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A methodology for valuing water option contract of Eastern Rout of South-to-North Water Transfer

Abstract: We consider water option contracts issued by water users along Eastern Rout of South-to-North Water Transfer that can be exercised many times during its lifespan as a new method of water resources allocation, which can increase the value of water resources. According to the fact of Eastern Rout, we construct a system for water option exchange, establish a stochastic model to determine water prices based on stochastic models of supply and demand, and simulate the process of this stochastic water price. We use dynamic programming method to value water option contract from the point of view of a water user, and describe the optimal exercise strategy. Our conclusion indicates that, in a deregulated market of Eastern Rout of South-to-North Water Transfer, water option contracts can help alleviate water supply problems associated with spikes of price and demand and reduce the cost of water resources allocation.

Keywords: Eastern Rout of South-to-North Water Transfer, Water option contract, Cost plus formulation, Dynamic programming

1. Introduction

Eastern Route (ER) of South to North Water Transfer project (SNWT) plays an important role in solving serious water shortage and optimizing allocation of water resources in northern China. It’s a complex system with multi-basin, multi-water source and multi –objective, which involves five provinces and links the Yangtse River, Huai River, Yellow River and Hai River. SNWT has functions of water supply, flood prevention, drainage discharge and water transportation.

How to allocate water resources rationally has become an urgent problem to be solved. At present, the allocation and management of water resources in China are deficient, for instance: ① The traditional allocation of water resources merely aimed at optimizing the profit of technology and economy, which ignored communication and coordination; ② The traditional water supply and demand was ruled by government rigidity, it may cause failure of market and government; ③ The traditional mechanism of water pricing and allocating could not adapt to the fast development of the society, economy, ecology and environment. It has been proved on both practical and theory aspect that it’s important to change the traditional ways for allocating water resources, and develop a new one in SNWT.

The broad application of option contract greatly optimized the allocation of its resources. In October, 1984, Central America Commodity Exchange, Kansas Futures Exchange and Minneapolis Grain Exchange in America took the lead in applying wheat option transactions, which play an important role on America’s global dominant of wheat market. In New York Cotton Exchange, the cotton option can stabilize the produce of cotton and avoid the risk of cotton price. It has become a new tool for managing risk. The option for electricity in Atalanta has optimized the allocation of electric resources, solved the dilemma among supply and demand, and avoided the risk in spot market. In addition, the option contracts are also introduced for aluminum, copper, soy, corn and rubber. All of these successful cases indicate that it’s feasible to apply option contract into water resources as a new method for water resources allocation in SNWT.

Allocating water resources based on water option contracts in SNWT will make the water right transaction more convenient, more feasible and will reduce the risk of water right transfer, reduce the cost of water resources allocation; also it can resolve problems that traditional theories and method solved hardly: Firstly, option contract can achieve “communication and coordination” perfectly, which makes the whole water resources system to be in the equilibrium of " double win". Secondly, the supply and demand of water are affected by many uncertain factors, such as rainfall, evaporation, economy, society and so on. The option contract for water can avoid the risk of water resources allocation and increase the reliability of water supply in dry years. Thirdly, option contract for water provide maximum flexibility in responding to the uncertain conditions. After paying premium, the buyer has a right to buy water, rather than an obligation. Fourthly, water option contract can reduce the cost for allocation. The premium the buyer paid for water option in option market is much less than the payment for water in spot market. At last, in order to satisfy the water demand in dry years, the option holder can only buy water options, rather than build reservoir to storage abundant water, which will need much money.

In this paper, we establish scientific model for pricing water and water option. The theoretical results here will, I hope, inform decision-makers in water-received areas along ER of SNWT when and how to allocate these water resources more flexibly.

2. Water allocation and transfer mechanisms based on water option contract

2.1 water option contract of ER of SNWT

Water option contract is a standard contract or agreement, with which the option holder has a right to buy some water from the seller by a fixed price and on a fixed time in the future. The option buyer only has a right of using water resources, and he can get the real water resources by exercising his option. The seller has an obligation to offer some water which is fixed in the option contract when the buyer requires exercising the option. In order to have this right, the option buyer should pay some money to the seller, which calls premium.

According to the domestic and abroad option theories and practice, and the fact of ER of SNWT, we introduce multiple-exercise option contract (also named Drought Water Option Contract), which can avoid the risk of water price, increase the reliability of water supply, reduce the cost of water allocation and improve the value of water resources. This multiple-exercise option is an European call option, which is more exotic option than financial exotic option. Just as its name, multiple-exercise option can be exercised more than one time during the life of option contract. It means in a given time of m, the option can be exercise no more than $\overline{R}$ times, m> $\overline{R}$ >0. The strike price for each period must be specified in advance in the contract. The holder of an option have right to exercise the option or not per period, up to $\overline{R}$ times in m periods. If the price is S_t in spot market, and the strike price in contract is K, the payoff from exercising the option today equal to the difference between S_t and K while the payoff from exercising in later periods in uncertain. In contrast, forgoing use of the option today earns the option holder zero monetary reward in the future. After the contract expires at the end of period m, however, any exercises of the option that remain unused are worth nothing. From this point of view, a new method should be introduced to value water option contract.

Suppose that every water user of ER of SNWT obtains the initial water right, and they can sell or buy water right with each other in water option exchange. Through paying premium, the option buyer can obtain a right to buy some water from the seller by a fixed price and on a fixed time in the future, rather than the obligation. If the option buyer is shot of water indeed, he can exercise the option. And the seller has the obligation to sell some water to he option holder. If the option buyer's water is in abundance, he can give up exercising this option, and the seller can get a return of option premium.

2.2 A framework of water allocation mechanism with option contract of ER of SNWT

Eastern Route of South-to -North Water Transfer is an open, complex and large-scale system with multi-basin, multi-source and multi –objective, in which it is difficult to achieve optimization of water resources allocation and management. It is also very difficult to coordinate the water demand and supply of every drainage basin along ER. Therefore, we introduce option contract to allocate the water resources in water market, avoid the risk of uncertainty caused by water supply and demand, then improve the whole efficiency of water resource allocation. The framework of water allocation mechanism based on option contract is as follows:

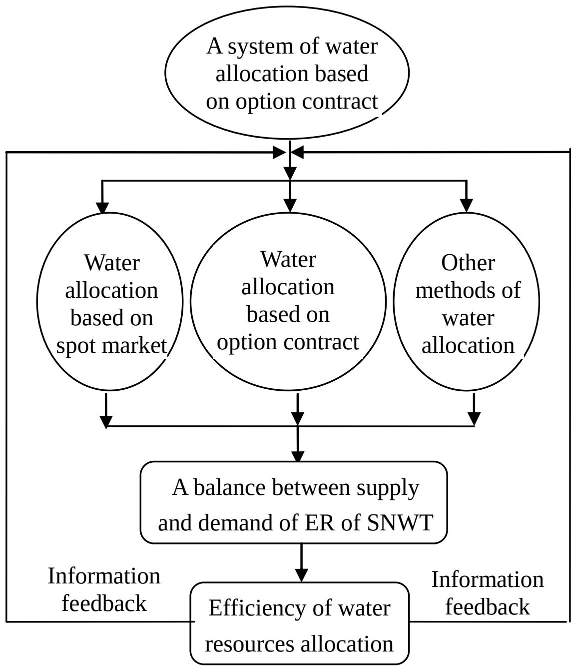

Figure 1 A framework of water allocation mechanism based on option contract

In consideration of ER crossing many provinces, we establish a water option exchange of ER and seven sub-water option exchanges in different drainage areas. They can share information through internet real-time and the sun-water option exchanges of drainage areas are controlled by the water option exchange of eastern route which is in charge of whole eastern route coordination. The water option exchange of eastern route is with responsibility for water exchange between drainage areas, while the water option exchanges of drainage areas are with responsibility for exchanges in each drainage area. See figure 2, a framework of water option exchange mechanism. Here, we only consider the exchange of option in one drainage area.

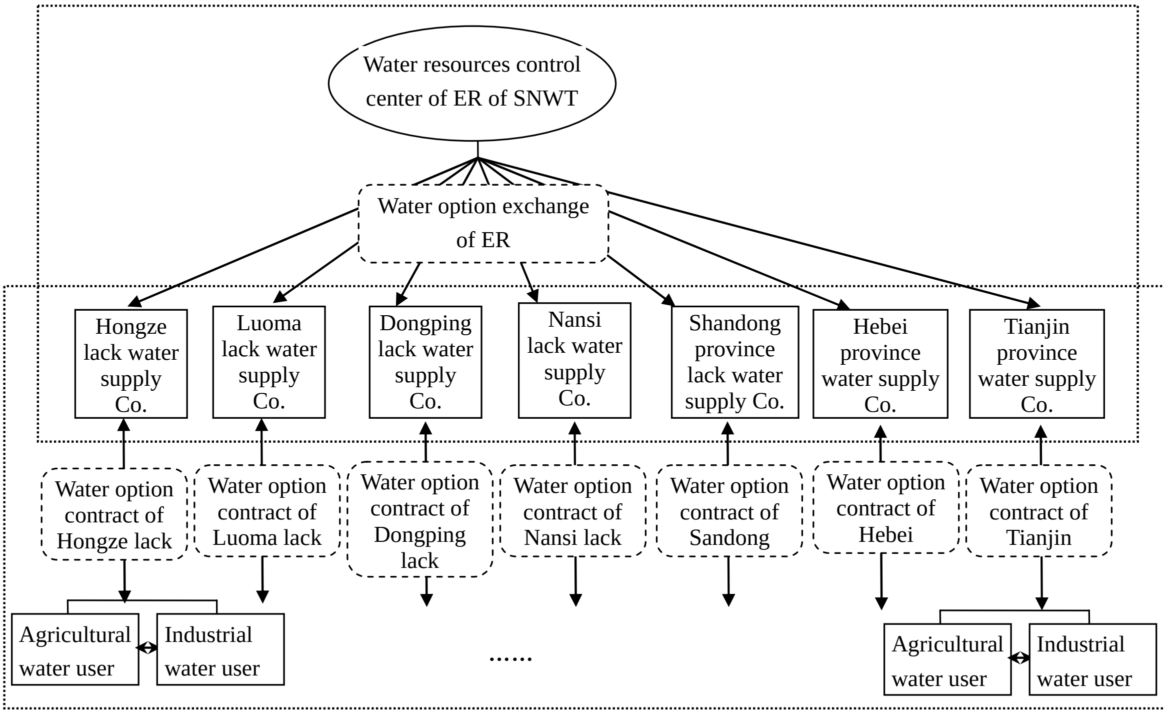

Table 2　A framework of water option exchange mechanism

We can divide water resources of ER into four types by using purpose: agricultural water, industrial water, domestic water and environmental water, among which, Water requirement of the last two types is less and also more stable than others. While the requirement of agriculture and industry is large (about 70% of the whole water demand), and it also changes greatly, which increases the difficulty of water allocation of the ER. Therefore, this paper mainly aims at the allocation of water for industry and agriculture based on water option.

3.water pricing model for ER of SNWT

Along with the development of water market, water pricing will become the key problem of water exchange. A reasonable water price will play an important role on promoting water right transfer and saving transaction cost. However, in china, water price is only based on its cost and profit rather than its supply and demand which affect water price greatly in water market. In this paper, we analyze the factors influencing water supply and demand along ER of SNWT and improve the traditional water pricing model. We establish a new reasonable model for pricing water in water market by the method of cost plus, which will establish a solid foundation of the research on improving water supply assurance.

3.1 Factors influencing water price

(1) The price of water diverted from ER of SNWT ($P_{S\text{-}N}$)

ER of SNWT project pumps water from the lower reach of Yangtze River, with mean annual water of 956 million m3 entering sea, and more than 600 billion m3 even in extreme dry year. Therefore, ERP will have enough water to be pumped north, and the water quantity to be diverted is based on the scale of ERP. However, the quantity of water depended on the scale of ERP can satisfy the demand of water users along ERP. $P_{S\text{-}N}$ is affected by the investment of project, depreciation of fixed assets, lending rate, and the charge of pumping station etc. Therefore, we can assume $P_{S\text{-}N}$ isn't followed stochastic process.

(2) Local water resources (Q_L) and its price (P_L)

The local water resources include available rainfall, ground water, surface water and reclaimed water. The water and surface water are affected by evaporation, water storage equipment, and so on, which is the average of multi-year ground water and surface water in this paper, and they can be seen as constants. Reclaimed water is affected by the technology of sewage treatment, the investment of treatment equipment, and so on. It also can be assumed as a constant during a certain period. Rainfall is a main factor affecting Q_L, which is stochastic and volatile. Generally speaking, the less the rainfall is, the higher the water price will become. Finally, PL is often determined by government, water quality and the development level of society and economy etc. which are also can be assumed as a constant during a certain period.

(3) Industrial, agricultural, domestic and environmental water（D_i，D_a，D_d，D_e）

Industrial water is less influenced by seasons, which changes little from one month to another. While agricultural production in china grows in natural environment, which depends on rainfall seriously. The uncertainty of rainfall leads to the uncertainty of agricultural water. Also the majority of water used for agriculture can not be reclaimed, so agricultural water should be satisfied by not only natural precipitation, but also the surface water, the ground water and diverted water. From these causes, the agricultural water is volatile. Furthermore, in china, the types of crop are influenced seriously by seasons. The quantity of water for crops is larger in summer and autumn than other seasons, which causes water shortage in these two seasons frequently. In winter and spring, local water can satisfy the industrial and agricultural water as a rule. Thereby, we mainly research on the water supply and demand of ER on July, August, September and October, and we introduce water option contract to avoid the risk of water shortage in these four monthly every year. Industrial and urban domestic water are affected by the development level of economy and society, urban population, and so on. According to the rule of water market, the larger water demand is, the higher water price will be.

It can be seen from the above analysis that the difference between supply and demand will effect greatly on water price. The larger the difference is, the higher the water price is.

3.2 The balance relationship between supply and demand in drainage areas along ER

Based on the research of special characteristics of water allocation in water-received areas along ERP, we conclude some balance relationship between supply and demand as follows:

① Local water resources= available rainfall＋available surface water＋available ground water＋reclaimed water

② Drainage area water resources＝available rainfall＋available surface water＋available ground water＋reclaimed water＋water diverted from ER

The loss of water resources in drainage area here includes the water flowing into sea, infiltrating into ground, evaporation, and so on. We assume it can be substituted by the loss of rainfall:

Loss of water resources in drainage area = k* rainfall $0 < k < 1$.

③ The supply of water resources in drainage area = agricultural water demand +environmental water demand + industrial water demand + domestic water demand + loss of water resources

3.3 Cost plus model

The method of cost plus formulation can be used here for water price as a result of characteristics of water resources in china, the supply and demand is considered the most important factor effecting on water price. In water-received area, industrial and urban domestic water is from both local and diverted water, through analysis of local water price and diverted water price, the water price of received area can be computed by the Cost plus formulation:

① If local water resources can satisfy water demand($D_e + D_a + D_i + D_d \le Q_L$):

$$P = P_L(1+c) \tag{1}$$

② If industrial and agricultural water are from both local water and diverted water($Q_L < D_e + D_a + D_i + D_d$):

$$P = \frac{[Q_L * P_L + (D_a + D_e + D_d + D_i - Q_L) * P_{S-N}](1+c)}{D_a + D_e + D_u + D_d} \tag{2}$$

Here $Q_L = Q_r(1-k) + Q_s + Q_g + Q_m$

Notation:

P : price on cost plus of industrial and urban domestic water in drainage area;

P_{S-N} : price of water diverted from ER; Q_L : Local water resources;

P_L : price of local water; D_e : environmental water demand;

D_a : agricultural water demand; D_d: domestic water demand;

D_i : industrial water demand; k : ratio of rainfall loss, 0<k<1;

Q_r : Rainfall in water-received area; c : Profit ratio

Q_s : initial surface water Q_g: Initial ground water

Q_m : Reclaimed water

According to the analysis above, agriculture and industry is often short of water in summer and autumn because of its large water demand. Therefore, we mainly research on water pricing method in July, August, September and October to avoid water shortage in these months.

3.4 Water price simulating

We take the Xuzhou which is a city along ER as an example to simulate its water prices in July, August, September and October using the model we have mentioned above,

Xuzhou is in the north of Jiangsu province, which is Neighboring with Shandong province. This city is short of water seriously, and it will be one of the water users from ER of SNWT. At present, in this city, we assume that local water price is 2.3 yuan/ton ($P_L = 2.3\text{yuan/ton}$), and the price of water diverted from SNWT is 4.23 yuan/ton ($P_L = 4.23\text{yuan/ton}$). Using the data of water supply and demand in July, August, September and October from 1994 to 2004 and the formulation (1),(2),(3), we can get the following water price.

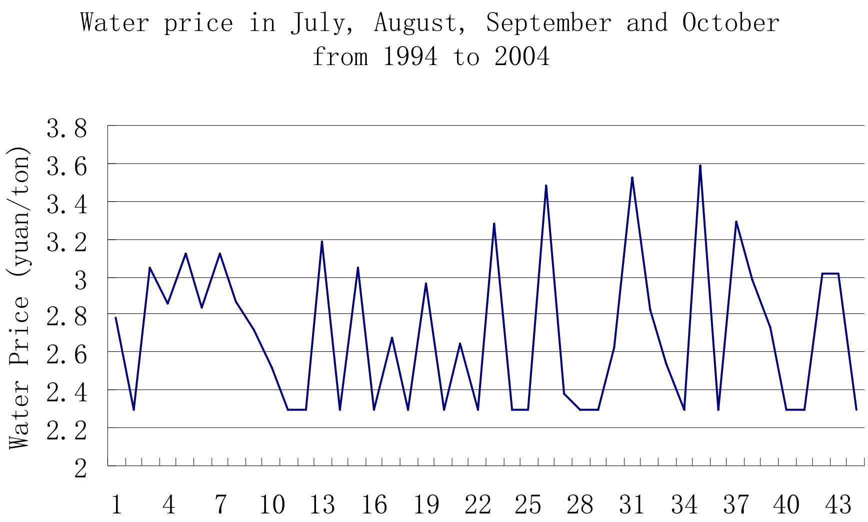

Figure 3 water price in July, August, September and October from 1994 to 2004

Variance ratio tests are a prominent empirical approach for detecting predictability over time in a dataset. Researchers have applied variance ratio tests to assess whether stock prices follow a random walk or exhibit mean reversion; Lo and MacKinlay (1999) use financial data form the U.S. while Grieb and Reyes (1999) focus on Mexico and Brazil. Faust (1992) examines variance ratio tests and concludes that they are generally the best method for detecting mean reversion. I rejected the null hypothesis of random walk with 95% confidence when the statistic's value was outside the interval [-1.96, 1.96]. According to the water price data of Xuzhou, I get the statistic's value was -3.67, which strongly implied that monthly water price of

Xuzhou don't fit the random walk model and it exhibit mean reversion. Next , we should calculate mean-reverting price and reversion speed.

In modeling the mean reverting process for water price, I use the Ornstein-Uhlenbeck process employed by Schwartz (1997) and Dixit and Pindyck (1994). In this simple process the long-run price of water tends toward some specific level, rather than fluctuating as unpredictably as a random walk. The Markov property is preserved by this process; tomorrow's price depends on today's price and a parameter $\overline{P}$. If the speed of reversion is denoted η , the contimuous-time Ornstein-Uhlenbeck is:

$$dP=\eta(\overline{P}-P)dt+\sigma dP \tag{4}$$

The discrete version of this process is equation (4), reprinted here for convenience:

$$P_{t+1}-P_t=\overline{P}(1-e^{-\eta})+(e^{-\eta}-1)P_t+\varepsilon_{t+1} \tag{5}$$

$$E[P_t]=\overline{P}+(P_0-\overline{P})e^{-\eta t} \tag{6}$$

$$Var[P_t-\overline{P}]=\frac{\sigma^2}{2\eta}(1-e^{-2\eta t}) \tag{7}$$

Here, the current price of water is P_0. The discrete form of the process can be estimated by OLS regression:

$$P_t-P_{t-1}=\alpha+\beta P_t+\varepsilon_t \tag{8}$$

Regression coefficients, then, determine the mean-reverting process parameters:

$$\overline{P}=\frac{-\hat{\alpha}}{\hat{\beta}} \qquad \hat{\eta}=-\ln(1+\hat{\beta}) \tag{9}$$

The regression also enables me to estimate the standard deviation of the stochastic component of the price process (ε), which is equal to the standard error of the regression.

I use the water price data of Xuzhou I generated to estimate the mean-reverting price and speed of reversion. A simple Matlab programming should be established according to the formulation above. Parameter estimation revealed reversion speed of 1.92 and long-run mean-reverting level of 2.71, the standard deviation of the stochastic component of the price process $\varepsilon = 0.42$.

4.Model for valuing water option of ER of SNWT

Option contracts for water are far more complicated than the comfortingly simple vanilla options. In some respects these water options are also more complex than the exotic options. The water price exhibit mean reversion rather than follow random walk, so we can't use Black-Scholes formulation to value water option, which demand price of underlying asset follows a geometric Brownian motion process. Therefore, we should find a new method to value water option.

Here I describe my dynamic programming method for valuing multiple-use options. I characterize the multiple-exercise option as a finite-horizon, stochastic dynamic programming problem with discrete and finite state and actions spaces and discrete time periods. I then give an overview of the numerical techniques I use to approximate the dynamic programming problem's solution. Dixit and Pindyck (1994) present dynamic programming as an analytical approach for valuing "real options", or investment opportunities. Their method is simply standard theory cast in a framework of investment decision-making with uncertainty and irreversibility. The model allows for finite or infinite planning horizons, facilitates both discrete-time and continuous-time analysis, and accommodates a range of stochastic processes that may drive uncertainty.

Translating this multiple-exercise option pricing problem into a standard dynamic programming formulation requires one control variable and two state variables. The control variable, x_t,presents the decision of whether to strike ($x_t = 1$) or hold ($x_t = 0$) in the current time period. The two states are P_t, the price of water in the current period, and R_t, the number of option exercises left in the contract. More formally,

$$P_t \in S_1 = [\tilde{P}, \hat{P}]$$
$$R_t = S_2 = \{0,1,2,\cdots,\overline{R}\}$$
$$x_t \in \chi = \{0,1\}$$
$$t \in \{0,1,2,\cdots,m\}$$

Here, $\tilde{P}$ and $\hat{P}$ are lower and upper limits respectively on the log price, parameters of the problem. Note that since the option cann't be used after the maximum number of exercises is attained. $x_t = 0$ necessarily when $R_t = 0$.

The state variables both change from period to period but their dynamics are quite distinct. The number of exercises remaining decreases whenever the option buyer strikes, evolving according to:

$$R_{t+1} = R_t - x_t \tag{10}$$

The state equation that describes the price path for water is more complicated, an Ornstein-Uhlenbeck mean-reverting process:

$$dP = \eta(\overline{P} - P)dt + \sigma dP \tag{11}$$

With η and $\overline{P}$ denoting the speed of reversion and mean-reverting price level. These parameters are estimated from price data.

The objective is to maximize, over the life of the contract, the present value of the sum of expected returns from the option by making the optimal decision each period regarding whether or not exercise,

$$\max_{x\in\{0,1\}} \sum_{t=0}^{T} \left(\frac{1}{1+r}\right)^r x_t (P_t - K)^+ \tag{12}$$

Subject to the state equations above, non-negativity of P, K, and R, and the following constraint:

$$\sum_{t=0}^{m} x_t \le \overline{R} \tag{13}$$

In a given period the reward function is a function of the two state variables, asset price, and number of uses remaining:

$$f(x_t, P_t) = x_t (P_t - K)^+ \tag{14}$$

For this problem the value function $V_t(P_t, R_t)$ is the value of the option at time t if the price of water is P_t and there are R_t uses of the call remaining. The value function must satisfy Bellman's equation, balancing the immediate payoff from exercising the option against the present value of expected payoffs from using the option in future periods:

$$V_t(P_t, R_t) = \max_{x\in\{0,1\}} \{x_t (P_t - K)^+ + \frac{1}{1+r} E[V_{t+1}(P_{t+1}, R_{t+1})]\} \tag{15}$$

The boundary condition needed to solve the dynamic programming problem arises from the terms of the option contract since the value function equals zero with certainty for t>m:

$$V_t(P_t, R_t) = 0 \qquad t > m \tag{16}$$

Using the Xuzhou water price dataset to compute the price process parameters completes the set of parameter inputs for mean reversion for the multiple-exercise option valuation program. The base case parameters are listed in table 4.

Parameter	Description	Value
xbar	Mean-reverting price	2.71
eta	Speed of reversion	1.92
r	Annual interest rate	0.05
mu	Mean of price shock distribution	0
sigma	Standard deviation of shocks	0.42
T	Lifespan of option (years)	10
Rmax	Maximum number of strikes	5
k	Strike price	2.6
n	Discretization points for price	500
a	Minimum price	2.30
b	Maximum price	4.23

Table 4 Parameter Values for Base Case Analysis of Xuzhou Under Mean Reversion

Parameters a and b are taken from Xuzhou; T and Rmax come from the option contract; xba, reta and sigma are calculated by the formulations above. The mean of the price shocks is zero. I computed the distribution’s standard deviation as described earlier, with a result of 0.42. Here. assuming two water users agreed with a water option contract with ten years lifespan, five maximum strike times and 2.6 yuan per ton strike price.

A matlab programming is established to realize the formulations (10)～(16). After input the parameters above, we can get the following option value:

Water price（yuan/ton）	Value in initial period（yuan）
2.3	1.56
2.47	1.57
2.6	1.58
2.92	1.76
3.83	2.75

Table 5 Option Contract Values for Base Case Xuzhou data, Under Mean Reversion

As table 5 shows, the value of a 5/10 option contract at its initiation depends on the price of water at that time. The mean-reverting price process causes price level to fall toward 2.71 yuan when the starting price is high, and causes the price level to rise toward 2.71 yuan when the starting water price is low. For a low initial price, roughly 2.3 yuan per ton for instance, the buyer expects water prices to rise toward 2.71 yuan then level off. He will not exercise the option until mean reversion has polled water price above 2.6 yuan. The value of the 5/10 option contract for a starting price of 2.3 yuan is 1.56 yuan.

When the starting price of water is above the mean-reverting level, the option buyer expects the mean-reverting process to force prices to fall and to eventually hover around the mean-reverting price. In this case the buyer will strike quickly to take advantage of temporarily elevated prices and large payoff to exercising the option. When the initial price of water is near 3.83, for example, the 5/10 option contract’s value is 2.75 yuan.

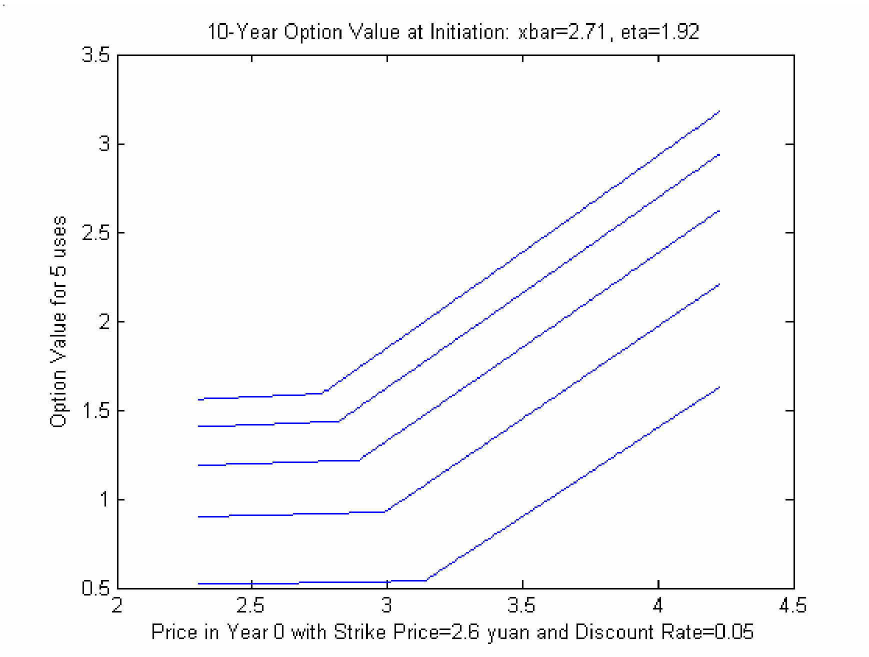

Figure 6 Baseline option contract values under mean reversion

Using the base case parameters of table 4, I compared the value of the 5/10 option with the value of option contracts with fewer than five strikes in ten years. In figure 6 the five lines correspond to the value of the option contract, as assessed in the initial time period, when the option has one to five strikes. The lowest line on the graph represents one strike available in ten years; the highest line shows contract values for five uses. As expected, additional strikes add value to the option contract; notice that contract value rises as the umber of exercises increases for any given initial price for water. The marginal value of additional strikes decreases rapidly then becomes almost constant. Again this is due to the mean-reverting process: in time periods after the price approaches the mean-reverting level, the undiscounted expected payoff from exercising the option is small.

5.Steps for water option transaction of ER of SNWT

In order to make up the insufficiency of spot water market , avoid the risk of water supply and optimize water allocation, we introduce water option contract transaction, the proceeding for which includes the following three steps:

(1) Preparation

1) Both option buyer and seller collect all information for transaction, forecast the trend of water price in the future, and choose his broker.

2) buyers of the call option and sellers of the put option should entrust broker to provide the explanation of water using purpose and the testify of water eligibility. This term can protect entironment and protect water from polluting, which can avoid pollution and waste when using water resources.

3) sellers of the call option and buyers of the put option is an individual or organization who have the water right in law, and he should provide water using license before water option transaction, which can reduce the risk in this transaction.

(2) Asking for water option contract

When an individual contacts a broker to buy or sell a water option, the broker relays the order to the floor broker in the exchange on which the option trads, the floor broker should operation according to this transaction order.

(3) Making the option contract valid

If a water option is valid, it should be checked by water option exchange and balance with option clearing corporation. After balance with option clearing corporation, the buyer of water option contract should pay premium immediately, and the option seller also should deposit margin into margin account immediately.

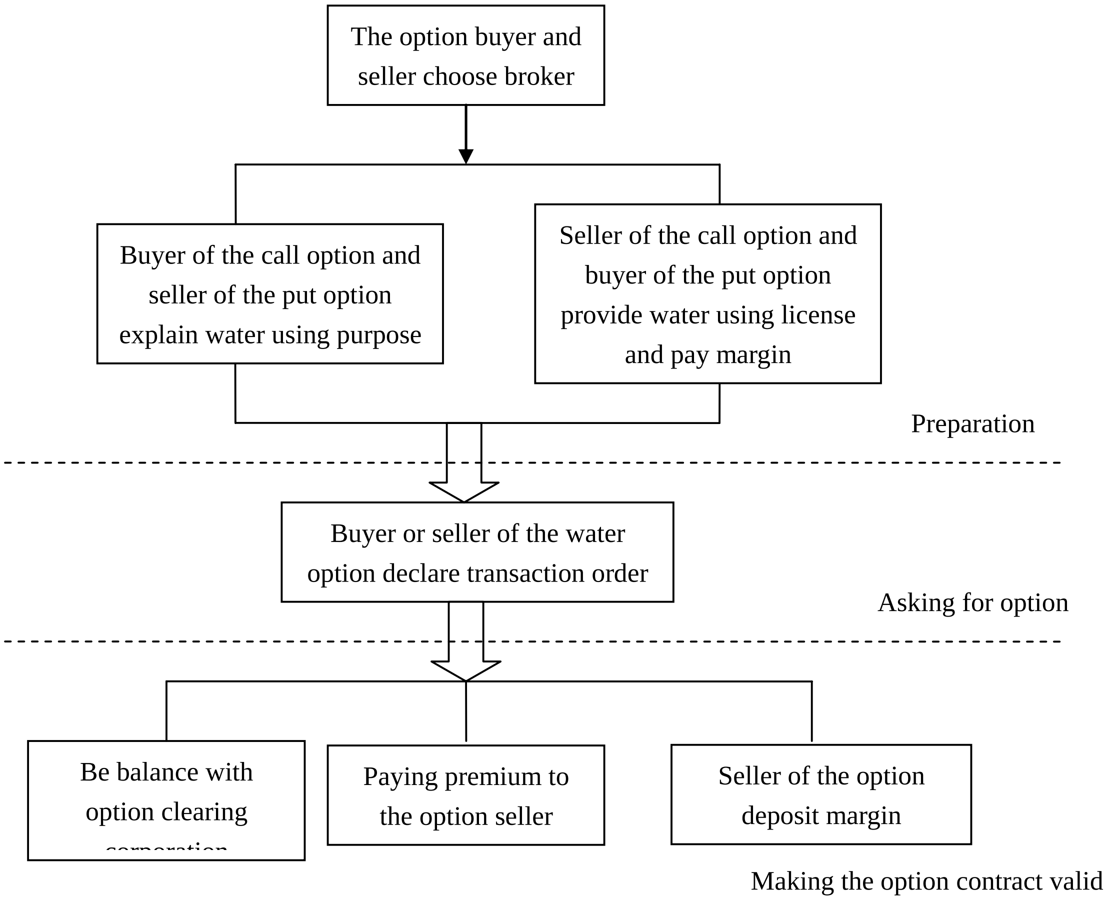

Figure 5 Steps for water option transaction of ER of SNWT

6. Conclution

According to the theory of finance engineering, we present "water option contract" for allocating water resources in received-water area along ER of SEWT. According to the fact of Eastern Rout, we construct a mechanism for water option exchange, establish a stochastic model to determine water prices based on stochastic models of supply and demand, and simulate the process of this stochastic water price. We use dynamic programming method to value water option contract from the point of view of a water user, and describe the optimal exercise strategy. Through the case study of Xuzhou, this method is proved to be feasible and effective. The theoretical we present here, I hope, inform decision-makers in water-scarce areas when and how to use this precious resources, give a guidance of how to allocate water resources between water diverted from South-to-East water diversion project and local water resources. This paper only devised an innovative idea of how to allocating water resources of SNWT, we will still work on water option contract in practice.

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Note:

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