding factors such as investor sentiment, the research boundary can now be reasonably relaxed, so it can also be used to measure the economic value of carbon sinks. The main assumptions of the B-S model are as follows. First, the party buying the option stipulates that the right is only available at expiration, that is, the option is a European-style option; Second, during the validity period of the option, the underlying asset does not generate dividends or other income; Third, there are no taxes and trading costs, that is, the market for options trading is frictionless; Fourth, carbon sink demanders have different trading conditions for different trading purposes, and the number of transactions is highly divisible, so carbon sink trading is assumed to be continuous; Fifth, during the validity period of the option, the risk-free interest rate is the average coupon rate of 5-year and 10-year treasury bonds at maturity. The model form under these basic assumptions is:

$$C = S[N(d_1)] - Xe^{-r\ (T-t)}[N(d_2)] \tag{1}$$

$$d_1 = \frac{\ln(S/X) + (r + \sigma^2/2)(T - t)}{\sigma\sqrt{T - t}} \tag{2}$$

$$d_2 = d_1 - \sigma\sqrt{T - t} \tag{3}$$

where ln(S/X) is the natural logarithm; N(d) is the cumulative probability function. The independent variable takes d and follows the standard normal distribution; d1 is the sensitivity of the option to price; d2 is the likelihood that the option will be exercised; X is the option strike price; r is the risk-free rate; T-t is the period of validity of the option from the expiration date, measured in years; σ is the standard deviation of return of the underlying asset, that is, the volatility of the transaction price; S is the current price of the underlying asset; C is the value of the underlying option.

$$\sigma_j = \sqrt{\frac{\sum_{\mathrm{i=1}}^{\mathrm{n}} \left(R_{\mathrm{t}} - \overline{R}\right)^2}{\mathrm{n}}} \tag{4}$$

$$R_{\mathrm{t}} = \ln\left(\frac{S_{\mathrm{t}}}{S_{\mathrm{t-1}}}\right) \tag{5}$$

where σj is the jth trading price benchmark rate, Rt is the t-year return of the underlying asset of the option, and $\overline{R}$ is the average return of the underlying asset during the validity period of the option; St is the price of the underlying asset in the tth year.

4. DATA DESCRIPTION AND FEATURE DETERMINATION

4.1 Data Description

The data of the China Forest Resources Report is published every five years, and the last data published was in 2018, so the relevant raw data on numerical calculations such as forest stock is from 2018. Forests can be divided into natural forests and plantations according to their origin, and the area of plantations in various provinces in China is shown in Table 1. Plantation area in Guangdong Province is second only to Guangxi Province. According to relevant information disclosed by the carbon emissions trading network, in 2021, Guangdong Province issued a total of 1.92 million t of carbon inclusion, and the cumulative trading volume of carbon allowances reached 199.7 million t, ranking first in the country. The data on carbon sink trading prices in this study are derived from the trading market data disclosed on the official platform of the Guangzhou Carbon Emissions Exchange. The data showed that from 2013 to 2022, the highest price of single-day trading was 97.98 yuan / t, and the maximum single-day transaction amount was 47 519 182.40 yuan. In this way, Guangdong Province was used as a large research object base, which had specific research significance.

Grading	Number of provinces	Coverage area
≥400	6	Guangxi 733.53, Guangdong 615.51, Inner Mongolia 600.01, Yunnan 507.68, Sichuan 502.22, Hunan 501.51
[300,400)	5	Fujian 385.59, Jiangxi 368.70, Guizhou 315.45, Liaoning 315.32, Shaanxi 310.53
[200,300)	6	Hebei 263.54, Shandong 256.11, Henan 245.78, Chekiang 244.65, Heilongjiang 243.26, Anhui 232.91
[100,200)	7	Hubei 197.42, Jilin 175.94, Shanxi 167.63, Jiangsu 150.83, Hunan 140.40, Gansu 126.56, Xinjiang 121.42
<100	7	Chongqing 95.93, Ningxia 43.55, Beijing 43.48, Qinghai 19.10, Tianjin 12.98, Shanghai 8.90, Tibet 7.84

Data source: China Forest Resources Report

Table 1: List of planted forest areas by province (unit: million hm2).

In recent years, Guangdong Province has shown a steady growth in forest cover, stock and other related resources, and ranks in the forefront of the country. According to the latest China Forest Resources Report, in the national forest area, natural forests account for approximately 63.55% of the total area, a total of 138.677 77 million hm2; planted forests account for approximately 36.45% of the total area, a total of 79.5428 million hm2. Among the forest stocks, natural forests accounted for about 80.14%, totalling 1 367 059.63 million m3, and plantation forests accounted for approximately 19.86% of the total, totalling 3 387 599 600 m3. Among them, the area of planted forest in Guangdong Province is about twice that of natural forest, the stock of planted forest is slightly less than that of natural forest, and the proportion is shown in Figure 2. In addition, according to the China Forest Resources Report, the total carbon storage of forest vegetation in Guangdong Province reached 284.8634 million t, of which the aboveground portion accounted for approximately 78.36% and the underground portion accounted for approximately 21.64%. Forestry sink increase is considered to be the most economical and effective way to combat climate change [2]. According to the 14th Five-Year Plan for the Protection and Development of Natural Resources in Guangdong Province, by 2025, the province's forest coverage rate will reach 58.9%, forest stock will reach 620 million m3, and total output value of the forestry industry will exceed 1 trillion yuan. In 2021, approximately 126,700 hm2 of afforestation should be completed, and construction of wasteland artificial afforestation should be accomplished to improve forest quality and carbon sink capacity [15]. However, due to the incomplete price system, opaque information, and scattered themes in China's carbon sink market, the transaction price is lower than the international market level [12].

4.2 Feature Determination

1. The current value of the underlying asset (S): The asset value is the income from the carbon sink of the plantation forest. Carbon sink income from plantations = carbon sink price × carbon sink. According to the forest stock conversion factor method [21][14][26], the carbon sink of plantations is calculated (only the carbon sequestration of tree biomass is considered here), and the calculation formula is as follows:

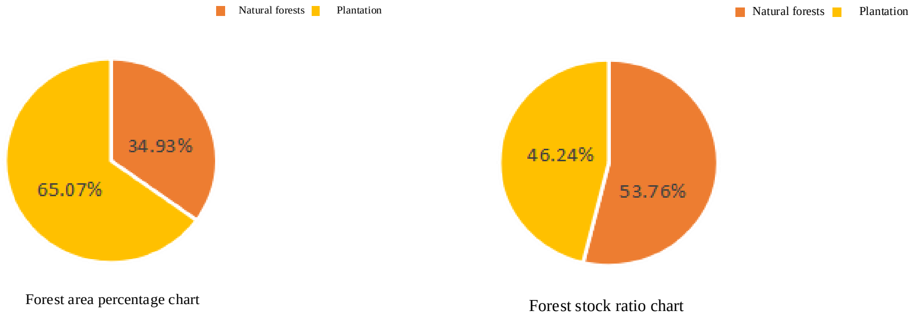

Figure 2: Proportion of forest area and forest stock in Guangdong Province by origin (Data source: China Forest Resources Report).

$$C_r = V_r \times \delta \times \rho \times \gamma \tag{6}$$

In the above formula, Cr represents the carbon sink of the plantation; Vr represents the amount of plantation stock; δ indicates the expansion factor of forest resource stock; ρ is the bulk density; γ is the carbon content rate. Among them, the expansion coefficient, volume density and carbon content of forest resources were selected from the default values of IPCC of the Intergovernmental Panel on Climate Change, namely δ = 1.90, ρ = 0.5, γ = 0.5.

Assuming that the stock of planted forests increases linearly from 2013 to 2032, it is analysed based on the time nodes of the China Forest Resources Report in 2013 and 2018, and specific calculation results are shown in Table 2. The carbon sink price is taken from the average closing price of 76.5 yuan/t disclosed by Guangzhou Carbon since January 2022, which was relatively stable with fluctuations, and was calculated using the alternative market method. Using 2013 as an example, the stock of plantations in Guangdong Province was 154.6769 million m3, and according to formula (6), the carbon sink of plantations in Guangdong Province in 2013 was 15 467.69×1.9×0.5×0.5=73.4715 million t, and the specific trend is shown in Figure 3. The carbon sink income of plantation forests is 7 347.15×76.5=562 056 975 million yuan. Table 2 shows the details.

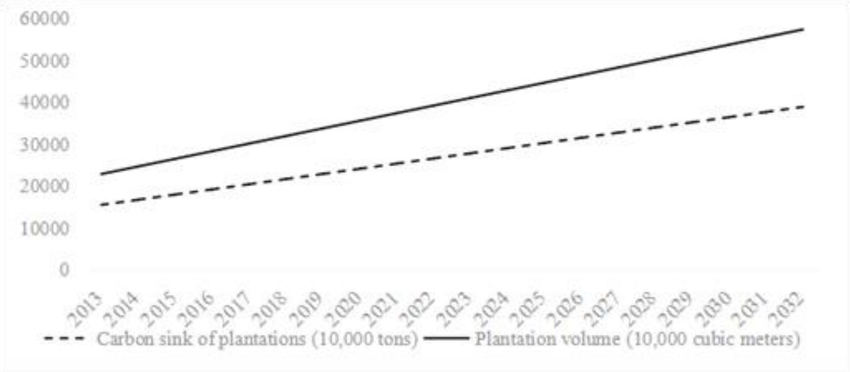

Figure 3: Carbon sink of planted forests in Guangdong Province from 2013 to 2032.

Year	*Plantation volume (10 000 m³)*	*Carbon sink of plantations (10 000 t)*	*Cumulative carbon sink (10 000 t)*	*Carbon sink revenues (million yuan)*	*Cumulative income 10 000 yuan)*
2013	*15 467.69*	*7 347.15*	*7 347.15*	*562 056.975*	*562 056.975*
2014	*16 697.622*	*7 931.368*	*15 278.518*	*606 749.652*	*1 168 806.627*
2015	*17927.554*	*8 515.586*	*23 794.104*	*651 442.329*	*1 820 248.956*
2016	*19 157.486*	*9 099.804*	*32 893.908*	*696 135.006*	*2 516383.962*
2017	*20 387.418*	*9 684.022*	*42 577.93*	*740 827.683*	*3 257 211.645*
2018	*21 617.35*	*10 268.24*	*52 846.17*	*785 520.36*	*4 042 732.005*
2019	*22 847.282*	*10 852.458*	*63 698.628*	*830 213.037*	*4 872 945.042*
2020	*24 077.214*	*11 436.676*	*75 135.304*	*874 905.714*	*5 747 850.756*
2021	*25 307.146*	*12 020.894*	*87 156.198*	*919 598.391*	*6 667 449.147*
2022	*26 537.078*	*12 605.112*	*9 9761.31*	*96 4291.068*	*7 631 740.215*
2023	*27 767.01*	*13 189.33*	*112 950.64*	*1 008 983.745*	*8 640 723.96*

2024	*28 996.942*	*13 773.548*	*126 724.188*	*1 053 676.422*	*9 694 400.382*
2025	*30 226.874*	*143 57.766*	*141 081.954*	*1 098 369.099*	*10 792 769.48*
2026	*31 456.806*	*14 941.984*	*156 023.938*	*1 143 061.776*	*11 935 831.26*
2027	*32 686.738*	*15 526.202*	*171 550.14*	*1 187 754.453*	*13 123 585.71*
2028	*33 916.67*	*16 110.42*	*187 660.56*	*1 232 447.13*	*14 356 032.84*
2029	*35 146.602*	*16 694.638*	*204 355.198*	*1 277 139.807*	*15 633 172.65*
2030	*36 376.534*	*17 278.856*	*221 634.054*	*1 321 832.484*	*16 955 005.13*
2031	*37 606.466*	*17 863.074*	*239 497.128*	*1 366 525.161*	*18 321 530.29*
2032	*38 836.398*	*18 447.292*	*257 944.42*	*1 411 217.838*	*19 732 748.13*

Table 2: Economic income statement of carbon sink of plantation forests in Guangdong Province from 2013 to 2032.

2. Option strike price (X): The option strike price of carbon sink options for plantations is the cost of carbon sequestration, which includes direct and indirect costs. The direct costs are mainly land preparation, seedlings, watering and drought control, tending and management costs, etc. Indirect costs are mainly planning and design, technical training costs, construction inspection fees, etc. Since carbon sequestration capacity fluctuates with forest age, the cost of carbon sequestration decreases with increase in forest age [29] Previous research noted the following; Zhang Zhijun et al.[25] calculated that the highest value of carbon sequestration cost of plantations was 283.4 yuan/t, and the lowest value was 48.9 yuan/t; Hou Yuanzhao et al. [7] calculated the cost of forest carbon sequestration as 273.3 yuan/t; Yu Xinxiao et al. [24] agree with the calculations of Hou Yuanzhao et al; Xiao Han et al. [22] used artificial afforestation costs of 251.4 yuan/t. Some researchers postulate that the cost of forest carbon sequestration should be maintained at a constant price of 260.9 yuan / t. Based on the current carbon sink market price and the above research

combined with the cycle characteristics of the research objects in this study, the fourth year is selected as the inflection point of carbon sequestration cost, and the average maximum value is 267.2 yuan/t as the cost price, and 48.9 yuan/t is taken as the carbon sequestration cost price after the inflection point, as shown in Table 3.

Year	*Carbon sequestration cost (10 000 yuan)*	*Year*	*Carbon sequestration cost 10 000 yuan)*
2013	*1 963 158.48*	*2023*	*644 958.24*
2014	*2 119 261.53*	*2024*	*673 526.50*
2015	*2 275 364.58*	*2025*	*702 094.76*
2016	*444 980.42*	*2026*	*730 663.02*
2017	*473 548.68*	*2027*	*759 231.28*
2018	*502 116.94*	*2028*	*787 799.54*
2019	*530 685.20*	*2029*	*816 367.80*
2020	*559 253.46*	*2030*	*844 936.06*
2021	*587 821.72*	*2031*	*873 504.32*
2022	*616 389.98*	*2032*	*902 072.58*

Table 3: Input cost of carbon sequestration in plantations in Guangdong Province from 2013 to 2032.

3. Option expiry T, trading price volatility σ, variation of underlying value σ2 and risk-free rate r. According to the China Forest Resources Report, there are many planted forests in Guangdong Province, and considering age group structure and effective carbon sink time, this study assumes that 20 years is the validity period of the plantation carbon sink option. According to the asset value in Table 2, the standard deviation of the change in the value of the subject matter can be calculated as σ=0.013. Since the country has not issued 20-year treasury bonds in recent years, this study uses the average coupon rate of 3.305% between the coupon rate of 10-year treasury bonds (code 220003) and 30-year treasury bonds (code 220008) issued by the Ministry of Finance in 2022 as the risk-free interest rate, which creates credibility. Considering the level of market interest rates and changes in market demand, this study uses 2013 as the base period to evaluate the discount value of carbon sink income from plantations according to the carbon sink and annual income, and uses the coupon rate of 10-year treasury bonds (code 220003) of 3.32% as the discount rate r1. The discounted cost-benefit value was calculated and specific values are:

Year	*Discounted value of earnings*	*Cumulative discounted earnings value*	*Discounted value of carbon sequestration costs*	*Accumulated discounted cost value*
2013	*543 996.30*	*543 996.30*	*1 900 075.96*	*1 900 075.96*
2014	*568 382.56*	*1 112 378.85*	*1 985 252.54*	*3 885 328.50*
2015	*590 639.90*	*1 703 018.75*	*2 062 993.22*	*5 948 321.71*
2016	*610 879.97*	*2 313 898.72*	*390 484.06*	*6 338 805.77*
2017	*629 209.42*	*2 943 108.14*	*402 200.53*	*6 741 006.30*
2018	*645 730.14*	*3 588 838.29*	*412 760.84*	*7 153 767.14*
2019	*660 539.46*	*4 249 377.74*	*422 227.18*	*7 575 994.32*
2020	*673 730.29*	*4 923 108.03*	*430 658.97*	*8 006 653.29*
2021	*685 391.36*	*5 608 499.39*	*438 112.91*	*8 444 766.20*
2022	*695 607.36*	*6 304 106.75*	*444 643.14*	*8 889 409.34*
2023	*704 459.12*	*7 008 565.88*	*450 301.32*	*9 339 710.66*
2024	*712 023.77*	*7 720 589.65*	*455 136.76*	*9 794 847.421*
2025	*718 374.88*	*8 438 964.53*	*459 196.49*	*10 254 043.91*
2026	*723 582.64*	*9 162 547.17*	*462 525.37*	*10 716 569.29*
2027	*727 713.96*	*9 890 261.12*	*465 166.18*	*11 181 735.46*
2028	*730 832.64*	*10 621 093.77*	*467 159.69*	*11 648 895.15*
2029	*732 999.51*	*11 354 093.28*	*468 544.78*	*12 117 439.94*
2030	*734 272.50*	*12 088 365.78*	*469 358.50*	*12 586 798.44*
2031	*734 706.83*	*12 823 072.61*	*469 636.13*	*13 056 434.57*

2032	*734 355.09*	*13 557 427.70*	*469 411.29*	*13 525 845.86*

Table 4: Discounted value of carbon sequestration costs and benefits of carbon sequestration in plantations (unit: 10 000 yuan).

5. ANALYSIS OF RESULTS

5.1 Analysis Of Traditional Net Present Value Method Results

The traditional net present value method has a more important position in the traditional capital budgeting method, and its evaluation concept is similar to the calculation of profit, which is roughly expressed as the difference between benefits and costs, which can judge whether it is financially feasible according to the characteristics of the difference, and the method is relatively simple and intuitive. However, when there are many uncertainties in the external decision-making environment, factors such as the value of decision-making flexibility are often ignored [11][19], resulting in decision-making bias, which is specifically manifested in evaluation of the object. Applying this method to the assessment of the trading value of carbon sinks in plantations, according to Tables 2 and 3, the difference between the benefits and costs of each year is taken directly, annual net cash flow is calculated at a discount rate of 3.32%, and the net present value data can be obtained:

$$NPV = \sum_t \frac{S_t - X_t}{(1+3.32\%)^t} = 31581.8363\ 4 \text{ million yuan.}$$

Specific annual NPV data are detailed in Table 5.

5.2 Analysis of B-S Option Pricing Method Results

According to the relevant formulae in Tables 2~4 and above, the values of d1 and d2 in each year can be calculated. The value of carbon sink options in 2013–2032 is positive, which meets the requirement of option pricing theory for exercise value greater than or equal to zero. Taking 2013 as an example, the calculation process of the underlying price, option strike price and other values is as follows：

$$S = \sum_{i=1}^{n} \frac{S_t}{(1+r_1)^t} = 13557427.7\ 0 \text{ million yuan;} \quad X = \sum_{i=1}^{n} \frac{X_t}{(1+r_1)^t} = 13525845.8\ 6 \text{ million yuan;}$$

σ=0.013；r=3.305%.

Using MATLAB R2020b software, the value of the 2013 plantation carbon sink option can be calculated as follows: $C = S[N(d_1)] - Xe^{-r(T-t)}[N(d_2)] = 471475.548$ million yuan. The size of the option value determines the reserve value of the transaction item in the future period, and as the option value is greater than zero, the carbon sink trading of plantations has a certain intrinsic value. Investors can decide whether to exercise the option according to the price of the carbon sink and the size of the investment value, and whether to exercise the option can produce two results: unlimited profit and timely stop loss, or maximum loss at the premium of the call option, specific calculation results are shown in Table 5.

Year	*NPV*	*C*	*Year*	*NPV*	*C*
2013	*-1 356 079.660*	*6 573 563.574*	*2023*	*-1 356 079.660*	*3 838 236.907*
2014	*-1 416 869.980*	*6 338 890.249*	*2024*	*-1 416 869.980*	*3 511 650.539*
2015	*-1 472 353.320*	*6 096 331.380*	*2025*	*-1 472 353.320*	*3 174 090.144*
2016	*220 395.910*	*5 845 621.994*	*2026*	*220 395.910*	*2 825 186.971*
2017	*227 008.888*	*5 586 488.217*	*2027*	*227 008.888*	*2 464 559.878*
2018	*232 969.307*	*5 318 646.970*	*2028*	*232 969.307*	*2 091 814.915*
2019	*238 312.275*	*5 041 805.664*	*2029*	*238 312.275*	*1 706 544.915*
2020	*243 071.320*	*4 755 661.875*	*2030*	*243 071.320*	*1 308 329.140*
2021	*247 278.451*	*4 459 903.021*	*2031*	*247 278.451*	*896 737.749*
2022	*250 964.224*	*4 154 206.013*	*2032*	*250 964.224*	*471 475.548*

Table 5: Calculation results.

6. VALIDITY TESTING AND DISCUSSION

6.1 Sensitivity Analysis

Sensitivity analysis is a commonly used method as an effectiveness test, and it is also a common analysis method used by investors when making investment decisions, considering that other factors remain unchanged, and only a single factor changes when the direction and degree of impact on the economic evaluation of the investment project are detected, and the most sensitive factors are established. In this study, carbon sink price, carbon sequestration cost, risk-free interest rate and discount rate were analysed individually as indicators of sensitive factors, change range of factors was 10%, and the specific calculation results and sensitivity analyses are shown in Table 6 and Figure 4.

Sensitivity factors		Option value		
Sensitivity factor	Magnitude of change（%）	Change percentage（%）	Total value change（million yuan）	Sensitivity factor
Carbon sink prices	+10	287.517	1 355 571.824	28.752
Cost of carbon sequestration	+10	-99.999	-471 475.475	-10.000
Risk-free rate	+10	9.151	43 144.321	0.915
Discount rate	+10	-30.980	-146 063.642	-3.098

Table 6: Sensitivity factor analysis table.

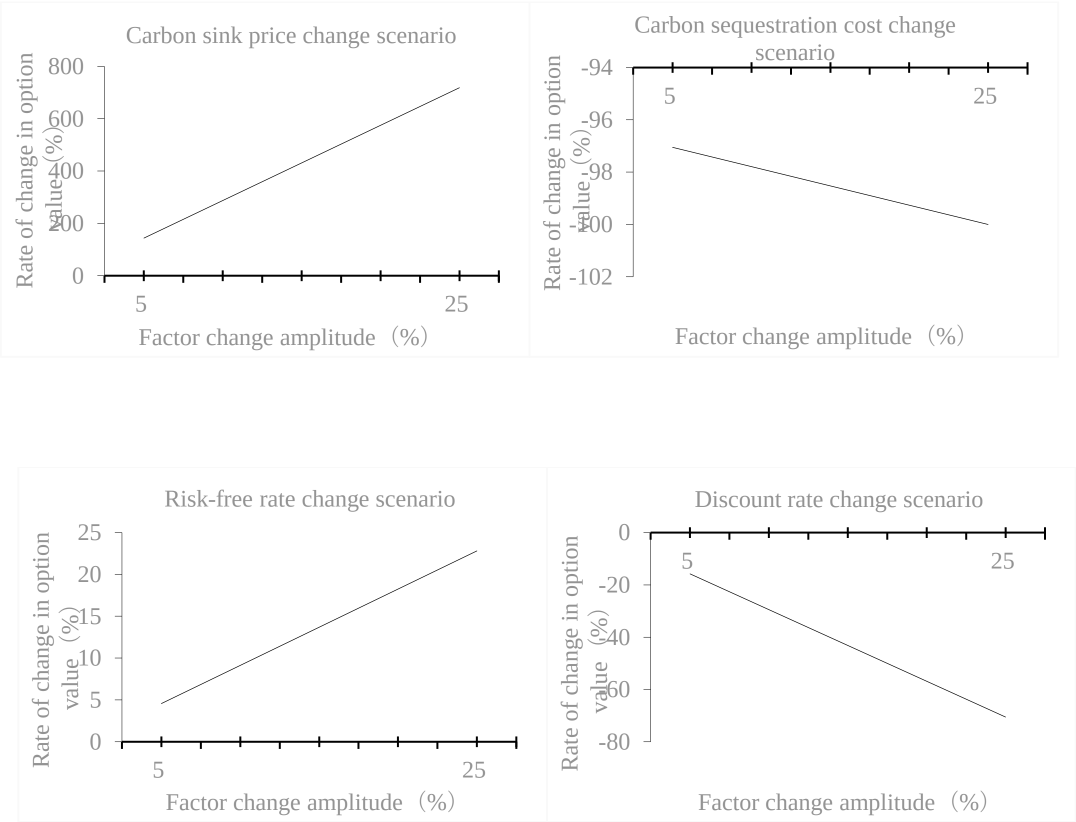

Figure 4: Sensitivity analysis plot.

Results of sensitivity factor analysis showed that carbon sink price and risk-free interest rate had a positive impact on the option value, and carbon sequestration cost and discount rate had a negative impact on the option value. Among them, the sensitivity coefficient of carbon sink price was the highest at 28.752, indicating that carbon sink price was the most sensitive to the value of options (when the price of carbon sinks rises by 10%, the value of carbon sink options will increase by 287.517%), followed by carbon sequestration costs. Specifically, when carbon sink price rises by 5% to 25%, the option value will increase by 143.74% to 718.85%; when the price of carbon sequestration rises by 5% to 25%, the value of the option will decrease by 97.05 to 100.00%; when the risk-free rate rises by 5% to 25%, the value of the option will increase by 4.57 to 22.81%; when the discount rate rises by 5% to 25%, the option value will decrease by 15.79 to 70.54%. It can be seen that to make the value of options rise reasonably and stably, the carbon sink market is actively and positively progressing, interests of option owners are protected, which are related to various indicators in the model to varying degrees, and the most prominent factor is the carbon sink price.

6.2 Discussion

1. In this study, the B-S option pricing model was used to calculate the carbon sink value of plantations in Guangdong Province from the perspective of investors, however, differences and fluctuations of tree species and biodiversity of plantations, fairness standards of carbon sequestration costs, determination of the effective period of carbon sink option trading, differentiation of the age structure of plantations, and the differentiation of regional environment had different degrees of impact on the research results. Therefore, although the research results have reference value for the evaluation of carbon sink value, there are limitations in the research object, and it is still necessary to plan a standard and unified carbon sink value accounting system in future research.
2. The scientific measurement method of carbon sink value is closely related to environmental quality and development of the green economy. An effective assessment of the value of carbon sinks will affect all aspects of economic and energy structure, and even lifestyle. The positive development of the carbon sink economy is conducive in mitigating a series of adverse effects of climate change. As a major country actively responding to climate change, China is formulating a plan and technology roadmap to support carbon peaking and carbon neutrality through science and technology, and accelerating the construction of a "1+N" policy, while the green economy will closely coordinate with economic and social development.

7. RESEARCH CONCLUSIONS AND RECOMMENDATIONS

7.1 Research Conclusions

1. Among the plantation trees in Guangdong Province, 71.79% are middle and young forests, accounting for a large proportion, which shows that the carbon sink of plantations in Guangdong Province has high economic growth strength and development potential. When market conditions permit, the calculation of relevant data from 2013 to 2032 showed that the option value was positive, which met the basic requirement of option pricing theory for option value and showed that the attributes of carbon sink trading in recent years had certain idiosyncrasies. Calculation results showed that the option value was 471 475 548 million yuan. Therefore, this study argues that it is feasible to implement carbon emission option trading when the time value can be afforded. Due to the unique nature of carbon sink trading, appropriate investment opportunities can be selected for option trading according to the current value of carbon sinks and future carbon sink trends, which puts forward new investment decision-making ideas for carbon sink demanders and investors. Given the complex and diverse structure of the carbon sink industry in the future, the implementation of

option trading and development in the current situation can only improve the technical level, reduce the cost of carbon sequestration, energy conservation and emission reduction, and healthy development of the carbon sink economy requires a joint effort between all parties.
2. Studies showed that different results were obtained for the same value assessment object using different methods. Specifically, the B-S option pricing model measured the value better than the traditional net present value method, which can underestimate the investment value of carbon sinks in plantations. Compared with the traditional net present value method, the B-S option pricing model not only considers the time value of money, but also considers the flexibility and uncertainties of investment decisions, making decision-making more flexible. Therefore, this study believes that it is more scientific and reasonable to use the B-S option pricing model to evaluate the carbon sink value of plantations.

7.2 Recommendations

1. Improve the training of carbon option professionals. In the new field of forestry carbon sink and carbon emission rights trading, it is the government's primary aim to strengthen construction of professional talent echelons, deeply understand the spiritual essentials of carbon neutrality and carbon peaking, not only to improve the training of special talents in forestry carbon sinks and carbon emission trading related fields, but also to create a foothold for the word "energy". Improvement of the carbon market requires the active support and coordination of talents in economics, finance, law, forestry, and other fields, not only to make accurate judgments on problems, but also to create solutions in the face of judgments, and solutions must be operable to ensure sound operation of the market. Targeted training of high-end compound talents is the most effective way to fundamentally solve difficulties, and it is also a top priority. China's carbon market cannot blindly learn from and imitate foreign countries, it must clearly understand the difficulties and crux of the current development and combine it with China's national development conditions.
2. Create a professional carbon sink options trading centre. The establishment of such a venue can not only achieve the purpose of publicising the knowledge of carbon sink option trading, its functions can also include the formulation and improvement of the trading system, ensuring open and fair conduct of option trading, and determining the qualifications of both parties to the transaction. Specifically, the venue can publicly disclose information of the two parties to the transaction that have passed the qualification determination, and simultaneously publish the daily carbon sink price and the final transaction price to ensure the openness and transparency of the transaction. This approach can not only attract more investors to participate in it, but also supervise the trading process, so that the development of carbon sink options trading is gradually improved and standardized. Infrastructure development plays a crucial role in establishing and supporting the infrastructure necessary for the effective functioning of a professional carbon sink options trading center.
3. Stabilize and improve the carbon sink market trading system. A sound carbon sink market trading system must not only make technological breakthroughs, but also combine the formulation and improvement of relevant policies. It is necessary to issue laws and regulations and relevant policy guidelines and improve laws and regulations on forestry development and compensation for ecological benefits. Enterprises can complete emission reduction targets and exercise their powers within the agreed period, providing legal protection for carbon sink demanders and suppliers, better encouraging enterprises to save energy and reduce emissions, and promoting the orderly development of the trading market. A sound carbon sink system must not only have a good trading operation mode, but also have corresponding safeguard measures. Since carbon sinks, as a special asset, are "invisible and intangible", it is difficult to establish a trading system for regulatory verification for implementation of carbon sink trading. For example, to strengthen the supervision and verification of carbon sink trading, a third-party or even a fourth-party verification agency could be established. Decentralization instead of centralization, independence instead of nepotism,

scientific and effective measurement of carbon sinks and carbon emissions, and monitoring of specific implementation progress of each unit is recommended.

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REFERENCES

[1] Cao, X.; Jia, X.; Shan, Y.; Wu, W.: Carbon sink value evaluation model and application of carbon sink afforestation project based on real options, Journal of Central South University of Forestry and Technology, 41(03), 2021, 187-196.
[2] Cheng, Y.; Liu, Q.; Pan, J.: Cost-benefit analysis of carbon sequestration projects in different types of bamboo forests, Zhejiang Agricultural Sciences, 62(02), 2021, 421-424+431.
[3] Ding, H.; C. Q.: Value evaluation of forestry carbon sequestration project using real option method, Journal of Northeast Forestry University, 48(05), 2020, 139-143+147.
[4] Fischer, B.; Myron, S.: The Pricing of Options and Corporate Liabilities, Fischer Black, Myron Scholes, 81(3), 1973, 627-654.https://doi.org/10.1086/260062
[5] Guan, J.; Cao, Y.; Zhu, Z.; Zou, Y.: Economic value evaluation and sensitivity analysis of larch carbon sink afforestation project based on B-S option pricing theory, Arid Land Resources and Environment, 34(01), 2020, 63-70.
[6] He, X.; Zhang, S.; Wang, D.; Zeng, S.: Simulation study on investment decision of forestry carbon sink project based on real option pricing method, Operations Research and Management, 28(02), 2019,139-147.
[7] Hou, Y.; et al.: Forest environmental value accounting, Beijing, China Science and Technology Press, 2002.
[8] Li, N.; Su, D.: Development trend and prospect of forestry carbon sink in China, China Environment, (09), 2018, 28-31.
[9] Li, N.: Forestry to cope with climate change and carbon sink trading, Land Greening, (01), 2017, 11-13.
[10] Li, Q.; Zhang, S.: Study on value evaluation model of forestry investment project with carbon sink income, Forestry Economics, 41(11), 2019, 88-96.
[11] Liu, B.: Limitations and solutions of traditional net present value method, Journal of Business Research, (16), 2003, 16-17.
[12] Liu, K.; Jin Sheng.: Comparative study on pricing methods of domestic forest carbon sink market, Agricultural Engineering, 1(02), 2011, 96-100.
[13] Liu, M.; Sun, M.: Research on supply and demand and price mechanism of forestry carbon sequestration projects in China, China Forestry Economics, (01), 2020, 1-4+10.
[14] Sin, W.; Li, F.; Feng, Y.: Discussion on forestry carbon sequestration project in Heilongjiang Province, Modern Agricultural Science and Technology, (02), 2011, 243+246.
[15] State Forestry and Grassland Administration, 2014-2018 China Forest Resources Report, Beijing, China Forestry Publishing House, 2019.
[16] Wang, G.: For our common future--Interview with Vice Chairman Kaleed and Member Ma Shijun of the World Commission on Environment and Development, World Knowledge, (15), 198710-12.
[17] Wang, P.; Lu, C.: Value evaluation of forestry investment project based on real option method, Journal of Northwest Forestry University, (05), 2021, 269-274 [2021-09-29]. http://kns.cnki.net/kcms/detail/61.1202.S.20210928.1642.010.html.
[18] Wang, X.: et al.: Analysis of forestry carbon sink and enhancement potential in Guangdong Province, Forestry and Environmental Science, 35(03), 2019, 7-12.
[19] Wei, J.; Mei, B.; Zhang, S.: Business Research, (06), 2006, 44-47.

[20] Wu, X.: To improve forest quality and carbon sink capacity, Guangdong completed afforestation of 1.9 million mu in 2021[EB/OL], (2021-03-26)(2021-08-27). http://www.tanjiaoyi.com/article-33189-1.html
[21] Xi, T.; Li, S.: Analysis of forest carbon sink potential in Heilongjiang Province, Forestry Economic Issues, (06), 2006, 519-522+526.
[22] Xiao, H.; Ouyang, Z.; Zhao, J.; Wang, X.: A preliminary study on forest ecosystem service function and its eco-economic value assessment: A case study of Jianfengling tropical forest in Hainan Island, Chinese Journal of Applied Ecology, (04), 2000, 481-484.
[23] Yan, Y.; Xiu, C.: Evaluation of grassland carbon sink value based on option pricing theory:A case study of Siziwangqi in Inner Mongolia, Arid Land Resources and Environment, 28(11), 2014, 31-36.
[24] Yu, X.; Lu, S.; Jin, F.; Chen, L.; Rao, L.; Lu, G.: Assessment of functional value of forest ecosystem services in China, Acta Ecological Sinica, (08), 2005, 2096-2102.
[25] Zhang, K.; Wang, S.: Application of real option pricing method in value appraisal of forestry listed companies, Forestry Economic Issues, 37(01), 2017, 87-92+111.
[26] Zhang, Z.: Measurement of forest carbon sink and economic evaluation by forest stock conversion factor method, Shanghai Economics, (01), 2017, 23-31.
[27] Zhang, Z.; Zhang, X.; Zhu, J.; Luo, Y.; Hou, Z.; Chu, J.: Cost accounting of carbon sequestration of major plantation forest types in Guangxi, Forestry Science, 46(03), 2010, 16-22.
[28] Zhibin, L.; Shan, H.: Research on Pricing of Carbon Options Based on GARCH and B-S Model; Research on Pricing of Carbon Options Based on GARCH and B-S Model, Journal of Applied Science and Engineering Innovation, 6(3), 2019, 109-116.
[29] Zhou, W.; Gao, L.; Zheng, B.: Cost-benefit analysis of carbon sequestration in two different types of plantations, Forestry Economics, 41(03), 2019, 93-97+118.
[30] Zhu, W.; Gu, L.; Li, J.; Shi, Y.; Ji, W.: Economic benefit evaluation of CCER bamboo forest operation carbon sink project in Anji County based on B-S option pricing, Journal of Nanjing Forestry University(Natural Science Edition), 42(04), 2018,18-24.