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RESEARCH ARTICLE

REAL OPTION ANALYSIS ON RENEWABLE ENERGY POLICY FOR CELLULOSIC ETHANOL PLANTS IN CHINA

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ABSTRACT

Based on real option analysis, this paper investigates the impact of renewable energy policy for cellulosic ethanol plants in China with two construction stages and double stochastic variables under government and investors perspectives. Considering the gasoline and corn cob prices as the independent stochastic variables, this paper constructs a quadrinomial lattice tree. Based on the results of the decision value function at each scenario, it indicates that at the current subsidy level, both government and investors can get more revenues if the stage-1 construction has been completed. With the subsidy increasing, the initial decision value decreases under government perspective but increases under investors perspective. However, if there exits no by-product, the initial decision values are negative when all the construction stages are completed immediately for both government and investors. Meanwhile, the value increases obviously if only the stage-1 construction is completed. Reducing subsidy can ease the loss of government and cut down the benefit of investors. Improving the technology to find more high value by-products is the effective way to enhance the revenues of cellulosic ethanol plant.

INTRODUCTION

In recent decades, energy crisis and environmental issues become severely, most countries develop renewable energy vigorously. Renewable energy sources such as hydropower, biomass, geothermal, wind and PV solar can replace the traditional fossil fuels and reduce the pressure on the environment, since they have the ability to be renewable and not subject to depletion. As a kind of clean and reproducible resources, fuel ethanol can be used as liquid fuel partly instead of the gasoline. Thus, it has become one of the focus of attention in many countries. According to Earth Policy Institute (EPI), Energy Information Administration (EIA), and Renewable Fuels Association (RFA), fuel ethanol industry starts from 1970s and ushers in the development spurt in 21st century. In 2014, the fuel ethanol production achieves 24,570 millions of gallons as shown as Fig 1.

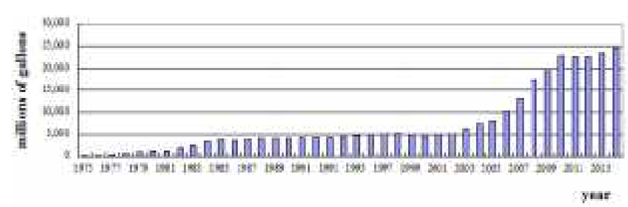

Fig 1 The fuel ethanol production in the world

As a big energy production and consumption country in the world, China has great potential and has made efforts of the development of renewable energy. The fuel ethanol industry of China based on grain, such as corn or wheat, began with 2001. From 2006, the government stopped grain-based ethanol projects gradually and focused on non-grain ethanol, especially cellulosic ethanol projects. In 2007, government document - the Middle and Long Term Program of Renewable Energy Development of China - stated that the available non-grain ethanol will reach more than 10 million tons in 2020. In order to

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encourage the investors, the Chinese government had made a subsidy plan for the cellulosic ethanol industry. So the appropriate level of subsidy is worthy of attention for both government and investors.

Some studies (Lee and Shih, 2010; Sharma *et al*., 2013; Zhang *et al*., 2014) have investigated the benefits of renewable energy policy based on lattice tree model. Lee and Shih (2010) presented a policy benefit evaluation model that integrated cost efficiency curve information on renewable power generation technologies into real option analysis (ROA) based on binomial lattice tree method. Their model evaluated quantitatively the policy value provided by developing renewable energy in the face of uncertain fossil fuel prices and renewable energy - related factors. In addition to assessing the policy value of current renewable energy development policy, their study also compared the policy values in terms of internalized external costs and varying FIT. Sharma, Romagnoli and Vlosky (2013) discussed the optimal strategic investment decisions by prospective biobased fuel and chemical enterprises with a real options - based stochastic integer programming model. They modeled a hypothetical, vertically integrated lignocellulosic enterprise that produced cellulosic ethanol and biosuccinic acid. They considered the bioproduct demands and prices as the uncertain factors. Specially, Zhang and researchers (2014) proposed a policy evaluation model under government and investors perspectives. Based on the American option method and two-factor learning curve method, their research evaluated the unit decision value and save-path rate for renewable energy development and examined the existence of balance point of interest. Their empirical results showed that real option analysis was more effective than net present value analysis when handling uncertainties. The results of the previous research showed that real option analysis is a highly effective means of quantifying how policy planning uncertainty including managerial flexibility influences renewable energy development. The simulation results demonstrated that the renewable energy subsidy policy was appropriate policy planning from sustainability point of view.

This paper establishes a renewable energy policy investment model with two construction stages and double stochastic variables under two perspectives of government and investors. By considering the prices of main raw material, products, subsidy, construction cost and carbon emission cost, we calculate the decision values for government and investors during the investment periods. Meanwhile, we observe the regularity with the change of subsidy and ratio of stage-1 construction cost. The remainder of this paper is organized as follows: Section 2 provides a literature reviews about the traditional methods and real option analysis. Furthermore, it generalizes the previous research of the real option analysis to renewable energy investment. Section 3 describes the two kinds of parameters, stochastic and non-stochastic, considered in the lattice tree model. Section 4 presents the parameters estimation. Section 5 constructs a multistage real option model. Section 6 indicates the empirical analysis. Section 7 concludes the study.

LITERATURE REVIEW

A simple rule to adopt to evaluate investments and real asset investments decisions is the net present value (NPV) method based on the discounted cash flow (DCF) analysis. DCF method was proposed by Fisher (1907, 1930), when he pioneered the theory of interest and the value of time. DCF method uses the future cash flow projections and discounts them to the present values, which are used to evaluate the potential for the investment. After discounting the future cash flows, the investors can make decisions based on the results of NPV, that is the difference between the present values of the cash inflows and outflows. Usually, the investors think that the investment project with positive NPV is more economic effective. On the contrary, the investors may give up the project. Although the traditional methods can easily to understand and apply, they still can not effectively reflect the uncertain factors in the investment process. The traditional methods limitations have been recognized by some researchers (Myers, 1984; Hodder *et al*., 1985; Trigeorigis and Mason, 1987; Brealey *et al*., 1992; Ross, 1995; Dixit and Pindyck, 1995; Herath and Park, 1999; Hayes and釘bernthy, 1980; Hayes and Garvin, 1982; Trigerorgis, 1997; Tseng and Barz, 2002; Lewis *et al*., 2004). The DCF method is inappropriate for a rapidly changing investment climate (Dixit and Pindyck, 1995; Herath and Park, 1999). However, DCF method cannot reflect the contingent decisions available and the managerial flexibility to act on those decisions. For example, the value of the future flexibility to expand, contract, or abandon is not captured by DCF (Hayes and Abernthy, 1980; Hayes and Garvin, 1982; Trigerorgis and Mason, 1987; Trigerorgis, 1997; Tseng and Barz, 2002; Lewis *et al*., 2004). Furthermore, the NPV is based on a set of fixed assumptions related to the project payoff (a deterministic approach), whereas the payoff is uncertain and probabilistic (Kodukula and Papudesu, 2006).

However, ROA offers new ways to fill the gaps that the traditional methods cannot address. The idea of the real option was from the financial option by Black and Scholes (1973) and Merton (1973), but its concept was proposed firstly by Myers in 1977. Real option is the right, but not the obligation, to undertake certain business initiatives, such as deferring, abandoning, expanding, staging, or contracting a capital investment projects. Ross (1978) considered such an investment opportunity as real options. He also discussed the theory of real option valuation based on analysis of risky projects. Trigeorigis and Mason (1987) referred to the investment value of an options value with managerial flexibility obtained as “expanded” or “strategic” NPV. This value was the sum of the traditional NPV and flexibility value. According to the differences in flexibility, the real options was divided into seven categories by Trigeorigis (1993), such as option to defer, staged investment option, option to alter operating scale, option to abandon, option to switch, growth option, and interacting option. Obviously, some new types emerges with the complexity and diversification of the investment projects.

Up to now, some scholars focus on the real option analysis to renewable energy investment (Venetsanos *et al*., 2002; Davis and Owens, 2003; Yu *et al*., 2006; Muñoz *et al*., 2009; Kjaerland, 2007; Bockman *et al*., 2008; Martinez and Mutale, 2011; Siddiqui *et al*., 2007; Kumbaroğlu *et al*., 2008; Arenairo *et al*., 2011; Oliveira *et al*., 2014). Main applications are about the new renewable power generations such as wind power, hydropower and solar PV power. They discussed the impact of uncertain factors on renewable energy investment and illustrate the decision-making process at different scenarios. Comparing with other methods, their results showed higher expected profits for projects planned with the advanced real option methodology. Another important application of real option to renewable energy is fuel ethanol project. Using the real option approach developed by Dixit and Pindyck (1994), Schmit *et al*. (2009) analyzed investment and decision of corn-based dry-grind ethanol plants. Kirby and Davison (2010) presented a real option model - like valuation of an ethanol plant as a spark spread between the corn price and the gasoline price. Their analyses showed that the value of an ethanol plant monotonically decreases with the increased correlation of corn price and gasoline price. At present, more and more scholars (Lee and Shih, 2011; Lin and Wessh, 2013; Zhang *et al*., 2014; Schmit *et al*., 2011; Maxwell and Davison, 2014) construct models to investigate the influence of the renewable energy policy. Schmit *et al*. (2011) indicated that U.S. ethanol policy has narrowed the distance between the optimal entry and exit curves with regardless of plant size. Maxwell and Davison (2014) used real option analysis to find the evidence of increased correlation between corn and ethanol prices.

In sum, these studies demonstrate deeply that the real option method is suit for evaluating the value of renewable energy project and investigating the influence of the related policies.

Parameters

Since the development of bio-fuel competes with human food and animal feed, China establishes the bio-fuel development principles: cannot compete with human food and land for food, and cannot destroy ecology. The government focuses on the 2nd generation bio-fuel - cellulosic ethanol - based on corn cob or corn stalk. According to the reports of National Development and Reform Commission of China (NDRC), the first large-scale cellulosic ethanol producer (SHANDONG LONGLIVE BIO-TECHNOLOGY CO., LTD.) with annual capacity of 50,000 tons has gone into operation in 2012. Through a special technology, the producer uses corn cob as feedstock, which can produce ethanol, xylitol, and other high value products as Fig 2. And the quantitative relation of the main raw material and products is indicated in Table 1.

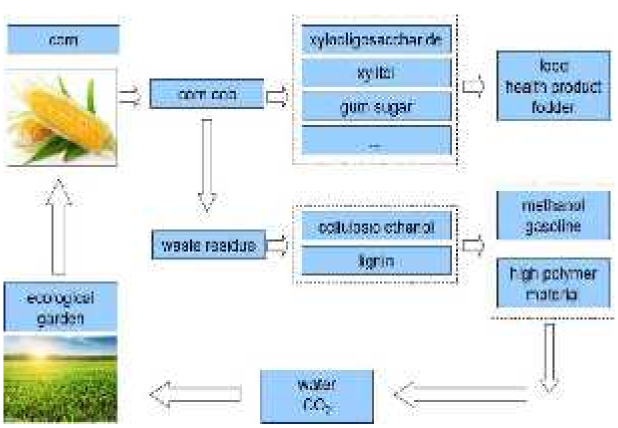

Fig 2 The 2nd generation cellulosic ethanol process flow diagram

Table 1 The main raw material and products of the '2nd generation cellulosic ethanol

Feedstock	Products
Corn cob (10 tons)	Xylitol (1.2 tons) Ethanol (1.5 tons) Pure lignin (1.0 tons)

Note: The table comes from the conference reports of the 6th Stakeholder Plenary Meeting of EBTP in 2014 (Kang,2014).

Stochastic variables

The significant difference with other countries is that the project and price of fuel ethanol is determined by the government of China. Based on the report of NDRC, the fuel ethanol price is set at 0.9111 times the price of No.93 gasoline from 2011.May.1 in China. Thus, the price of gasoline is one key factor in the fuel ethanol investment.

Suppose that the gasoline price follows Geometric Brownian Motion (GBM). Let $P^g(i,n)$ denote the gasoline price with n periods elapsed and i downward movements, where $0 \le n \le T$, $0 \le i \le n$. T is the number of time periods. In particular, the gasoline price for the next period can be presented as binomial lattice tree as Fig 3 shown.

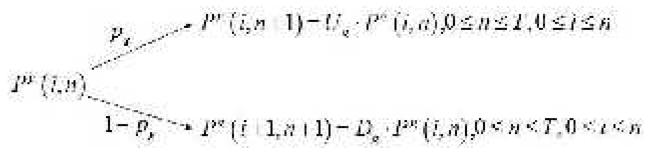

Fig 3 The binomial lattice tree of the gasoline price

Here, U_g is the range of the gasoline price upward movements. D_g is the range of the gasoline price downward movements. p_g is the risk-neutral probability of the gasoline price increase. As the main raw material, the price of corn cob is also assumed to follow GBM. Let $P^c(j,n)$ denote the corn cob price with n periods elapsed and j downward movements, where $0 \le n \le T$, $0 \le j \le n$. Its binomial lattice tree can be shown by Fig 4.

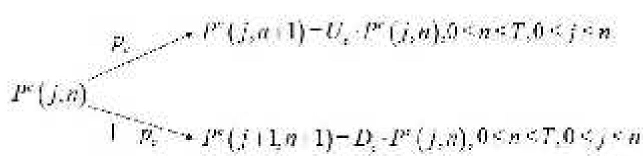

Fig 4 The binomial lattice tree of the corn cob price

Similarly, U_c is the size of the corn cob price upward movements. D_c is the size of the corn cob price downward movements. p_c is the risk-neutral probability of the corn cob price increase.

Non-stochastic parameters

Suppose that the xylitol, pure lignin are by-products, zymin is another important raw material in the cellulosic ethanol project. Let P^x, P^l denote the prices of xylitol and pure lignin, P^z present the expense of zymin for every ton cellulosic ethanol. Meanwhile, we assume that the government must pay the cost of CO_2 emission, which is denoted by P^{cb}. Furthermore, all these parameters are assumed as constants.

Since the cellulosic ethanol project can obtain the support of subsidy in China, so let symbol S present the subsidy for every ton cellulosic ethanol, and it is a constant as well.

Parameters estimation

The values of non-stochastic parameters can be obtained easily from government documents, conference reports and company announcements. Assume that the price of xylitol is 23,000 yuan/ton, the price of pure lignin is 4,500 yuan/ton. At the same time, producing one ton cellulosic ethanol needs 2,600 yuan zymin, and the government pays 800 yuan subsidy to the investors.

By the announcement of LONGLIVE company in 2012, suppose that the capacity 50,000 tons cellulosic ethanol project needs 166 million yuan as the total investment costs (such as land, equipment, etc). Since there are two stages for the construction program, we choose the ratio $a = 0.5$ firstly, thus each stage costs is 83 millions yuan. Based on the treasury bond in China, this paper uses the average interest of treasury bond in early 2015 to represent the risk-free interest rate. Hence, $r_f = 0.032$. From the Middle and Long Term Program of Renewable Energy Development of China, suppose that the cellulosic ethanol investment right will be lost if the construction program is not completed on or before 2020 which is started from 2015. That is, the number of time periods T is 5.

Table 2 The parameters and parameters estimated values in lattice tree model

parameter	description	value	note
i	the number of gasoline price downward movements		
j	the number of corn cob price downward movements		
n	the number of time periods elapsed		
T	the number of time periods	5	2015 to 2020
Q	the capacity of cellulosic ethanol	50,000 tons	some reports from NDRC of China
P^x	the price of xylitol	23,000 yuan/ton	The 6th stakeholder Plenary Meeting of EBTP
P^l	the price of pure lignin	4,500 yuan/ton	The 6th stakeholder Plenary Meeting of EBTP
P^z	the price of zymin	2,600 yuan/ton cellulosic ethanol	The 6th stakeholder Plenary Meeting of EBTP
P^{cb}	the average price of carbon	50 yuan/ton	the average price of carbon mitigation price from 2015.January to 2015. May based on China Beijing Environmental Exchange
S	the subsidy	800 yuan/ton cellulosic ethanol	some reports from NDRC of China
r_f	the risk-free interest rate	0.032	the average interest rate of treasury bonds in China in 2015
J_1	the cost of 1st-stage	83 millions yuan	
J_2	the cost of 2nd-stage	83 millions yuan	
C_{other}	all the costs of the investment except corn cob and zymin	166 millions yuan	
a	the ratio of the cost of 1st-stage	0.5	
$\pm_g$	the volatility of gasoline price	0.12	calculate with the history data between 2011.March.1 and 2015.May.31
U_g	the range of gasoline price upward movements	1.12	$U_g = e^{\pm_g}$
D_g	the range of gasoline price downward movements	0.89	$D_g = \frac{1}{U_g} = e^{-\pm_g}$
p_g	the risk-neutral probability of gasoline price increasing	0.61	$p_g = \frac{e^{r_f} - D_g}{U_g - D_g}$
$\pm_c$	the volatility of corn cob price	0.77	calculate with the history data between 2012.March.1 and 2015.May.31
U_c	the range of corn cob price upward movements	2.17	$U_c = e^{\pm_c}$
D_c	the range of corn cob price downward movements	0.46	$D_c = \frac{1}{U_c} = e^{-\pm_c}$
p_c	the risk-neutral probability of corn cob price increasing	0.33	$p_c = \frac{e^{r_f} - D_c}{U_c - D_c}$

Suppose that the cellulosic ethanol investment involves two construction stages, and each stage can be completed in one period. Furthermore, the construction cost is paid in advance and is irreversible. Assume that J_k ($k=1,2$) presents the cost of the stage-i. That is, $J_1 = aC_{other}$, $J_2 = (1-a)C_{other}$. Here, a is the ratio of stage-1 construction cost. C_{other} is other costs of the investment except corn cob and zymin.

According to the report of NDRC in China, the first-scale cellulosic ethanol producer is settled in Shandong province in 2012. So we use No.93 gasoline price of Shandong province between 2011.March.1 and 2015.May.31. Using the daily history data of gasoline price and the logarithm cash flow returns method (Kodukula and Papudesu,2006), the volatility of gasoline price with the year as unit equals 0.12. Furthermore, the range of gasoline price upward movements equals 1.12 and the risk-neutral probability of gasoline price increase equals 0.61. Table 3 shows the values in the binomial lattice tree of gasoline price with initial data $P^g(0,0) = 8368$ yuan per ton.

Table 3 The value in the binomial lattice tree of the gasoline price (yuan/ton)

	n=0	n=1	n=2	n=3	n=4	n=5
i=0	8368	9372	10497	11756	13167	14747
i=1		7448	8341	9342	10463	11719
i=2			6628	7424	8315	9312
i=3				5899	6607	7400
i=4					5250	5880
i=5						4673

Similarly, based on the daily history data of corn cob price between 2012.March.1 and 2015.May.31, the volatility of corn cob price with the year as unit is 0.77, the range of corn cob price upward movements is 2.17, the risk-neutral probability of corn cob price increase is 0.33. Table 4 describes the values in the binomial lattice tree of corn cob price with initial data $P^c(0,0) = 451$ yuan per ton.

Table 4 The value in the binomial lattice tree of the corn cob price (yuan/ton)

	n=0	n=1	n=2	n=3	n=4	n=5
j=0	451	979	2124	4608	10000	21701
j=1		207	450	977	2120	4600
j=2			95	207	449	975
j=3				44	95	207
j=4					20	44
j=5						9

Specially, in Table 3, the value at node $(i,n+1)$ equals to $U_g = 1.12$ times the value at node (i,n), the value at node $(i+1,n+1)$ equals to $D_g = 0.89$ times the value at node (i,n). In Table 4, the value at node $(j,n+1)$ equals to $U_c = 2.17$ times the value at node (j,n), the value at node $(j+1,n+1)$ equals to $D_c = 0.46$ times the value at node (j,n).

Real option model

Based on real option analysis, this section establishes a evaluation model and investigates the impact of subsidy policy under government and investors perspectives.

Government and investors perspectives

The similar idea is that the decision value is the revenue minus the cost (Lee and Shih, 2010; Lee and Shih,2011; Lin and Wessh,2013; Zhang *et al*.,2014). According to Table 1, every 10 tons corn cob can produce 1.5 tons cellulosic ethanol, 1.2 tons xylitol, and 1.0 ton pure lignin. In the production process, it needs to expense zymin P^z for every ton cellulosic ethanol. Meanwhile, the government pays the subsidy S to the investors. In China, one ton fuel ethanol can be instead of one ton gasoline, and one ton gasoline will release 3.15 tons CO_2 by BP carbon emission calculator (the Chinese version is launched in early 2007 by BP company, which is one of the big oil and gas company in the world). So suppose that the government pay the emission cost P^{cb} for each ton CO_2. We define $X(i,j,n)$ to be the market value of the completed project at node (i,j,n). Therefore, the market value under government and investors perspectives can be presented as follows:

Case 1: Government perspective

$$X_G(i,j,n) = Q\cdot\left[0.9111P^g(i,n) - \frac{4}{5}P^x + \frac{2}{3}P^l - \frac{20}{3}P^c(j,n) - P^z - S - 3.15P^{cb}\right], \quad (1)$$

Case 2: Investors perspective

$$X_I(i,j,n) = Q\cdot\left[0.9111P^g(i,n) - \frac{4}{5}P^x + \frac{2}{3}P^l - \frac{20}{3}P^c(j,n) - P^z + S\right], \quad (2)$$

where $0 \le n \le T$, $0 \le i,j \le n$. $X_G(i,j,n)$ is the market value of the completed cellulosic ethanol project for government at decision node (i,j,n), $X_I(i,j,n)$ is the market value of the completed cellulosic ethanol project for investors at decision node (i,j,n).

Decision tree

By the assumptions of two construction stages, we can construct the decision tree for the multistage investment.

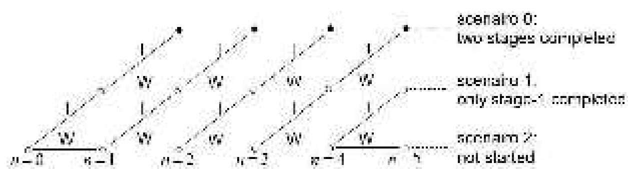

Fig 5 The decision tree for the multistage investment

Following the method of decision tree in Guthrie (2009), let label W stand for action "wait", label I stand for action "invest". As Fig 5 shown, the owners have two actions that can be chosen - "wait" or "invest" at date 0. If the owners wait, there is zero cash flow at date 0 and all stages are not started. If the owners build the stage-1 construction, there is a cash flow of $-J_1$ at date 0 and only stage-2 construction is remained. At date 1, the stage-1 construction will be either completed or not. If the stage-1 construction has not been started, the owners face the same situation as at date 0. But if the stage-1 construction has been completed, the owners must choose action "wait" or action "invest" the stage-2 construction. If they wait, there is also zero cash flow at date 1 and only the stage-1 construction has been completed. On the contrary, if they undertake the stage-2 construction, there is a capital expenditure of J_2 at date 1 and two stages will be completed at date 2. Starting from date 2, the project will be in one of three scenarios: two stages completed, only stage-1 completed and not started, which are denoted as scenario 0, scenario 1 and scenario 2. After expiration date T, the owners can do nothing since the investment right has expired.

Scenario functions

Since we have two state variables, i.e. variable i represents the gasoline price and variable j represents the corn cob price, then we wish to incorporate multiple state variables. To do this, we generalize the notion of Guthrie (2009). Let $V_m(i, j, n)$ denote the market value of the investment right at date n if there are i downward movements in the first state variable and j downward movements in the second one. Here, $m = 0,1,2$ represents the number of stages of construction remaining to be completed.

Scenario 0: two stages completed

If the construction program is completed immediately, the investment right is worth whatever the owners will obtain from the imminent sale value. Therefore, the decision value functions under government and investors perspectives can be written as

$$V_{G0}(i, j, n) = -aC_{other} - e^{-r_f}(1-a)C_{other} + X_G(i, j, n), \qquad (3)$$

$$V_{I0}(i, j, n) = -aC_{other} - e^{-r_f}(1-a)C_{other} + X_I(i, j, n), \qquad (4)$$

where $0 \le n \le T$, $0 \le i, j \le n$.

Scenario 1: only stage-1 completed

Since the investment right will be lost if the construction program is not completed on or before expiration date T . It satisfies terminal conditions as

$$V_{G1}(i, j, T) = 0, \qquad (5)$$

$$V_{I1}(i, j, T) = 0, \qquad (6)$$

where $0 \le i, j \le T$.

For each date, gasoline price may increase with probability p_g or decrease with probability $1-p_g$. Meanwhile, corn cob price may increase with probability p_c or decrease with probability $1-p_c$. Hence, there are four cases in the next date as Fig 6 shown, which ignores the subscripts G and I. This quadrinomial lattice is called bidimensional binomial lattice approach named by Fan (2013). This paper uses the same idea to construct the real option model.

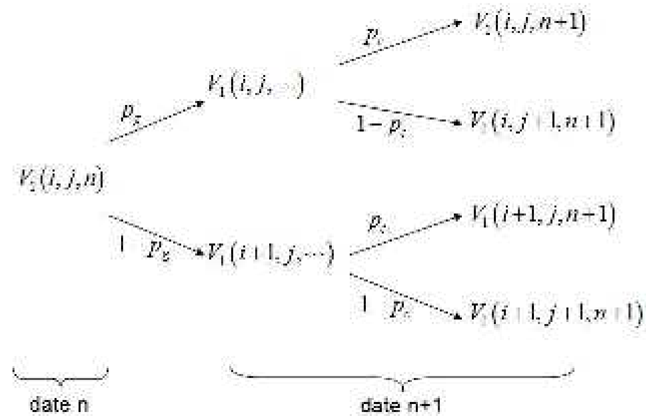

Fig 6 The stochastic decision-making process with double stochastic variables

By backward induction, the lattices for decision value V_1 under government and investors perspectives can be filled by

$$\begin{aligned} V_{G1}(i, j, n) = \max\{ & -J_2 + X_G(i, j, n), \\ & e^{-r_f}\left[p_g\left[p_c V_{G1}(i, j, n+1) + (1-p_c)V_{G1}(i, j+1, n+1)\right] \right. \\ & \left. +(1-p_g)\left[p_c V_{G1}(i+1, j, n+1) + (1-p_c)V_{G1}(i+1, j+1, n+1)\right]\right]\} \end{aligned} \qquad (7)$$

$$\begin{aligned} V_{I1}(i, j, n) = \max\{ & -J_2 + X_I(i, j, n), \\ & e^{-r_f}\left[p_g\left[p_c V_{I1}(i, j, n+1) + (1-p_c)V_{I1}(i, j+1, n+1)\right] \right. \\ & \left. +(1-p_g)\left[p_c V_{I1}(i+1, j, n+1) + (1-p_c)V_{I1}(i+1, j+1, n+1)\right]\right]\} \end{aligned} \qquad (8)$$

where $0 \le n \le T$, $0 \le i, j \le n$.

Thus, the government and investors can choose the action that maximized the market value of the project.

Scenario 2: not started

Scenario 2 has the same terminal conditions. Since the construction program is never started, the project right value must equal 0 for both government and investors at expiration date T .

$$V_{G2}(i, j, T) = 0, \qquad (9)$$

$$V_{I2}(i, j, T) = 0, \qquad (10)$$

for all i, j satisfying $0 \le i, j \le T$.

Similarly, the last line of lattice trees for V_2 can be filled by the terminal conditions. Then the decision values of the investment right at each node can be calculated by backward induction based on the equations (11) and (12).

$$V_{G2}(i,j,n)=\max\left\{\begin{array}{l}-J_1+e^{-r_f}\left[p_g\left[p_cV_{G1}(i,j,n+1)+(1-p_c)V_{G1}(i,j+1,n+1)\right]\right.\\ \left.+(1-p_g)\left[p_cV_{G1}(i+1,j,n+1)+(1-p_c)V_{G1}(i+1,j+1,n+1)\right]\right],\\ e^{-r_f}\left[p_g\left[p_cV_{G2}(i,j,n+1)+(1-p_c)V_{G2}(i,j+1,n+1)\right]\right.\\ \left.+(1-p_g)\left[p_cV_{G2}(i+1,j,n+1)+(1-p_c)V_{G2}(i+1,j+1,n+1)\right]\right]\end{array}\right\} \quad (11)$$

$$V_{I2}(i,j,n)=\max\left\{\begin{array}{l}-J_1+e^{-r_f}\left[p_g\left[p_cV_{I1}(i,j,n+1)+(1-p_c)V_{I1}(i,j+1,n+1)\right]\right.\\ \left.+(1-p_g)\left[p_cV_{I1}(i+1,j,n+1)+(1-p_c)V_{I1}(i+1,j+1,n+1)\right]\right],\\ e^{-r_f}\left[p_g\left[p_cV_{I2}(i,j,n+1)+(1-p_c)V_{I2}(i,j+1,n+1)\right]\right.\\ \left.+(1-p_g)\left[p_cV_{I2}(i+1,j,n+1)+(1-p_c)V_{I2}(i+1,j+1,n+1)\right]\right]\end{array}\right\} \quad (12)$$

where $0\le n\le T$, $0\le i,j\le n$.

Scenario analysis

Basic case analysis

The purpose of basic case analysis is to analyze the benefit of subsidy under government and investors perspectives, which is derived from renewable energy policy. If two construction stages are completed, the decision values of the the project are shown as Table 5. If only the stage-1 construction has been completed, the decision values of the project are presented as Table 6. Meanwhile, if the project is not started, the decision values of the project are shown as Table 7.

Case 1: government perspective

Table 5 indicates that the initial decision value equals 959 million yuan in 2015, if two stages are completed. The initial decision values from 2015 to 2017 are greater than zero, which reflect that the government will obtain the benefit during these periods, although the government pays the carbon emission cost and the subsidy. But with the time elapsed from 2018 to 2020, the decision values are less than zero if the gasoline price decreases 0 time. It is clearly that if the cost of feedstock is too high, the benefit is too lower. If the government complete the stage-1 construction, the project right value increases from 959 to 1127 million yuan in 2015 (see Table 5 and Table 6). Thus the government can make optimal decision after observing the movements of the gasoline and corn cob prices, if the stage-1 construction can be completed one year in advance. Based on scenario 2, if the project is not started, the initial decision value decreases from 1127 to 1028 million yuan (see Table 6 and Table 7), which is also more than 959 million yuan under scenario 0 (see Table 5). Table 7 indicates that it is the earlier the better to choose action "invest". It is not optimal to invest the project at the last two years.

In the following three tables, in the year 2015+k ($k=1,2,3,4,5$), both gasoline and corn cob prices can decrease k times.

Table 5 The decision values of the cellulosic ethanol investment at scenario 0 (million yuan, G = government, I = investors)

2015		2016		2017		2018		2019		2020	
G	I	G	I	G	I	G	I	G	I	G	I
959	1047	829	917	499	586	-271	-183	-2004	-1917	-5833	-5745
		741	829	400	488	-381	-293	-2128	-2040	-5971	-5883
		1086	1174	322	410	-469	-381	-2225	-2138	-6080	-5992
		998	1086	1056	1144	-538	-450	-2303	-2215	-6167	-6079
				958	1046	938	1026	-2365	-2277	-6236	-6149
				880	968	828	916	621	709	-6291	-6204
				1175	1262	741	829	498	586	-132	-44
				1076	1164	671	759	400	488	-270	-182
				998	1086	1195	1283	323	410	-380	-292
						1085	1173	261	349	-467	-379
						997	1085	1178	1266	-536	-448
						928	747	1055	1143	-591	-503
						1249	1337	957	1045	1075	1163
						1139	1227	879	967	937	1025
						1052	1140	818	905	827	915
						982	1070	1296	1384	740	828
								1173	1261	671	759
								1075	1163	616	704
								997	1085	1331	1419
								936	1024	1193	1281
								1321	1409	1084	1171
								1198	1286	996	1084
								1100	1188	927	1015
								1022	1110	872	960
								961	1049	1385	1473
										1247	1335
										1138	1226
										1051	1139
										982	1069
										926	1014
										1397	1485
										1259	1347
										1149	1237
										1062	1150
										993	1081
										938	1026

From top to bottom, the first $k+1$ rows stand for the gasoline price decreases 0 time, the second $k+1$ rows stand for the gasoline price decreases 1 time, and so on. In each $k+1$ rows, the values present the corn cob price decreases from 0 to k times.

Table 6 The decision values of the cellulosic ethanol investment at scenario 1 (million yuan, G = government, I = investors)

2015		2016		2017		2018		2019		2020	
G	I	G	I	G	I	G	I	G	I	G	I
1127	1127	1040	1026	863	835	517	481	0	0	0	0
		938	941	757	747	427	408	0	0	0	0
		1261	1254	673	678	356	349	0	0	0	0
		1154	1167	1245	1225	300	303	0	0	0	0
				1126	1126	1145	1106	0	0	0	0
				1031	1048	1011	996	855	790	0	0
				1359	1343	905	909	705	667	0	0
				1240	1245	821	840	586	569	0	0
				1145	1167	1393	1363	492	491	0	0
						1259	1253	416	429	0	0
						1153	1166	1393	1347	0	0
						1069	1096	1243	1223	0	0
						1446	1417	1124	1125	0	0
						1312	1307	1030	1048	0	0
						1206	1220	955	986	0	0
						1121	1151	1507	1465	0	0
								1358	1341	0	0
								1239	1244	0	0
								1144	1166	0	0
								1069	1104	0	0
								1532	1490	0	0
								1382	1366	0	0
								1263	1269	0	0
								1168	1191	0	0
								1093	1129	0	0
										0	0
										0	0
										0	0
										0	0
										0	0
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										0	0
										0	0
										0	0

Case 2: investors perspective

Comparing these three tables, under investors perspective, the initial decision value at scenario 0 equals 1047 million yuan (see Table 5), which is less than 1127 million yuan at scenario 1 (see Table 6), but it is a little more than 1026 million yuan at scenario 2 in 2015 (see Table 7). Table 5 indicates the same phenomenon as government perspective. If the investors have completed the construction immediately, the decision values from 2015 to 2017 are greater than zero as well. With the time elapsed from 2018 to 2020, the decision values are less than zero when the gasoline price decreases 0 time. Clearly, the benefit decreases with the increase of costs. Table 6 shows that it is better to complete the stage-1 construction one year in advance as well. At scenario 2, although the government offers the subsidy for the cellulosic ethanol project, the investors are still better to choose action "wait" at the last two years.

In addition, the managerial flexibility can be well underestimated using real option analysis under government and investors perspectives. The shade areas in Table 5 present that the government and investors will suffer loss if the construction is completed at these nodes. The blue areas in the Table 6 and Table 7 indicate that choosing action "wait" is better at these nodes.

Varying the subsidy

Set the subsidy for cellulosic ethanol to different numerical values, Fig 7 to Fig 9 show the changes at each scenario for government and investors.

Fig 7 shows the change of decision values for government and investors at scenario 0. With the subsidy increasing from 0 to 1800, the initial decision value decreases for government but increases for investors if two stages have been completed.

Based on the scenario 1 and scenario 2, Fig 8 and Fig 9 indicate the changes of the initial decision values for government and investors. These two Figs show the same regularity as scenario 0. The initial decision value decreases for government but increases for investors with the subsidy increasing. Either the stage-1 construction is completed or not, the initial decision value curves intersect at the subsidy 800 yuan (see Fig 8 and Fig 9).

Table 7 The decision values of the cellulosic ethanol investment at scenario 2 (million yuan, G = government, I = investors)

2015		2016		2017		2018		2019		2020	
G	I	G	I	G	I	G	I	G	I	G	I
1028	1026	957	943	780	752	434	398	0	0	0	0
		855	858	674	664	344	325	0	0	0	0
		1152	1143	590	595	273	266	0	0	0	0
		1046	1055	1136	1114	217	220	0	0	0	0
				1017	1016	1038	997	0	0	0	0
				923	938	904	887	0	0	0	0
				1250	1231	798	800	0	0	0	0
				1131	1133	714	730	0	0	0	0
				1036	1055	1284	1251	0	0	0	0
						1150	1141	0	0	0	0
						1044	1054	0	0	0	0
						960	985	0	0	0	0
						1336	1305	0	0	0	0
						1203	1195	0	0	0	0
						1096	1108	0	0	0	0
						1012	1039	0	0	0	0
								0	0	0	0
								0	0	0	0
								0	0	0	0
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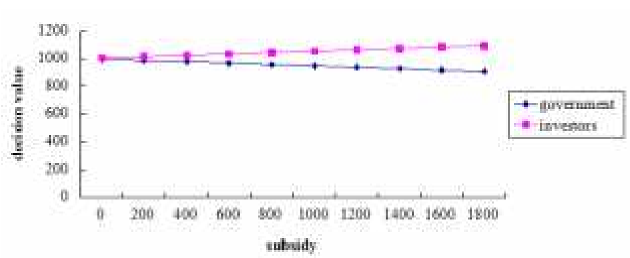

Fig 7 The change of the initial decision values at scenario 0

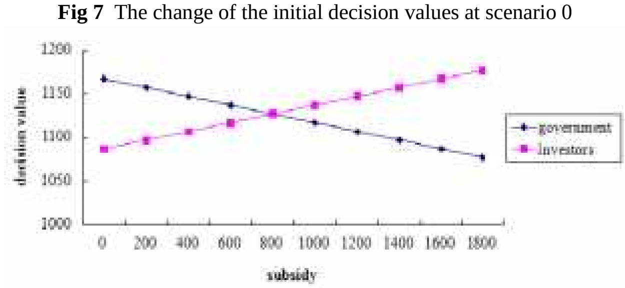

Fig 8 The change of the initial decision values at scenario 1

If people exploit the by-products such as xylitol and pure lignin in cellulosic ethanol project, reducing subsidy will not affect the decision values too much. But if there exists no by-product, government and investors will not invest immediately. These decision values can be calculated as Table 8 shown. Thus reducing subsidy will ease the loss of government and cut down the benefit of investors.

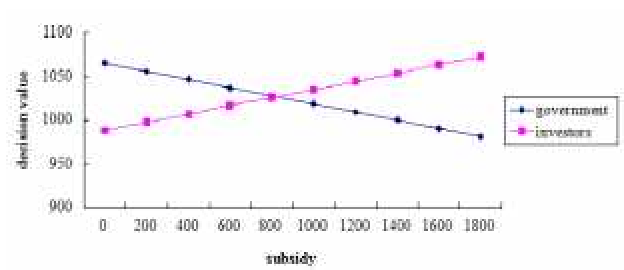

Fig 9 The change of the initial decision values at scenario 2

Hence, enhancing subsidy is good for the promotion of renewable energy investment. The result seems similarly in the reality.

Table 8 The initial decision values with no by-product (million yuan)

	$s = 800 \quad a = 0.5$		$s = 0 \quad a = 0.5$	
	government	**investors**	**government**	**investors**
scenario 0	-110	-22	-70	-62
scenario 1	158	151	187	122
scenario 2	91	84	119	60

Varying the ratio of stage-1 construction cost

According to the value functions at each scenario, the ratio of stage-1 construction cost a shows that the capital expenditure profile will affect the decision values. Fig 10 and Fig 11 present the changes of the initial decision values under government and investors perspectives with subsidy $s = 800$. These two pictures show a similar phenomenon. For both government and investors in 2015, with the ratio of stage-1 construction cost increasing, the initial decision value decreases at scenario 0, increases at scenario 1 and decreases at scenario 2. But the variation is more significant to the investors than to the government. Thus, the capital expenditure profile gives more risk to investors.

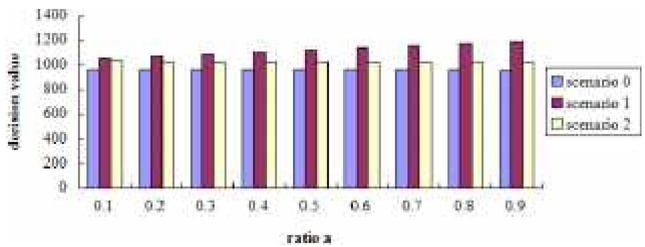

Fig 10 The change of the initial decision values under government perspective with s=800

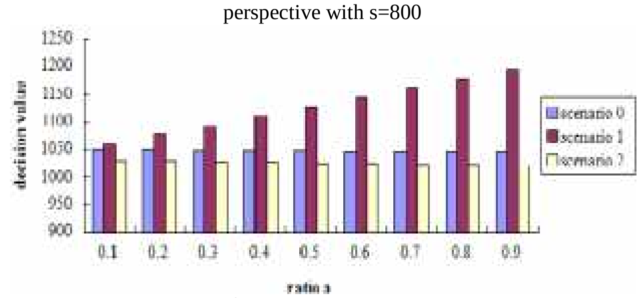

Fig 11 The change of the initial decision values under investors perspective with s=800

If there does not exist any by-products in the cellulosic ethanol process, the varying ratio of stage-1 construction cost shows more influence to the initial decision value at scenario 1 than other scenarios under two perspectives in Fig 12 and Fig 13. At this case, the capital expenditure profile indicates more risk to both government and investors. Meanwhile, no matter how the ratio changes, improving the technology of cellulosic ethanol and finding high value by-product are the effective ways to enhance the benefit.

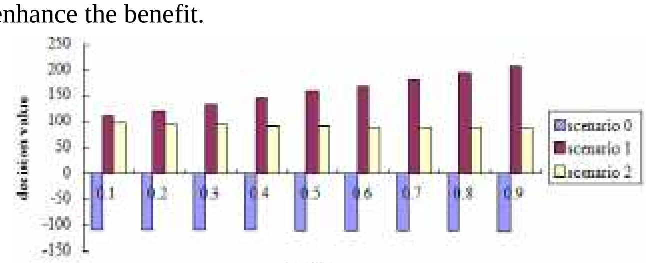

Fig 12 The change of the initial decision values under government perspective with no by-product and s=800

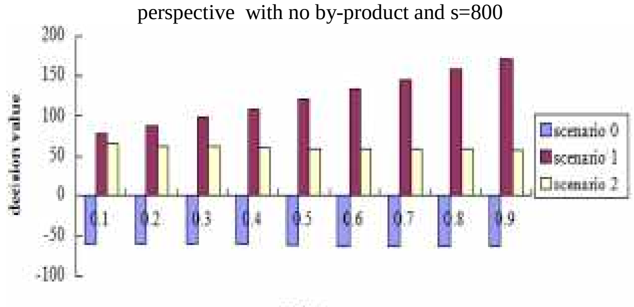

Fig 13 The change of the initial decision values under investors perspective with no by-product and s=800

CONCLUSIONS

Using real option analysis, this paper establishes a multistage evaluation model for cellulosic ethanol investment under government and investors perspectives. Firstly, at the current subsidy level, if the stage-1 construction has been completed, both government and investors can get more revenues, although the government must pay the carbon emission cost and subsidy. Secondly, because of the by-products, the initial decision value at each scenario is positive. With the subsidy increasing, the initial decision value decreases under government perspective but increases under investors perspective. And the two decision value curves intersect at subsidy 800 yuan. Thirdly, adding the stage-1 construction cost can enhance the initial decision value of the cellulosic ethanol project, and it gives more influence to investors. At last, if there exits no by-product, the initial decision values are negative if two construction stages are completed immediately for both government and investors. Meanwhile, the value increases obviously if only the stage-1 construction is completed. Thus, reducing subsidy can ease the loss of the government and cut down the benefit of the investors. Improving the technology to find more high value by-products is the effective way to enhance the revenues of cellulosic ethanol plant.

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