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A Real-Option Approach on Energy Security Appraisal

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Abstract – *The traditional energy portfolio decision-making depends greatly on the costs of energies. However, the cost-based view of energy security would incur huge risks when the volatility of energy price dramatically increases. In addition, many scholars have dealt the risk-return problem with CAPM model. The mean-variance model considered the tradeoff between risk and return in energy portfolios and treated the energy sources such as nuclear and wind power as risk-free. Different from the previous research, in this paper we adopted a real-option approach on energy security appraisal. Beyond the risk-return tradeoff, this research takes time and price factors into consideration and thus can evaluate the effect of new energy research and development on energy security.*

Keywords – Energy security, real option, CAPM, dependency index, vulnerability index

1. INTRODUCTION

Since the energy crisis in the 1970's, most countries have recognized the important role of a stable energy supply in consumption, economic development, and state safety. Following the evolution of environment, technology, and concept of sustainable development, the energy policies focusing on uncertainty control have resulted in many different indexes about energy security.

In twentieth century, the major goal of energy security falls on the stability of energy supply which includes two dimensions. The first is energy price. Since market price change would lead to cost uncertainty of energy supply, the solutions would be increasing energy conservation, long term contract, or hedge with future trade. The second is the quantity of energy supply. Regional suppliers usually limit energy supply. To deal with such incidence, one can access different energy sources, invest in foreign oil well, increase native supply ratio, or demand control. According to these, the main energy security indexes on the quantity and sources of energy would be energy dependency and vulnerability indices [1], [2].

For the last decade, the concept about sustainable development has evolved rapidly with consideration of limited resources. The 2002 World Summit on Sustainable Development appraised sustained energy utility as one of the most important issues and many countries have build sustainable energy evaluation systems to estimate the performance of sustainable energy development and offer adequate energy policies. Besides the indexes mentioned above, since the leading threats to energy security is the significant increase in energy prices, the traditional energy matrix evaluation had focused on hoe to find the most cheap energy supply. They applied portfolio theory to reflect energy security, involving kinds of energy prices and variance-covariance matrix to estimate energy security [3].

The environmental benefits of renewable energy technologies are widely recognized, but the contribution that they can make to energy security is less well known. Renewable technologies can enhance energy security in electricity generation, heat supply, and transportation [4].

2. TRADITIONAL INDEXES ON ENERGY SECURITY

Indexes on energy supply

In the traditional energy supply indexes, dependency index is defined as the ratio of import energy, which stands for the dependence level of a nation to different sources or types of energy. In Taiwan, the import energy dependency was 95.92% in 1996 and 97.85% in 2005, which indicates the emergency of the demand on renewable energy as a self-owned energy source.

Compared with dependency index, the supply indexes of vulnerability may offer more information about energy security [1], which includes diversification and concentration index. The most popular diversification index is Shannon-Weiner index (SW index):

$$SW = -\sum_{i=1}^{n} X_i \ln X_i \tag{1}$$

X_i denotes the ratio of energy import from nation i divided by total import amount. Taking political stability $(b_i)^2$into consideration, the SW index will be:

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[2] Generally, we adopt "Worldwide Governance Indicators" issued by World Bank as the political stability index.

$$SW_1 = -\sum_{i=1}^{n} (X_i \ln X_i) b_i \quad (2)$$

Involving the native supply ratio (g)[3], we can modify SW index as:

$$SW_2 = -\sum_{i=1}^{n} [(X_i \ln X_i) b_i](1+g) \quad (3)$$

The SW index will change with measurement scope, calculating by countries and areas may get significant different results [5]. Besides, the political stability index would affected closely by regime switch and make it not appropriate on long term policy appraisal. Therefore, Jansen *et al.* [6] substitute political stability index with Human Development Index (HDI)[4] and add energy exhaustive index[5] of energy source area to estimate long term energy security index for policy making.

In concentration index, International Energy Agency (IEA) referenced the idea from Herfindahl-Hirschman industry concentration index and designed the Geopolitical Market Concentration Index (GMC) to judge whether the energy supply sources is diversified enough.

$$GMC = \sum_{i=1}^{n} (X_i)^2 \quad (4)$$

X_i denotes the ratio of energy import from nation i divided by total import amount. Taking political stability (b_i), the GMC index would be:

$$GMC_1 = \sum_{i=1}^{n} (1-b_i)(X_i)^2 \quad (5)$$

These indexes mainly considered the energy security on energy supply but not considered energy demand, consumer preference, and risk attitude. The most limitation of such indexes falls on not dealing with price change, and thus, could not produce information about energy cost for policy maker.

3. APPLICATIONS OF MODERN PORTFOLIO THEORY

Modern portfolio theory proposed how rational investors optimize their portfolios by diversification investment and how to price a risky asset. The basic concepts of the theory include Markowitz diversification, the efficient frontier, capital asset pricing model (CAPM), the alpha and beta coefficients, the Capital Market Line (CML) and the Securities Market Line (SML) [7]. Since this model considered the risk adjusted value of assets in portfolio, [8], [9] had used Modern portfolio theory to build an evaluation framework in energy security with renewable energy.

Portfolio Theory

According to modern portfolio theory, an energy asset's return is a random variable, and an energy portfolio should be a weighted combination of energy assets so that the return of a portfolio is the weighted combination of the energy assets' returns. Moreover, a portfolio's return is a random variable, and consequently has an expected value and a variance. Energy risk, in this model, is the standard deviation of return. In general, expected return is:

$$E(R_p) = \sum_{i=1}^{n} w_i E(R_i) \quad (6)$$

Where R is return and w_i is the weighting of component energy asset i, and portfolio variance is:

$$\sigma_p^2 = \sum_{i=1}^{n}\sum_{j=1}^{n} w_i w_j \sigma_{ij} = \sum_{i=1}^{n}\sum_{j=1}^{n} w_i w_j \sigma_i \sigma_j \rho_{ij} \quad (7)$$

Energy portfolio volatility is:

$$\sigma_p = \sqrt{\sigma_p^2} \quad (8)$$

The sign ρ_{ij} in Equation 7 denotes the correlation coefficients of energies in portfolio, which are major factors about energy risk. In the two kinds of energy case in Figure 1, every possible energy asset combination were plotted in risk-return space, and the collection of all such possible energy portfolios defines a region in this space. The lines along the upper edge of relative regions are the minimized risk portfolios in different correlation coefficients. The end point A and B stand for specific return-risk level of energy asset A and B. The curves link A and B are minimum variance portfolios (MVP) of variant ratios in specific correlation coefficients, which is also called Markowitz Efficient Frontier.

For a given amount of risk, the energy portfolio lying on the efficient frontier represents the combination offering the best possible return. The region above the frontier is unachievable by holding risky energy assets alone. No portfolios can be constructed corresponding to the points in this region. Points below the frontier are suboptimal. A rational investor will hold a portfolio only on the frontier.

Capital market line (CML)

The capital market line (CML) is the line of expected return plotted against risk (standard deviation) that connects all portfolios that can be formed using a risky energy asset and a risk-free energy asset such as nuclear and wind power. It can be proven that it is a straight line and that it has the following equation.

$$E(R_C) = R_f + \sigma_C \frac{E(R_p) - R_f}{\sigma_p} \quad (9)$$

[3] Native supply ratio is native energy production divided by total energy consumption.

[4] The Human Development Index (HDI) is an index combining normalized measures of life expectancy, literacy, educational attainment, and GDP per capita for countries worldwide.

[5] Energy exhaustive index is the ratio energy mine already found divided by developed amount.

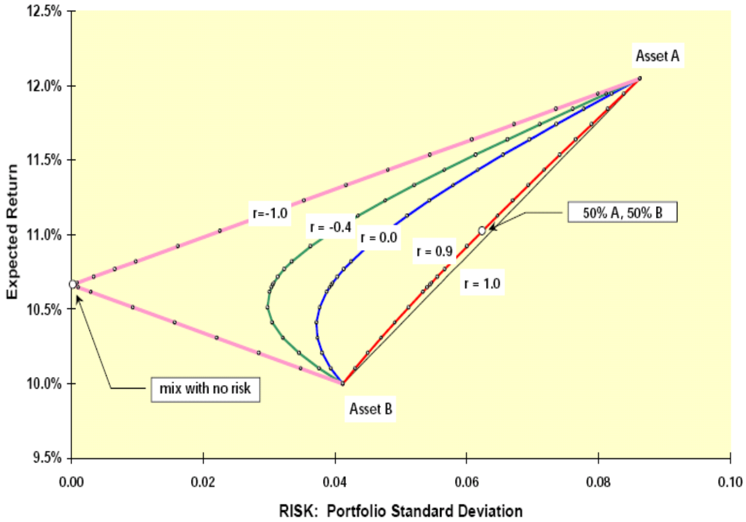

Fig. 1. Efficient Frontier for two-asset portfolio given different correlation coefficients [8].

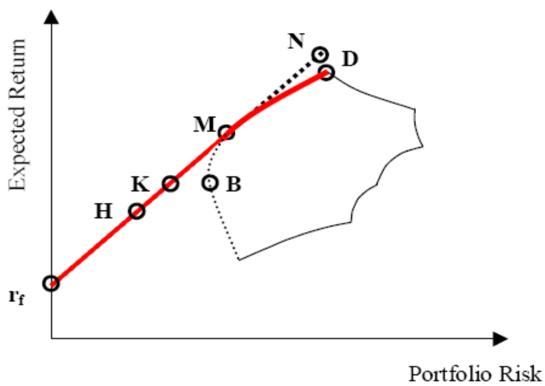

Fig. 2. CML of risk and risk-free energy portfolio [8].

In Equation 9, *P* is the risky portfolio, *f* is the risk-free portfolio, and *C* is a combination of portfolios *P* and *f*. R_f is the return of fix cost energy, $E(R_p)$ is the return of market energy portfolio, σ_C is risk of portfolio C, and σ_p is risk of market energy portfolio.

In energy portfolios, the market-trade traditional energies such as fuel, LNG, coal are risk assets for their price are variety with market demand and supply. And energies which are not trade in international market, like nuclear and renewable energy, could be risk-free assets assume that their unit costs are fixed.

According to Figure 2, the efficient frontier is curve DMB when there are only traditional energies in portfolio. If renewable energy is involved in the energy portfolio, the efficient frontier will expand to curve HMD. Comparing point K with B, the former with renewable energy in the energy portfolio will reduce risk under the same expected return in B with only traditional ones.

Recently, given the rapidly changing environment, sifting electricity planning from emphasis of evaluating alternative technologies to evaluating alternative generating portfolios and strategies is necessary. Mean-variance portfolio (MVP) theory seems to suite to the problem of planning and evaluating a nation's electricity portfolios and strategies. It is easy to find that in addition to its application in financial portfolio optimization, MVP has gradually been applied to energy issues, such as valuing offshore oil leases, energy planning [8], quantifying climate change mitigation risks [10], and optimizing real and derivative electricity trading options [11].

Nevertheless, owing to the theoretical assumptions, MVP is limited to estimate risk and return in a specific time period, and could not valuate portfolios in different time span, changes in marketable energy price and renewable energy cost. It is also hard to use MVP model to evaluate new energy techniques under research and development period.

4. REAL OPTIONS APPLICATION ON RENEWABLE ENERGY RESEARCH AND DEVELOPMENT VALUATION

Smit and Trigeorgis [12] used real options method to examine the value of investment opportunity in research and development when the future benefits are uncertain. Grenadier and Weiss [13] applied compound options model to measure research and development decisions of adopting a new technology immediately or waiting for the next generation's technological innovation.

In the energy arena, since the deregulation of energy market, [8], [14], and [15] argued that the traditional DCF approach is obsolete to evaluate renewable energy techniques in an era of volatile spot prices. In contrast, real options approach is an appropriate market-based instrument to value energy investments within the deregulated environment.

Davis and Owens [16] used a numerical example to calculate the option value of US Federal government funding of renewable energy research and development. Their approach assumes that both the non-renewable energy cost and renewable energy cost reductions due to research and development evolve according to a geometric Brownian motion process, and concluded that a deterministic DCF approach to research and development evaluation would significantly underestimate the value of renewable energy research and development investments. Under the partial differential equations approach, we can calculate real option price by replacing all derivatives into finite differences and solving the grid of algebraic equations and inequalities that approximate the partial differential equations under terminal-time boundary conditions [16].

Such method has the advantage of handling early exercise or flexibility conditions in projects. However, since the finite-difference approach focuses on solving the partial differential equations numerically at each time point, which does not present the relationship between option value and the underlying value of the investment. Furthermore, the finite-difference approach is subject to approximation error while the project considering uncertainties at every node. Although we can alleviate this shortcoming by decreasing the size of the discrete time-steps, the instabilities and inconsistencies of continuous time approach still cannot be easily resolved unless it is displaced by discrete one.

5. REAL OPTION APPROACH TO ENERGY SECURITY

When using real option approach to evaluate energy security, we can first define energy security as the converse of cost spent to acquire energy in a specific price and security period. The more one nation should pay for it, the less energy is secured. For example, if there are two countries want to make sure that they can acquire energy in 5 cent/kWh in 3years, country A spend 1 cent/kWwh and country B spend 2 cent/kWh to get the promise (or contract) of some energy supplier to fulfill it. Then energy security in country A is higher than it in country B.

Black–Scholes model

According to the Black–Scholes model [18], the key assumptions are:

i. The price of the energy portfolio S_t follows a geometric Brownian motion with constant drift μ and volatility σ, and the price changes are log-normally distributed:

$$dS_t = \mu S_t dt + \sigma S_t dW_t$$

ii. It is possible to short sell energy.

iii. There are no arbitrage opportunities.

iv. Trading in energy is continuous.

v. There are no transaction costs or taxes.

vi. All energy commodities are perfectly divisible (e.g. it is possible to buy any fraction of a share).

vii. It is possible to borrow and lend cash at a constant risk-free interest rate.

viii. The energy portfolio does not pay a dividend.

As per the model assumptions (1) above, we assume that the price of energy portfolio follows a geometric Brownian motion. That is,

$$dS_t = \mu S_t dt + \sigma S_t dW_t \tag{10}$$

W_t is a Wiener process.

Now let V be some sort of option on S—mathematically V is a function of S and t. $V(S, t)$ is the value of the option at time t if the price of the underlying stock at time t is S. The value of the option at the time that the option matures is known. To determine its value at an earlier time we need to know how the value evolves as we go backward in time. By Ito's lemma for two variables we have:

$$dV = \left(\mu S \frac{\partial V}{\partial S} + \frac{\partial V}{\partial t} + \frac{1}{2}\sigma^2 S^2 \frac{\partial^2 V}{\partial S^2} \right) dt + \sigma S \frac{\partial V}{\partial S} dW \tag{11}$$

Now consider a trading strategy under which one holds one option and continuously trades in the energy portfolio in order to hold $-\frac{\partial V}{\partial S}$ shares. At time t, the value of these holdings will be

$$\Pi = V - S\,\frac{\partial V}{\partial S} \tag{12}$$

The composition of this portfolio, called the delta-hedge portfolio, will vary from time-step to time-step. Let R denote the accumulated profit or loss from following this strategy. Then over the time period [t, t + dt], the instantaneous profit or loss is

$$dR = dV - \frac{\partial V}{\partial S} dS \tag{13}$$

By substituting in the equations above we get:

$$dR = \left(\frac{\partial V}{\partial t} + \frac{1}{2}\sigma^2 S^2 \frac{\partial^2 V}{\partial S^2} \right) dt \tag{14}$$

This equation contains no dW term. That is, it is entirely risk-free. Thus, given that there is no arbitrage, the rate of return on this portfolio must be equal to the rate of return on any other risk-free instrument. Now assuming the risk-free rate of return is r we must have over the time period [t, t + dt]

$$r\Pi dt = dR = \left(\frac{\partial V}{\partial t} + \frac{1}{2}\sigma^2 S^2 \frac{\partial^2 V}{\partial S^2}\right)dt \tag{15}$$

If we now substitute in for Π and divide through by dt we obtain the Black–Scholes partially differentiate equation (PDE):

$$\frac{\partial V}{\partial t} + \frac{1}{2}\sigma^2 S^2 \frac{\partial^2 V}{\partial S^2} + rS\frac{\partial V}{\partial S} - rV = 0 \tag{16}$$

This is the law of evolution of the value of the option. With the assumptions of the Black–Scholes model [18], this partial differential equation holds whenever *V* is twice differentiable with respect to S and once with respect to t.

The above assumptions lead to the following formula for the price *C* of a European call option with exercise price K on a energy portfolio currently trading at price *S*, i.e., the right to buy a unit of the energy portfolio at price *K* after *T* years. The constant interest rate is r, and the constant energy portfolio price volatility is σ.

$$C(S,T) = S_d N(d_1) - Ke^{-rT} N(d_2) \tag{17}$$

where

$$d_1 = \frac{\left[\ln(S_d/K) + \left(r + \sigma^2/2\right)T\right]}{\sigma\sqrt{T}}$$

$$d_2 = \frac{\left[\ln(S_d/K) + \left(r - \sigma^2/2\right)T\right]}{\sigma\sqrt{T}} = d_1 - \sigma\sqrt{T}$$

Here N (.) is the standard normal cumulative distribution function. $N(d_1)$ and $N(d_2)$ are the probabilities of exercise under the equivalent exponential martingale probability measure (energy portfolio) and the equivalent martingale probability measure (risk-free asset), respectively. The equivalent martingale probability measure is also called the risk neutral probability measure.

6. REAL OPTION VALUE AND ENERGY SECURITY

Awerbuch and Berger [8] argued the application of MVP theory in energy field can help establish renewable energy targets and portfolio standards that make economic and policy sense. They also provided the analytic basis to devise efficient generating portfolios that maximize energy security while minimizing expected cost. While real option approach provides not only the information mentioned above but also more detail and concrete analysis about energy security and expected cost. Besides, real option approach supports advanced analysis in dynamic environment.

Energy portfolio and energy security

One of the most important factors on option value is the volatility of renewable portfolio. Assume that an energy portfolio includes fluctuant marketable energy and fix-cost energy, the weight of different energy would decide portfolio volatility. Other things be equal, increasing weight of renewable energy might reduce portfolio volatility, make real option value depreciate and increase energy security. But the cost of energy portfolio will also rise with increasing renewable energy weight because its cost is higher than traditional energy, which might elevate real option value and decrease energy security.

In Awerbuch and Berger's model, renewable was viewed as a risk-free asset, which means that an energy portfolio with renewable must expand the efficient frontier and create more value than pure marketable energy portfolio. While real option approach considered both the volatility reducing and cost rising effect in adding renewable to an energy portfolio. Whether energy security will increase depend on if volatility reducing effect is great than cost rising effect.

Time span and energy security

The longer expiration period being, the higher real option value is. If we ask a right to acquire energy on certain price for longer period, we should pay higher premium for it, which means a lower energy security.

Changes in marketable energy price and energy security

In option pricing model, the spread between asset price and exercise price will affect option value positively. If the price of marketable energy portfolio getting higher, the option value of this energy portfolio also getting higher, and the energy security going more vulnerable.

In a stable market, one can apply information of risk and expected return estimated by historical data to make policy choice. Meanwhile, the energy market has experiencing more violent shift, thus, the real option approach evaluation on energy security would offer more flexibility and information about market price variation.

Changes in renewable energy cost and energy security

Renewable energy is not trade in market and the cost could be assumed to be fixed after set up. Meanwhile, once we want to build new equipment to increase power supply from renewable energy, the cost may differ from prior facility. The material price volatility will increase or decrease renewable energy cost, and technical progress will decrease renewable energy cost.

If the renewable energy cost goes up, the option value of energy portfolio with renewable also goes higher, and the energy security goes more vulnerable.

New energy techniques (research and development) and energy security

The prior models, whatever traditional cost based or risk adjust cost MVP model, could only valuate marketable energy and set up renewable energy but not new energy techniques under research and development period, while new techniques, research and development do valuable in long term energy policy planning. In real option approach, we take the new techniques, research and development project as owning an extra option which may increase the probability to acquire energy on certain price in the future. If one country has invested an energy research and development project, the real option value of such project should be a minus item of total energy option value, which means the energy research and development may increases energy security.

7. RESULTS

To make a contrast between MVP model and real option approach, we duplicate the scenarios designed by [19], the variance-covariance matrix of energy shows in Table 1 and energy cost shows in Table 2. The energy price of portfolio in 2004 is 1.85NTD/kWh. They used historical electricity and energy data in Taiwan and designed three scenarios: First, zero nuclear and unlimited renewable energy. Second, nuclear was limited up to 20% and unlimited renewable energy. Third, nuclear energy was limited up to 20% and renewable energy was limited up to 11%. Chang and Chen [19] calculated the capital market line and compared with portfolio in 2004 for each scenario. Based on their research, we have calculated the real option values of every portfolio, compared the result with MVP model, and make advanced sensitivity analysis on security period, traditional energy price, and renewable energy cost that MVP model could hardly considered.

Scenario analysis – A comparison of mean-variance model and real option model

All the ten portfolios appeared lower option value and higher energy security than portfolio 2004.

In scenario I, both portfolio 1A and 1B fall in the efficient frontier, but we can distinguish each option value and get the conclusion that energy security in 1B is better than 1A.

The same methodology could be applied in the other two scenarios, 2B is the best portfolio concerning with energy security in scenario II, while 3C is the best portfolio concerning with energy security in scenario III.

Table 1. Variance-covariance matrix of energy.

	Fuel	LNG	Coal	Nuclear	Water
Fuel	0.05152	0.02987	0.00609	0.00009	0.00014
LNG	0.02987	0.02778	0.00588	-0.00258	0.00363
Coal	0.00609	0.00588	0.02814	0.00252	-0.00199
Nuclear	0.00009	-0.00258	0.00252	0.0025	-0.00117
Water	0.00014	0.00363	-0.00199	-0.00117	0.01137
S.E	0.227	0.1667	0.1677	0.05	0.1066

Table 2. Energy costs (NTD/kWh).

	Fuel	LNG	Coal	Nuclear	Water	Renewable
Cost	1.93	2.75	0.92	0.76	2.78	2

Table 3. Real option value of energy portfolios in different scenarios (NTD/kWh).

Portfolio	2004	1A	1B	2A	2B	2C	2D	2E	3A	3B	3C
Fuel	10.2%	0.0%	0.0%	2.6%	4.5%	4.6%	3.6%	0.0%	0.0%	7.8%	0.0%
LNG	33.4%	0.0%	0.0%	0.0%	0.0%	27.5%	9.8%	39.6%	35.6%	2.0%	0.0%
Coal	28.9%	46.8%	58.0%	32.7%	56.0%	23.7%	39.5%	28.4%	27.4%	53.2%	80.0%
Nuclear	14.6%	0.0%	0.0%	10.4%	17.8%	20.0%	15.6%	20.0%	20.0%	20.0%	20.0%
Water	12.8%	3.2%	3.9%	6.2%	10.6%	8.8%	9.4%	12.0%	12.0%	12.0%	0.0%
Renewable	0.1%	50.0%	38.0%	48.0%	11.0%	0.0%	22.0%	0.0%	5.0%	5.0%	0.0%
Option Value	0.2647	0.0992	0.0640	0.1127	0.0304	0.0767	0.0990	0.2567	0.2438	0.0352	0.0024

Sensitivity analysis

In real situation, the decision–making on energy policy should consider many issues, which includes how long should energy supply secured, how to deal with energy price rising and how to evaluate the cost reduction of renewable energy. Hence, we make sensitivity analysis about the security period, traditional energy price, and renewable energy cost on above cases. Our results shows that real option approach can offer more information for practical decision-making about energy security and is superior than traditional cost oriented valuation method and mean-variance model.

Security period

Figure 3 indicates that real option value will increase and energy security will decreased while we ask longer security period. And the time span effect on every case seems to be equal.

Traditional energy price

We assumed that prices of fuel and LNG (liquefied natural gas) rise simultaneously. Figure 4 indicates that option value of portfolio with higher weight of these two energies rise rapidly when prices of fuel and LNG rise. In another word, if we expect that prices of fuel and LNG will keep rising, we should decrease their weight in energy portfolio to satisfy energy security.

According to Figure 4, option value of portfolios with higher weight of fuel and LNG, *e.g.* 2004, 2E, 3A, 2C, will rise rapidly when the prices of fuel and LNG boost. In contrast, option value of portfolios without fuel and LNG, *e.g.* 1A, 1B, 3C, will be irrelevant with the prices boost of fuel and LNG.

Renewable energy cost

The renewable energy cost will goes down with advanced energy technique or lower material price, and goes up with higher material price. Figure 5 indicates that option value of portfolio with higher weight of renewable energy rise exponentially when renewable energy cost rise. In another word, the benefit of renewable energy on energy security is nonlinear.

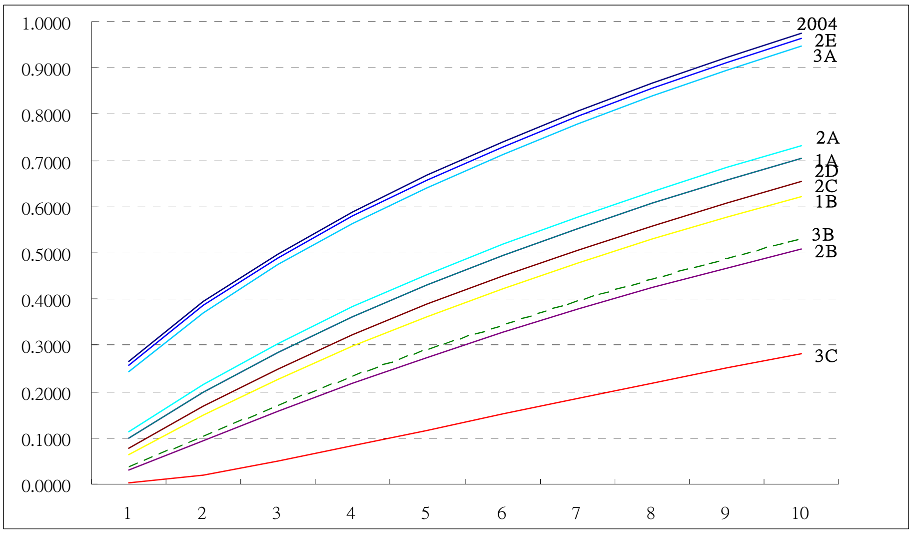

Fig. 3. Real option values of different scenarios when security period change from 1 to 10 years.

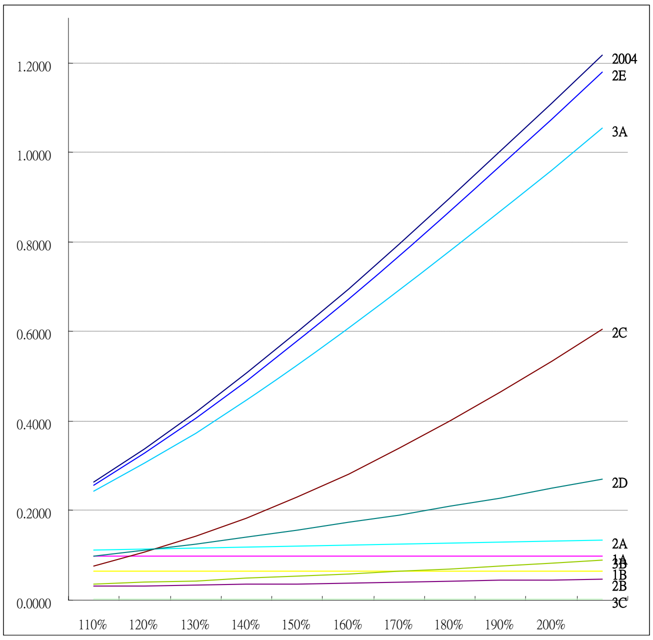

Fig. 4. Real option values of different scenarios when fuel and LNG price rise from 100% to 200% compared with 2004.

According to Figure 5, option value rising of portfolios with higher weight of renewable energy, *e.g.* 2A, 1A, 1B, will accelerate when the renewable energy cost goes up. This means that these portfolios are very sensitive to renewable cost, and the marginal benefit of cost down are decreased. In another word, trying to increase energy security by purely making effort to reduce renewable energy cost would not be better than diversify energy sources.

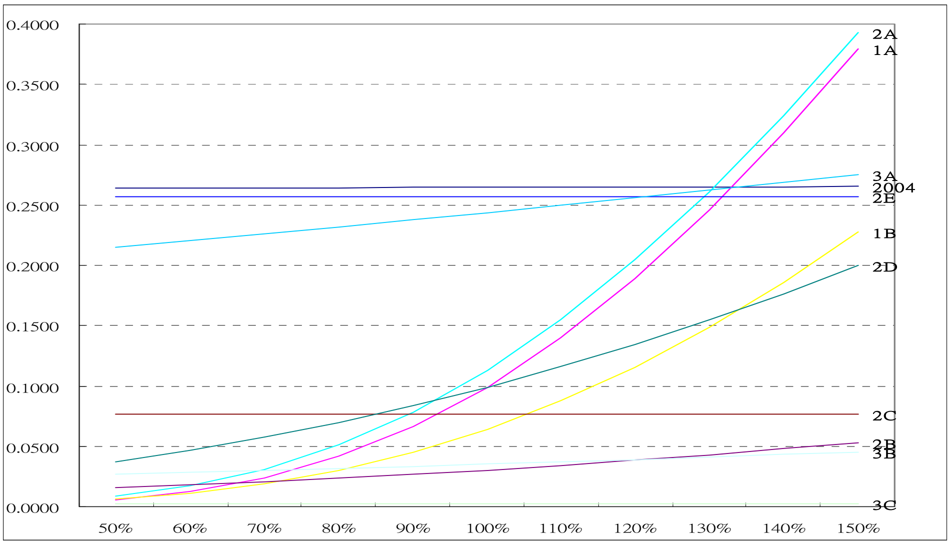

Fig. 5. Real option values of different scenarios when renewable energy cost change from 50% to 150% compared with 2004.

8. CONCLUSIONS AND SUGGESTIONS

Contrast to the stable environment in the last century, today's energy decision making needs more kinds of information and more predictable model to make an appropriate policy. It is impossible to make the "best" choice. All we can do is to consider the trade-off between many factors and the limitation in the political and technology contexts then choose the most valuable portfolio, and this calls for more information for policy simulation and prediction. The efforts on this research illustrate the benefits of applying the real option approach to energy policy with rigorous comparison and analysis.

Through real option appraisal, one can evaluate energy security in various energy portfolio and takes security period, marketable energy price, renewable and nuclear energy cost into consideration. We can also use the same approach to valuate the benefit of new energy technique research and development on energy security.

The real option valuation approach has been well applied in many fields, and was one of the most popular financial tools on decision making. We expect more application of this approach in energy field to assist making better policy for sustainable development.

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