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Analysis of firm dynamic green energy investment strategy - application of real options

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Abstract. This paper mainly adopts the Real Options Approach (ROA) to construct a dynamic green energy investment strategy analysis model for firms that reduce carbon emission during production to meet the government's policy, to provide optimal investment opportunities and to evaluate the value of investment projects. Recently, governments around the world have formulated environmental protection policies to reduce greenhouse gas emissions. Under the implementation of polluter pays, the carbon emissions produced by firms are no longer free riders. When the government implements restrictions on carbon emissions the carbon emission limits will affect corporate investment decisions. This article assumes that there are uncertainties in production volume and carbon emissions, and the change follows the geometric Brownian motion. The carbon emission trading will be conducted according to the market supply and demand status when a firm's carbon emissions exceed or fall below the prescribed emissions. Under this premise, this paper constructs the most appropriate investment strategy model and analyses the investment decision threshold for the firm from a financial point of view to evaluate the corporate value. It serves as a reference for a firm's green energy investment and provides the government with a reference policy for carbon emissions, and with a view to creating a business, government, and social environment tripartite win-win situation.

1. Introduction

Based on the issue of global warming, the international community is actively proposing responses to climate change. Many governments have formulated relevant environmental protection policies and encouraged companies to invest in technologies and equipment for reducing greenhouse gas emissions. This research is mainly based on financial perspectives. Under the government's environmental protection policy, the Real Options Approach (ROA) is used to assess the feasibility of a firm's green energy investment projects, and to provide optimal investment opportunities and evaluate the value of investment projects. Generally, the traditional methods for the feasibility evaluation of investment projects include Payback Period, Average Accounting Return (AAR), Net Present Value Methods (NPV), Profitability Index (PI) and the Internal Rate of Return (IRR). However, in a complex and uncertain investment environment, the manager's investment strategy should adopt a dynamic decision analysis model, in which the Real Options Approach (ROA) is more adaptable to the complex investment environment than the traditional NPV method [1,2]. Liu et al. used the Real Options



Approach (ROA) evaluation model to construct an optimal carbon right trading strategy model to discuss clean energy policy options, and further used the optimal energy ratio clean strategy when there is insufficient energy cleanliness or an energy cleanliness Carbon trading strategy [3]. Cheng, et al. used a binomial model of sequential compound options to analyze historical data to analyze the impact of possible future GDP changes on electricity demand, which in turn influenced the development path of clean energy investment strategies. This model takes into account the uncertainties of future environmental changes and the impact of policy pre-phase, which can be used as a reference for the decision-making of government agencies and capital-intensive investment companies that have a relatively long pre-term period [4]. Tang et al. used the Real Options Approach (ROA) to explore the opportunities and recommendations for optimal investment when China invests in overseas oil and energy under irreversible and flexible management environments with uncertain investments. In a high-risk investment environment, investment strategies should be implemented as soon as possible [5]. Pereira et al. used a dynamic general equilibrium model for carbon taxation issues to explore the impact of carbon taxes on Portugal. The results showed that the carbon tax revenue will give back to other lower taxation companies, and can improve the efficiency of energy use [6]. Torani et al. took the development of clean energy technologies and used the stochastic dynamic model of choice of options to explore changes in solar technology. Under the circumstances of uncertain electrical prices and solar energy costs, they proposed assessing energy, electrical prices, innovation subsidies, carbon tax, as well as the optimal investment threshold and timing of the company's investment as the main key factors [7]. Moriarty and Palczewski used the Real Options Approach (ROA) to evaluate the value of the power system's reserve capacity over a limited period of time [8]. Ansariipoor and Oliveira constructed a model using the Real Options Approach (ROA) with the managerial flexibility to calculate uncertain prices, fuel prices, fuel consumption, and technological advances and analyzed how to choose the resulting value for uncertain fuel prices and technological progress [9]. This paper mainly focuses on enterprises' efforts to do their best to fulfill their social responsibilities, cooperate with government policies to strengthen environmental protection, carry out innovative production technologies, reduce pollution emission investment projects, and use the Real Options Approach (ROA) to evaluate feasible investment strategies and firms value.

2. The model

This study considers the use of dynamic investment decision-making in the application of continuous time to evaluate the model. The derivation of the model is the best investment opportunity for firms to implement green energy investment decisions in line with government environmental policies, invest in innovative technology, save energy consumption, and reduce carbon emissions.

2.1. The assumption

Under risk-neutral considerations, if firms invest in innovative technologies and change their production facilities using green energy, they will not consider the changing cost-benefit function of carbon emissions as Eq.(1):

$$f(Q_s(t), P_s) = Q_s(t) \times P_s \times E(g) - I_g \quad (1)$$

Where $Q_s(t)$ is the production volume; P_s is the net profits per unit product. That is the product price minus the variable cost of revenue, which does not include the cost of carbon emissions. $E(g)$, $E(g) > 1$ is the firms to invest in green energy production and enhance corporate social responsibility and reputation benefits, will increase corporate profits. I_g is the update equipment investment costs.

In the production process, the cost of carbon emissions generated by an enterprise is expressed as Eq.(2):

$$C(Q_c(t), g) = H \times Q_c(t) \times P_c + (H \times Q_c(t) - Q_c(t) \times D(g)) \times P_c \times G(l) \quad (2)$$

Then, $Q_c(t)$ is the carbon emissions in the production process of firms; P_c is the cost per unit of carbon emission required; g is the amount of green energy input; $D(g)$ is the benefits that firms invest in green energy to reduce carbon emissions, $0 < D(g) \leq 1$. Assume that the government sets firms carbon emission limits according to the characteristics of the company, expressed by $H \times Q_c(t)$, then $H > 0$. If carbon emissions exceed $H \times Q_c(t)$, the carbon trading price will be progressively increased $G(l)$, $G(l) \geq 1$. When $H > 1$, the carbon emission of the company's production process is lower than the emission limit, the excess clean carbon rights can be traded, and the surplus can be sold. When $0 < H < 1$, the lack of clean energy, one must purchase carbon rights, carbon trading price is $P_c \times G(l)$.

Assuming that the production $Q_s(t)$ and the CO_2 emissions $Q_c(t)$ are uncertain variables, the variation follows the joint geometric Brownian motion:

$$dQ_s(t) = \alpha_s Q_s(t)dt + \sigma_s Q_s(t)dZ_s(t) \quad (3)$$

$$dQ_c(t) = \alpha_c Q_c(t)dt + \sigma_c Q_c(t)dZ_c(t) \quad (4)$$

Where α_s is the expected grow rate of $Q_s(t)$; α_c is the expected grow rate of $Q_c(t)$; σ_s^2, σ_c^2 are the variances of $Q_s(t)$ and $Q_c(t)$, respectively. $dZ_s(t), dZ_c(t)$ are the increment of standard Wiener process. Here, $E\{dZ_s(t)\} = 0, E\{dZ_s(t)\}^2 = dt$, $E\{dZ_c(t)\} = 0, E\{dZ_c(t)\}^2 = dt$ and $E(dZ_s(t)dZ_c(t)) = \gamma_{s,c}\sigma_s\sigma_c dt$, $\gamma_{s,c}$ is related factors, $-1 \leq \gamma_{s,c} \leq 1$. The expected revenue of the firm's production operation cost of CO_2 emissions is as Eq.(4):

$$E \left[\int_0^\infty Q_s(t) \times P_s \times E(g) \times e^{-rt} dt - H \times Q_c(t) \times P_c \times e^{-rt} dt - (H \times Q_c(t) - Q_c(t) \times D(g)) \times P_c \times G(l) \times e^{-rt} dt \right] - I_g \quad (5)$$

Where r is the discount rate. In the Eq.(5), the first item is the net income of the firm's unconsidered CO_2 emissions, and the expected future cash inflows. The second item is the cost of government-mandated firm CO_2 emissions. The third item is excess or insufficient CO_2 emission of carbon rights trading income. The fourth item denotes the firm investment in innovation to save the fixed costs for energy equipment. Then, the expected net revenue is:

$$\pi(Q_s(t), Q_c(t)) = \frac{Q_s(t) \times P_s \times E(g)}{r - \alpha_s} - \frac{H \times Q_c(t) \times P_c}{r - \alpha_c} - \frac{(H \times Q_c(t) - Q_c(t) \times D(g)) \times P_c \times G(l)}{r - \alpha_c} - I_g \quad (6)$$

2.2. The decision model

Assume that the government has to limit carbon emissions in the production process in order to solve environmental pollution problems. Firms need to pay for their costs in terms of carbon emissions, and their cost of payment has a correlation with output. Under the uncertainty of the economic environment, the output and carbon emissions of firms follow the joint geometric Brownian movement. This paper constructs a decision-making model for firms to update production equipment investment in order to reduce carbon emissions. The model determines the optimal output and carbon emission ratio of the firm. Assume that the firm updates the value of the production equipment is $V(Q_s(t), Q_c(t))$. The firm value is the expected net present value plus the management flexibility value from uncertainties. In this paper, Ito's Lemma (Ito's Lemma, 1951) [10] is used, and the firm value of the management flexibility is shown in Eq.(7):

$$dV(Q_s(t), Q_c(t)) = V_{Q_s}(\cdot)dQ_s + V_{Q_c}(\cdot)dQ_c + \frac{1}{2} [V_{Q_s Q_s}(\cdot)(dQ_s)^2 + 2V_{Q_s Q_c}(\cdot)dQ_s dQ_c + V_{Q_c Q_c}(\cdot)(dQ_c)^2] \quad (7)$$

Among them, $V_{Q_s}(\cdot)$, $V_{Q_c}(\cdot)$, and $V_{Q_s Q_s}(\cdot)$, $V_{Q_s Q_c}(\cdot)$, $V_{Q_c Q_c}(\cdot)$ are respectively the first-order and second-order differential equations from $V(\cdot)$ for Q_s, Q_c . The total expected return over an interval

time dt , $rV(.)dt$, is equal to its expected potential value based on the conditions of neutral risk and discount rate r . The Bellman equation is as Eq.(8):

$$rV(.)dt = E[dV(.)] \quad (8)$$

Substituting Eq.(3), Eq.(4) to Eq.(7) and Eq.(8), The firm value equation with the management flexibility is as Eq.(9):

$$\frac{1}{2}\sigma_s^2 Q_s^2 V_{ss}(\cdot) + \gamma_{sc}\sigma_s\sigma_c V_{Q_s Q_c}(\cdot) + \frac{1}{2}\sigma_c^2 Q_c^2 V_{Q_c Q_c}(\cdot) + \alpha_s Q_s V_{Q_s}(\cdot) + \alpha_c Q_c V_{Q_c}(\cdot) - rV(\cdot) = 0 \quad (9)$$

To satisfy the boundary, the solution must take the form $V(Q_s(t), Q_c(t)) = A Q_s(t)^\beta Q_c(t)^{1-\beta}$ [11,12], the study see by substitution that it satisfied the equation provide β is a root of the quadratic equation:

$$-\frac{1}{2}\sigma^2\beta(\beta-1) - \beta(\alpha_c - \alpha_s) + (r - \alpha_s) = 0 \quad (10)$$

At $\sigma^2 = \sigma_s^2 - 2\gamma_{sc}\sigma_s\sigma_c + \sigma_c^2$, the two roots are:

$$\beta_1 = \frac{\left(\frac{1}{2}\sigma^2 + \alpha_s - \alpha_c\right) + \sqrt{\left(\frac{1}{2}\sigma^2 + \alpha_s - \alpha_c\right)^2 + 2\sigma^2(r - \alpha_s)}}{\sigma^2} > 1 \quad (11)$$

$$\beta_2 = \frac{\left(\frac{1}{2}\sigma^2 + \alpha_s - \alpha_c\right) - \sqrt{\left(\frac{1}{2}\sigma^2 + \alpha_s - \alpha_c\right)^2 + 2\sigma^2(r - \alpha_s)}}{\sigma^2} < 0 \quad (12)$$

So the general solution can be written as $V(Q_s(t), Q_c(t)) = A_1 Q_s(t)^{\beta_1} Q_c(t)^{1-\beta_1} + A_2 Q_s(t)^{\beta_2} Q_c(t)^{1-\beta_2}$. Where A_1, A_2 are constants to be determined. The constraints of the value of its management elasticity strategy must satisfy $\lim_{Q_s(t) \rightarrow 0} V(Q_s(t), Q_c(t)) = 0$. The boundary condition that if $Q_s(t)$ goes to zero, it will stay at $V(Q_s(t), Q_c(t)) = 0$. The solutions must take the form as $V(Q_s(t), Q_c(t)) = A_1 Q_s(t)^{\beta_1} Q_c(t)^{1-\beta_1}$. To solve optimum output $Q_s(t)$ and carbon emission $Q_c(t)$ based on the value matching condition and smoothing condition [1].

At the threshold $Q_s(t)^*, Q_c(t)^*$, the value of the management elasticity strategy $A_1 Q_s(t)^{\beta_1} Q_c(t)^{1-\beta_1}$ equals the present value of expected net income $\pi(Q_s(t), Q_c(t), g) - I_g$, this is value matching condition:

$$V(Q_s(t)^*, Q_c(t)^*) = \pi(Q_s(t)^*, Q_c(t)^*) \quad (13)$$

Then, the marginal value is equal in the first-order derivative function, that is, it satisfies the conditions of equal marginal value; this is smoothing condition such as Eq.(14), Eq.(15):

$$\frac{\partial V(Q_s(t)^*, Q_c(t)^*)}{\partial Q_c(t)^*} = \frac{\partial \pi(Q_s(t)^*, Q_c(t)^*)}{\partial Q_c(t)^*} \quad (14)$$

$$\frac{\partial V(Q_s(t)^*, Q_c(t)^*)}{\partial Q_s(t)^*} = \frac{\partial \pi(Q_s(t)^*, Q_c(t)^*)}{\partial Q_s(t)^*} \quad (15)$$

Where $Q_s(t), Q_c(t)$ are satisfied by the value function $V(.)$ that is linearly homogeneous. Then $v(Y) = \frac{V(Q_s(t), Q_c(t))}{Q_c(t)}$, $w(Y) = \frac{\pi(Q_s(t), Q_c(t), g)}{Q_c(t)}$, order $Y = \frac{Q_s(t)}{Q_c(t)}$ [12], Therefore, Eq.(16), Eq.(17), Eq.(18) can be expressed as:

$$\lim_{Y \rightarrow 0} v(Y) = 0 \quad (16)$$

$$v(Y^*) = w(Y^*) \quad (17)$$

$$\frac{\partial V(Y^*)}{\partial Y} = \frac{\partial W(Y^*)}{\partial Y} \quad (18)$$

$Y^* = \frac{Q_s(t)^*}{Q_c(t)^*}$ is the threshold for the ratio of output and carbon emissions of enterprises to update green energy equipment. The firm update green energy device value function is:

$$V(Y^*) = \begin{cases} A_1 Y^{\beta_1}, Y < Y^* \\ Y \times \frac{P_s \times E(g)}{r - \alpha_s} - \frac{H \times P_c}{r - \alpha_c} - \frac{(H - D(g)) \times P_c \times G(l)}{r - \alpha_c} - I_g, Y \geq Y^* \end{cases} \quad (19)$$

When $Y < Y^*$ the ratio of output to carbon emissions is less than the threshold Y^* , the firm will adopt a conservative strategy and wait for a better time to update the green energy equipment. When $Y \geq Y^*$ the ratio of output to carbon emissions is greater than or equal to the investment threshold Y^* , the firm should choose to update the investment decision of the green energy equipment. To solve Y^* and A_1 based on the value matching condition and smoothing condition from Eq.(14), the solutions is Eq.(20):

$$\begin{cases} A_1 Y^{\beta_1} = \frac{Y^* \times P_s \times E(g)}{r - \alpha_s} - \frac{H \times P_c}{r - \alpha_c} - \frac{(H - D(g)) \times P_c \times G(l)}{r - \alpha_c} - I_g \\ A_1 \beta_1 Y^{*\beta_1 - 1} = \frac{P_s \times E(g)}{r - \alpha_s} \end{cases} \quad (20)$$

Derived from Eq.(20) yields:

$$Y^* = \frac{\beta_1}{(\beta_1 - 1)} \times \frac{r - \alpha_s}{P_s \times E(g)} \left[\frac{P_c \times H + (H - D(g)) \times P_c \times G(l)}{r - \alpha_c} + I_g \right]; A_1 = \left(\frac{P_s \times E(g)}{r - \alpha_s} \right) \times \frac{Y^{*(1 - \beta_1)}}{\beta_1} \quad (21)$$

In addition, if output $Q_s(t)$ and carbon emissions $Q_c(t)$ are non-random variables. So $Q_s(t) = Q_s(0)e^{\alpha_s t}$, $Q_c(t) = Q_c(0)e^{\alpha_c t}$ [4]. With the determination of production scale, it is assumed that the input of green energy will result in an output increase function of $E(g) = e^{h \times g}$, $h \geq 0$. Putting green energy g will increase the output by $e^{h \times g}$ multiple, and it can reduce the carbon emission function by $D(g) = e^{-k \times g}$, $k \geq 0$. Assume that the firm's optimal green energy input is g^* . With the largest revenue to yield, the optimum green energy input g^* . The first-order derivative function by Eq.(6) is:

$$\text{Max } \pi(g) \Rightarrow \frac{\partial \pi(g)}{\partial g} = 0 \quad (22)$$

The optimal amount of green energy input from Eq. (22) is:

$$g^* = \frac{1}{(h + k)} \times \ln \frac{k \times Q_c(0) \times e^{\alpha_c t} \times P_c \times G(l)}{h \times Q_s(0) \times e^{\alpha_s t} \times P_s(t)} \times \frac{r - \alpha_s}{r - \alpha_c} \quad (23)$$

Solve the threshold of optimal ratio of output to carbon emissions Y^* in the model. The threshold provide the best opportunity for companies to update their production equipment. Then, determine the optimal amount of green energy input g^* under the optimal scale of production and carbon emissions. Provide reference for companies to choose green energy investment.

3. Numerical examples

The following section uses real options to construct an investment strategy model for Section 2. Analysis of the feasibility of updating high-tech production equipment to reduce environmental pollution under the premise of national importance on environmental protection issues. In the production process of enterprises, the government limits carbon emissions. If the amount of emissions exceeds or falls below the limit, it can be bought and sold in the trading market. Suppose that output $Q_s(t)$ and carbon emissions $Q_c(t)$ follow the joint geometric Brownian motion and find the optimal

investment threshold Y^* for firms to adopt investment strategies. For numerical analysis, the relevant exogenous variables are hypothesized as shown in Table 1:

Table 1. Exogenous variables.

Exogenous variables	Significance	Value	Exogenous variables	Significance	Value
P_s	Net income per unit of product (unit: dollar).	500.000	P_c	Cost per unit of carbon emissions (Unit: dollar).	100.000
α_s	Expected growth rate of output $Q_s(t)$.	0.060	α_c	Expected growth rate of carbon emissions $Q_c(t)$.	0.040
σ_s	Standard deviation of output $Q_s(t)$.	0.600	σ_c	The standard deviation of carbon emissions $Q_c(t)$.	0.500
r	Input green energy to reduce carbon emission function parameters.	0.200	$\gamma_{s,c}$	Correlation coefficient between output $Q_s(t)$ and carbon emissions $Q_c(t)$.	1.000
$E(g)$	Enterprises invest in green energy production, resulting in increased returns.	1.002	$D(g)$	Firm invest in green energy production to generate benefits and reduce carbon emission rates.	0.800
$G(l)$	Carbon trading price increase rate.	1.200	H	Government stipulates firm carbon emission rate.	1.50
I_g	Update equipment input costs (Unit: ten thousand).	5000.000	h	The input of green energy results in an output increase function parameter.	0.002
r	Risk-free interest rate.	0.150			

From table 1 Numerical data, the study uses real options to build investment strategy models. Numerical analysis and analysis results: the optimal ratio of output to carbon emissions $Y^* = 2.023$; optimum green energy input $g^* = 11.251$; parameter $A_1 = 594.536$. Based on the assumptions of the parameters, the data results show that it is timely to provide enterprises with the opportunity to update their production equipment. When the optimal ratio of output to carbon emissions $Y^* \geq 2.023$, advise companies to choose to update production equipment that reduces carbon pollution. Simultaneously, At the time when the optimal output and carbon emissions ratio threshold is reached, the optimal amount of green energy input will be derived $g^* = 11.251$. To provide the reference for enterprises to make good use of corporate social responsibility and update production equipment that reduces carbon emissions.

4. Conclusions

From the perspective of flexible strategy management, this study considers that the government's role is to reduce pollution and limit corporate carbon emissions as the main axis. Without compromising social welfare and the polluter pays principle, carbon emissions in the production process will become production costs. In the uncertain and dynamic production environment, this study aims to establish whether the company will update the green energy investment strategy model of investment equipment. Our model assumes that the government sets a cap on carbon emissions. Carbon emissions trading can be carried out when the firm's carbon emissions exceed or fall below the cap. The production volume and carbon emissions of firms are uncertain variables. Under the consideration of the joint geometric Brownian movement, the assessment criteria of the Real Options Approach (ROA) are used to construct a green energy investment strategy model. When the optimal investment strategy threshold is determined, the optimal investment strategy threshold can be used to determine the optimal amount of green energy input. This paper adopts the evaluation criteria of the Real Options Approach (ROA) to construct a green energy investment strategy model and provides a more flexible decision-making mode of thinking than other trend forecasting criteria. In addition, the results of the study can provide the government with reference to green economy issues when formulating relevant

energy strategies. It can also provide a reference for how the government can make more feasible energy policies under the comprehensive consideration of energy economy, industrial economy and national interests.

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