“Analysis of a power plant investment opportunity under a carbon neutral world”

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Analysis of a power plant investment opportunity under a carbon neutral world

Abstract

We study investment opportunities for the two types of base load power plant technologies burning different fuels such as coal and uranium in the context of emission allowance trading mechanism. We apply the real options approach to evaluate investment opportunities contingent on, at least, two underlying assets featuring different price evolution behaviors. As main pricing skeletons, we adopt a mean reversion model for electricity price evolution to include its inherent feature of seasonality, and the geometric Brownian motion model for CO_2 allowance and the construction cost of the nuclear power plant. In order to approximate investment values, we use the Monte Carlo simulation approach to overcome a limitation of the analytic approach and to reach appropriate results. Our research shows a Nuclear Power Plant could play a timely role as an alternative to fossil fuel plants and change the map of the energy mix across the world, should we consider impacts of Green House Gas emission factors which are now provoking much attention from scholars and the public.

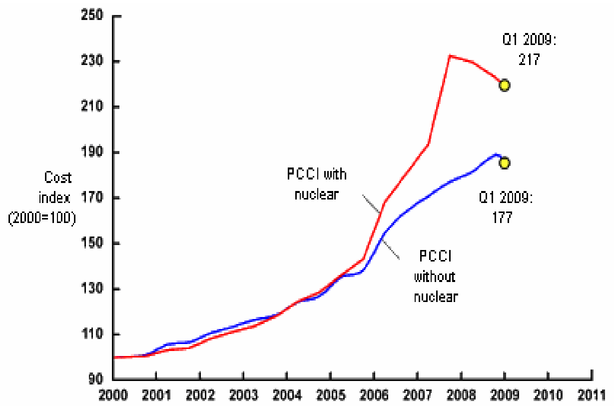
Keywords: real option approach, base load plant, CO_2 allowance, mean reversion, geometric Brownian motion, Monte Carlo simulation.
JEL Classification: C02, C53, C61.

Introduction

The main purpose of this paper is to examine the investment opportunity for a new power capacity. We test when and what type of a plant technology we should build under a liberalized market environment considering the CO_2 emission constraint. We conduct evaluations using the concept of the real option approach to reflect uncertainty and flexibility of a capital intensive project. We apply two different stochastic processes to interpret the behaviors of multi-dimensional variables: the geometric Brownian motion model for both CO_2 allowance price evolutions and investment cost changes of nuclear power plant (NPP), and then the mean reversion model for the electricity price evolution process.

Geometric Brownian motion (*gBm*) has been recognized as the most suitable medium to model stock-like assets which have a pattern of upward or downward movements with a weaker mean reversion (Dixit and Pindyck, 1994). We apply *gBm* to modeling the investment cost of NPP on the basis of the CERE (2009) report that shows the trend of costs to construct an NPP would increase up to \$2.17 billion in 2009 from \$1 billion in 2000 (Fig. 1).

On the other hand, we use the mean reversion approach to model electricity prices (Bessembinder, Coughenour et al., 1995). As seen in Figure 3, the price evolution of electricity is different from the construction cost showing an upward trend in Figure 1.



Source: Cambridge Energy Research Association.

Fig. 1. PCCI[1] with and without Nuclear

Like other commodity prices, electricity prices tend to follow the mean reversion. In addition, we calculate Hurst Exponents for the monthly electricity spot price and the daily CO_2 allowance spot price using a built-in Hurst Exponents function supplied by shareware connection (www.sharewareconnection.com). The calculation result shows that the Hurst Exponent value of the electricity price is 0.41 demonstrating the feature of the mean reversion and that of the CO_2 allowance price is 0.56 demonstrating *gBm*.

We revise the reference models to apply to real world issues. Our model introduces a simple and direct way to capture the relevant insights of optimal investment planning in a world of uncertainty with regard to changes of electricity price, investment cost, and CO_2 prices. The model is able to generalize beyond the cases referred to in this paper. With this framework, any investment involving more than

[1] PCCI: Power Capital Cost Index.

two stochastic variables could be analyzed through a relatively simple transformation.

The remainder of this paper is organized as follows: in the next section, we enumerate previous studies mostly dealing with the gBm model as the main stochastic approach for the underlying asset such as the electricity price. Section 2 discusses the current status of the NPP's role in the light of environmental issues and the CO_2 emission policy including a brief overview of the CO_2 allowance trading scheme. Section 3 demonstrates the statistics of data for simulation including Nord Pool electricity spot prices and CO_2 allowance trading prices. In section 4 we derive stochastic models for the underlying assets; electricity price, CO_2 allowances, and construction cost. We suggest real option models to be fit in each unique investment case in section 5 and their empirical result in section 6. Finally, we summarize what we have done and discuss possible future works in the final section.

1. Literature review

Considering an investment project in a new power plant especially with features of capital intensiveness and a long-term processing period, the real option approach becomes in the center of interest as one of the prospective methodologies. A project constructing a power plant is, for instance, a representative example including features which invoke, at all times, uncertainties over future financial revenue streams.

Dixit and Pindyck (1994) defined the concept of irreversibility and flexibility in property investments as options an investor can exercise at a favorable time and price. For example, when an owner of electric utility has an opportunity to invest in an irreversible utility such as a new power plant, he could wait and see for the better information at the expense of the profit he would earn by investing now. As such, the real option approach can be considered as a practical way of evaluating projects which are at the mercy of opaque future.

Laughton (2003) applied the real option approach to climate change policy to assess the value of a geological Green House Gas sequester in a power plant which burns coal fuel using a simplified option model. He dealt with CO_2 stream to illustrate the process of relevant risk source. He demonstrated that the real option approach could well reflect uncertainties caused by the introduction of the GHG policy rather than a traditional deterministic discount cash flow (DCF) which is difficult to account for the complex effects of risk and uncertainty on values.

Yang and Blyth (2007) published the report with the support of International Energy Agency (IEA). They quantified the impacts of climate change policy uncertainties on a coal power plant investment. They demonstrated both traditional discounted cash flow approach and real option approach to clear cut the strength of the real option methodology. They simulated stochastic processes of variables such as energy prices and carbon trading prices, because the volatility of electricity prices and carbon prices have occupied the central position for power sector investors and government policy makers since the deregulation of the electricity industry in many countries. However, they modeled electricity prices to follow the geometric Brownian motion, gBm, to make the model simple, even though the commodity such as gold, fuel, and electricity should be treated to follow the mean reversion in the process of evolution.

Sekar (2005) evaluated investments in three coal fired generation technologies using real option valuation considering uncertain CO_2 prices: pulverized coal, standard Integrated Gasification Combined Cycle (IGCC), and IGCC with pre-investments to reduce the cost of future carbon capture and storage (CCS), retrofitting. He developed the cash flow model for each technology, though the simulation dealing with the CO_2 price appeared as the sole uncertain variable in the cash flow. His approach combined two elements: market-based valuation to evaluate cash flow uncertainty, and dynamic quantitative modeling to reflect the effect of uncertainty. The study used Monte-Carlo cash flow simulation in the place of simple scenarios to incorporate cash flow uncertainty.

Electric Power Research Institute (EPRI) develops the Greenhouse Gas Emission Reduction Analysis Model, mostly using a discounted cash flow (DCF) analysis to evaluate the revenues, costs and expected after tax gross margin accruing from investment in the technology of greenhouse gas reduction. The model adopted sophisticated statistical and economic tools, including Monte Carlo simulation.

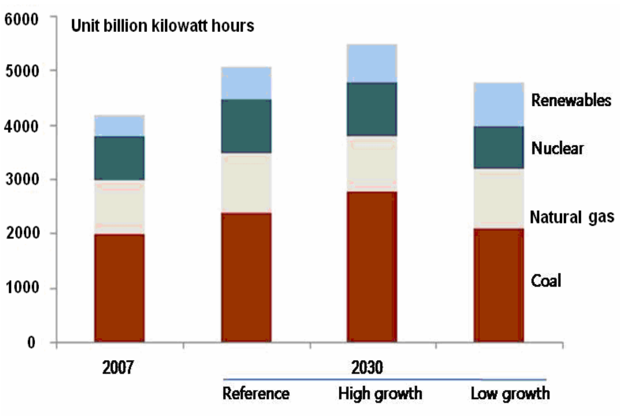
Laurikka (2006) presented a simulation model using the real option approach to assess the value of Integrated Gasification Combined Cycle (IGCC) technology within an emissions trading scheme. He designed and simulated three types of stochastic variables: the price of electricity, the prices of fuel and the price of emission allowances. He found that a straightforward application of the traditional valuation scheme to IGCC investment can bias results incurred by an uncertain emission trading scheme. He showed the IGCC technology is not competitive within the EU ETS without the consideration of CO_2 prices.

Ming and Blyth (2007) undertook the real option approach with the computer modeling to quantify the impacts of the climate change policy which is looming up as an essential factor in the power sector investment. Different from the previous studies, they formulated multi stage investments taking two stochastic variables into account: prices of electricity and CO_2 allowance.

Different from previous studies we develop the model to evaluate the investment opportunity with more than two different assets which have different features of price evolutions. We adopt a concept of mean reversion model for electricity price evolution to reflect its inherent features of seasonality, and a geometric Brownian motion model for CO_2 allowance and the construction cost of the nuclear power plant to consider their sensitivity of uncertainties.

2. NPP status vs. CO_2 emission

Despite the overall alarm arising from concerns over global warming mainly invoked by Kyoto Protocol, energy experts predict in 2008[1] that coal, one of the main culprits of Green House Gas emission will still be in a dominant position in the world energy mix as demonstrated in Figure 2 (IEA 2008).



Source: International Energy Outlook, 2008.

Fig. 2. Electricity generation by fuels

The recent issue of global warming has led to the reconsideration of nuclear energy as an alternative to the fossil on top of such issues as higher fossil fuel prices, and energy security concerns. Following two decades of apathy toward NPP, Europe started to consider nuclear power plants as a prominent substitute to reduce its dependence on oil and gas imports and to cut greenhouse gases to meet the Kyoto Protocol.

Asia is the only region where nuclear power is rising constantly to keep up with the speed of its economic development. There are over 109 nuclear power reactors in operation, 18 under construction in 2005. The projected new generating capacity in this region will reach some 38GWe and 56GWe per year in 2010 to 2020, respectively. The fastest growth in nuclear generation should be in China, Japan, South Korea and India. Especially South Korea and Japan rely heavily on nuclear power which provides around 30% of the total electricity production capacity.

Each generation technology emits different quantity of CO_2 per unit power, MWh, depending on its fuel usage. For example, a Natural Gas Combined Cycle (NGCC) emits about 0.42 tCO_2/MWh, a typical Integrated Gasification Combined Cycle (IGCC) station, on the other hand, emits about 0.83tCO_2/MWh. The emission will be the big factor in raising the generation cost if it has to pay the environmental cost on over emitting GHG or to install equipment for carbon capture and storage (Rathmann, 2007).

In an individual company's perspective, the cost to abide by the Kyoto Protocol is regarded as a sunk cost, which they have to write off or transfer to customers by raising electricity rates. Alternative energy sources such as wind, solar, tidal power, etc., have emerged as a solution, but they are still considered too far to reach due to their economic ambiguities.

3. Descriptive statistics

3.1. Electric prices. We acquired daily spot price data of Nord Pool through the database, *'DataStream'*, during the period May 1992 until September 2007. The top left panel of Figure 3 shows the daily price evolution and the top right panel demonstrates the rate of daily return of the electricity price during the period, respectively. As plant investments for the base load rely more on the long-term price trend than on the short-term spiky fluctuations (Olsina, 2006), we transform the daily spot price into monthly price data to neutralize short-term spikes and use eventually to estimate the long-term investment value. The bottom left panel shows the prices demonstrating monthly spot prices showing a clear upward sinusoidal features, but not as high fluctuations as those of the daily prices.

3.2. CO_2 allowance data. As seen in Figure 4[2], CO_2 allowance prices have fluctuated around prices between \$25 to \$30 per tone of CO_2, *tCO_2*, since the market was commenced. However, the price after May 2006 dropped drastically to near \$6/tCO_2 as of January 2007.

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[1] As forecasted by DOE in March, 2007, world net electricity generation grows by 85 percent from 16,424 billion kWh in 2004 to 30,364 billion kWh in 2030. This report also forecasts that coal and natural gas remain the dominant fuels for electricity generation throughout the projection.

[2] These data come from EEX-EU CO_2 Emissions Spot E/EUA through DataStream.

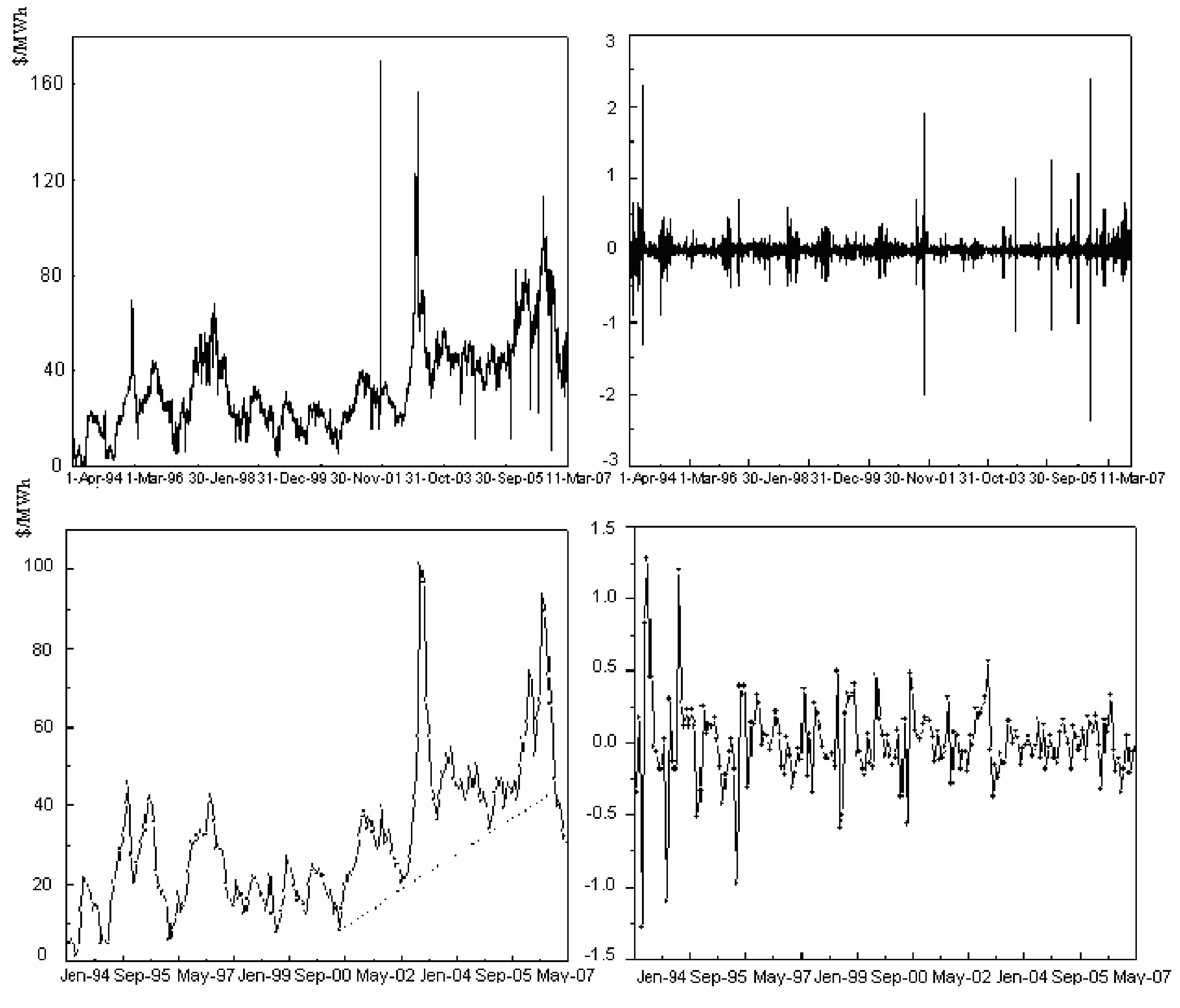


Fig. 3. Daily (the top) and monthly (the bottom) electricity price[1]

The Point Carbon published on May 24, 2007, gave a few potential reasons explaining the allowance price drop; a result of emission reductions due to the new investment in energy efficiency facilities, the switch to fuels with lower carbon content and the excessive allocation of the emission permit to large companies.

However, it is likely that most of plant owners, for the time being, would buy emission allowances to make up for emission externality of their fossil fuel power plant as a result of which the prices of CO_2 allowance would be on the rise with the feature of the geometric Brownian motion behavior like that of stock prices. And the calculation result of the Hurst Exponent of CO_2 allowance prices is 0.56 demonstrating gBm. Hence, we assume that CO_2 allowance prices follow *gBm*, with the same standard deviation as that of the Nord Pool electricity spot price, because CO_2 allowance prices are much correlated with electricity prices, for example, the rise of CO_2 allowance prices directly influences that of electricity prices.

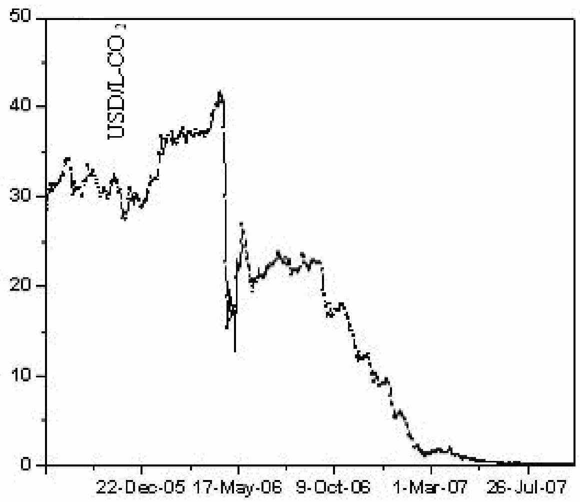


Fig. 4. CO_2 allowance price and trading volume

4. Stochastic electricity spot price model

4.1. Parameter estimation based on historical electricity spot prices. We estimate most parame-

[1] The variation of the prices in the Nord Pool market is well correlated with the variation of precipitation because of its dependency on hydro-power generation.

ters from historical spot data to depict a reliable evolution of electricity prices displaying changes of features of the underlying asset.

(1) Seasonality and volatility

Electricity supply is mainly affected by natural phenomena such as the temperature and the precipitation level as well as by industrial activity. In the first equation (3), $f(t)$ represents the seasonality function which accounts for the historical monthly data of the Nord Pool to demonstrate a discernable shape of a sinusoidal function. In this model, we apply the Fourier series 4th degree regression function which is calculated by the Matlab Regression Tool box. Figure 5 shows the seasonality of the Nord Pool market during September 2005 to August 2006. The reason we choose the data of that period is that they exhibit a dynamic behavior and they cover the price range from below $40/MWh to almost $90/MWh which demonstrates not only the price behavior in winter[1] (point 4 to 6) but also an abnormal price jump in summer [point 11 to 12 of X-axis]. We can finally estimate volatility using the SMA (Simple Moving Average)[2] approach with the maximum likelihood method.

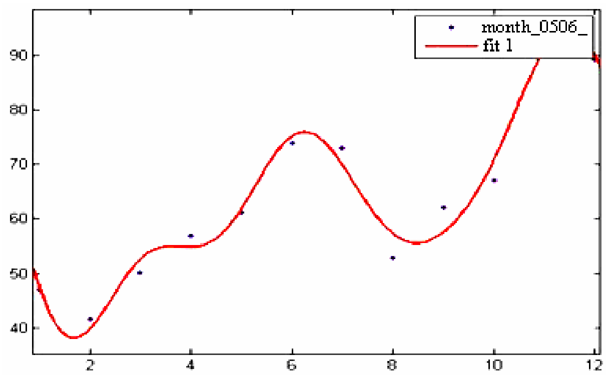


Fig. 5. Seasonality of Nord Pool data

(2) Mean reversion rate and drift

The rate of log spot prices is used to estimate the drift (equation 1). For the estimation of the mean reversion rate, we follow equations

$$Drift = LN\left[\frac{S(t_i)}{S(t_{i-1})}\right], \quad (1)$$

$$MR = LN(2)/T_{1/2}, \quad (2)$$

where in equation (1), $S(t_i)$ is the electricity price of today, and $SP(t_{i-1})$ is the electricity price of yesterday, and in equation (2), T is one cycle of time which includes the highest and the lowest electricity prices, and LN is the natural log.

(3) Electricity price model

We revise the Ornstein-Uhlenbeck (OU) model of Schwartz (1998) and the geometric mean reversion model of Abadie (2004). Equation (3) demonstrates the price evolution including the feature of mean reversion and the seasonality, and Equation (3b) shows the mean reversion process of the electricity price.

$$S_t = \exp(f(t) + X_t), \quad (3a)$$

$$dX_t = k(P_{m(t)} - P_t)dt + \sigma P_t dz. \quad (3b)$$

In equation (3a), S_t denotes the spot price with seasonality effects at time t, and X_t is the electricity price before considering seasonality effect, and $f(t)$ demonstrates seasonality using Fourier degree 4. In equation (3b), k is the mean reverting rate and $P_{m(t)}$ and P_t are the mean values of electricity prices and a spot price, respectively, and z is a Wiener process and σ is volatility.

Table 1. Parameters used for the simulation

Price		MR rate*	Volatility	Fourier fitting
Current	Mean			
$60.27/MWh	$60.27/MWh	0.167	0.579	Degree 4

5. Real option model

In order to calculate an option value with more than two state variables, we use the concept of the spread option which is an option written on the difference or the spread of the value of two underlying assets $S_2(t) - S_1(t)$ at time t. In case of IGCC plant, $S_2(t)$ is electricity prices considering seasonality and $S_1(t)$ is CO_2 allowance prices, respectively, and for NPP, $S_2(t)$ is electricity price and $S_1(t)$ is NPP construction costs each. To exercise the option, the buyer must pay at maturity T, a pre-determined strike price K, and the payoff of a spread option at maturity should be $max[(S_2(T) - S_1(T) - K), 0]$.

We apply different asset pricing models to reflect their unique features respectively: (a) the electricity price like other commodities evolves following the mean reversion, (b) the construction cost of a new NPP is dealt with by the geometric Brownian motion because an NPP is exposed to endless safety issues which aggravate construction costs, and (c) the evolution of CO_2 allowance is also regarded as geometric Brownian motion. We derive three kinds of real option models.

5.1. Real option model for an IGCC plant. Equations (4a) and (4b) describe electricity and CO_2 price evolutions to value the investment opportunity of an IGCC plant; equation (4a) for the electricity price and equation (4b) for the evolution of CO_2 allowance prices. To model the option value contingent on more than two underlying assets, we should

[1] Normally the demand for the Nord Pool market is high in winter for the heat-up. However, price behaviors show the abnormality in summer as well.
[2] We used the Matlab Tool box to estimate volatility for electricity prices.

allow the uncertainty to be correlated to consider some common macroeconomic shocks between them.

$$dS_1(t) = k[S_m - S_1(t-1)]dt + \sigma_1 S_1(t-1)dz_1, \quad (4a)$$

$$dS_2(t) = \mu S_2(t-1)dt + \sigma_2 S_2(t-1)[\rho dz_1 + \sqrt{1-\rho^2}dz_2], \quad (4b)$$

where S_1 and S_2[1] are CO_2 allowance price and electricity spot price, respectively, and dz_1 and dz_2 are independent standard real-valued Wiener processes. The intuitive interpretation of equations (4a) and (4b) is as follows: at each time t, the infinitesimal changes in the return on $S_i(t)$ are normally distributed with means $\mu S_2 dt$, $k[S_m - S_1(t-1)]dt$ and variance $\sigma_i^2(t, S_i(t))dt$, $\rho(t, S_i(t))$ giving the instantaneous correlation between these two conditionally normal random variables $\rho dz_1(t)$, $\rho dz_1 + \sqrt{1-\rho^2}dz_2$, which are randomly drawn from a normal distribution with mean zero and standard deviation $dt^{1/2}$ with correlation. We also assume that the coefficients μ_i, σ_i, and ρ are smooth enough for the existence and uniqueness of a strong solution (Karatzas and S.E. Shreve, 1998).

$$E(dz_1)=0, \qquad E(dz_2^2)=dt, E(dz_1 dz_2)=\rho dt. \quad (5)$$

We revise the general spread option formula (Cox and Ross, 1975) to consider the technical specification of a plant. For example, $(e_f - f_a)$ is a new coefficient to reflect the emission impact on the decision making of a power plant investment[2]. Emission factor, e_f, is an inherent emission quantity per MWh intrinsic to a plant technology type and free allocation, f_a, is a permitted emission quantity per MWh allocated by a regulation body. On the basis of equations (4a) and (4b), the investment opportunity can be estimated by the equation below for an IGCC plant,

$$F(S_1,S_2) = \exp^{-rT} \max \left\{E_0\left[(S_2(T) - (e_f - f_a)\times S_1(T) - K\right], 0\right\}, \quad (6)$$

where *exp* represents exponential, E_0 is the expectation at time *'0'* and K is the strike price represented here as the investment cost.

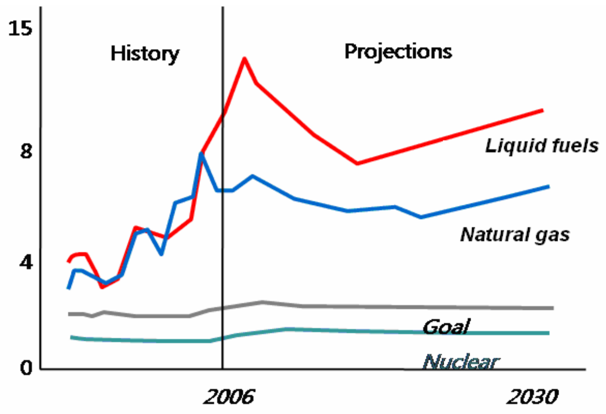
5.2. Two asset real option model for NPP. We use the revised model from Margrabe's method (Carr, 1995) to approximate the investment value of a new NPP. He suggests an evaluation formula which relies on two stochastic variables without a fixed strike price. We assume electricity price and investment cost as stochastic values due to their longer period of construction[3] than the other generation plants. The longer period means more likelihood of construction cost changes. Equations (4a) and (4b) can also be applied to NPP investment evaluation; the first equation for electricity price movements and the second one for construction cost movements.

$$F(S_1,S_2) = e^{-rT} \max\{E_0[(S_2(T) - S_1(T)], \ 0\}. \quad (7)$$

6. Empirical results

6.1. Assumption

- 1,000MW of power supply is needed to meet demand in 10 years.
- We limit the stochastic change of variables to electricity price, CO_2 allowance price and NPP construction cost. As seen in Figure 6, fuel prices of nuclear and coal plant have kept steady without large fluctuation for the long period.
- We assume the fixed Operation and Maintenance (O&M) costs and ignore the start-up cost as well.
- We use the different discount rate: IGCC: 5%, NPP: 10% to reflect the risk averseness of investors. According to Standard & Poors (2008), NPP construction seems to be unfavorable to investors. Because it has no recent experience with high construction cost and longer construction periods.
- On the basis of the Nord Pool data, we estimate the drift of CO_2 allowance prices 0.167 and the correlation coefficient between electricity prices and CO_2 allowance prices 0.876.
- We assume the volatility of the NPP construction cost is the same as that of CO_2 allowance prices, 0.2587.



Source: International Energy Outlook 2008.

Fig. 6. Fuel prices (2006 USD/million BTU)

6.2. Representative parameters. We use the values of Table 2 which divides two categories, IGCC and new NPP investment.

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[1] We use the Nord Pool data for the two cases because of which the market trades both commodities.

[2] Since there is no appropriate reference, we name an emission impact as GHG coefficient for the first time.

[3] The construction period of nuclear power plants is at least 5 years for the new design based plants but construction generally takes over 10 years including preliminary regulation reviews.

Table 2. Representative parameters

Specification		IGCC	NPP
Plant size (output)	(MWe)	1,000	1,000
Plant's useful life	(Years)	40	40
Capacity factor	(%)	85	85
Net efficiency	(%)	46	33
Discount rate	(%)	5	10
Investment cost	($/kWe)	2,500	4,500
	($/MWh)	29.17	52.5
Fuel cost	($/MWh)	18.4	4.6
O&M cost	($/MWH)	5.4	12.6
Heat rate	(BTU/KWh)	9,773	10,200
CO_2 emission	(kg/KWh)	0.83	0
Target	(kg-CO_2/kWh)	0.35	0.35

Notes: [1] This is the efficiency of a light water reactor. [2] Investment costs are converted into $/MWh using Stoft (2001) formula $FC = r \times OC/(1-(1+r)^T)$.

6.3. Valuation of the investment opportunity. In a position to choose one option among the two alternatives, we face the options.

$$F = Max(V_{igcc}, V_{new\_npp}, 0), \qquad (8)$$

where V_{igcc}, and V_{new_npp} are the option values of an IGCC and a nuclear power plant.

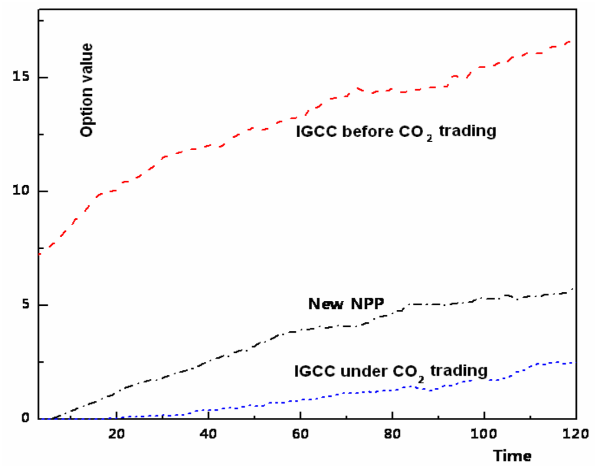

Fig. 7. Simulation results of the option value

Table 3. Option value and NPV

Evaluation approach		IGCC CO_2 trading Before	IGCC CO_2 trading After	NPP
NPV		4.71	-19.71	-3.45
Option value	European	9.80	1.65	2.09
	American	13.37	2.87	5.73
				Unit : $/MWh

As shown in Figure 7 and Table 3, the IGCC plant is the favorable candidate in case of no CO_2 constraints in both European and American contingent claim contexts. It is, however, the least preferable plant under a CO_2 trading mechanism in respect of both NPV and option valuation contexts. In the case of new investment in an NPP, despite not being preferable under NPV appraisal, it gives an investment opportunity under the option valuation context whose value is larger than that of IGCC. In a nutshell, it is not optimal to invest 'NOW' in either IGCC or new NPP. Investors should wait until the spread becomes larger; electricity price and CO_2 allowance for an IGCC, electricity price and construction cost for a new NPP. Furthermore, the value of American option in every plant type demonstrates more expensive than that of every European option shown in Table 3, which could be interpreted that exercising the option whenever investors wants needs more premium invoking higher risks by the cost of early exercise.

6.4. Sensitivity test. What happens to the option price and the NPV when parameters vary? The base case to which all the values are compared is: As seen in Figure 8, the larger the current electricity price and the volatility of electricity price, the more the option value, which is a normal sense of option valuation. On the other hand, the long-run average electricity price and the volatility of CO_2 allowance lead the option value down. This is because the large value of the long-run average level of the electricity price prevents the electricity price from roaming over the upper territory and the CO_2 volatility and drift rate representing the cost side offset the option value. Higher drift rate and volatility of the cost lead to a higher chance of expensive CO_2 prices in the future resulting in a lower option value. By the way, the small change of the mean reversion rate of the electricity price, which is the case for the evaluation of a long-term investment project, has not a great influence on the option value.

Conclusion and discussion

This study addresses two research problems: First, the real options approach can be applied to the evaluation of a real property investment analysis especially demonstrating different stochastic behaviors, second, we can estimate which plant technology is optimal under CO_2 allowance trading context.

We propose a simple but insightful approach to price the investment value using the spread options methodology on multiple assets mixed with the features of mean reversion and geometric Brownian motion. It is the first attempt to introduce the Green House Gas coefficient to demonstrate its impacts on investment decision making.

We verify the robustness of our model by applying it to the real world market. It shows that different combinations of asset features can be well modeled in three simulation cases; IGCC without CO_2 constraint, IGCC under CO_2 trading, and new NPP.

Our research shows that NPP could play a timely role as an alternative to fossil fuel plants and change the map of the energy mix across the world, should we consider impacts of Green House Gas emission factors which are now provoking much attention from scholars and the public. Regardless of potential investors or existing plant owners, reining in Green House Gas emissions should be an irresistible priority to survive. To make matters worse, it is impossible to predict the limit of oil and gas prices due to sharp increase of demand from the developing countries and the geopolitical economic strategy of crude oil and natural gas producing countries.

Our model, therefore, could provide a stepping stone for the application of the real option approach to evaluate various types of power plant technologies with multiple underlying assets.

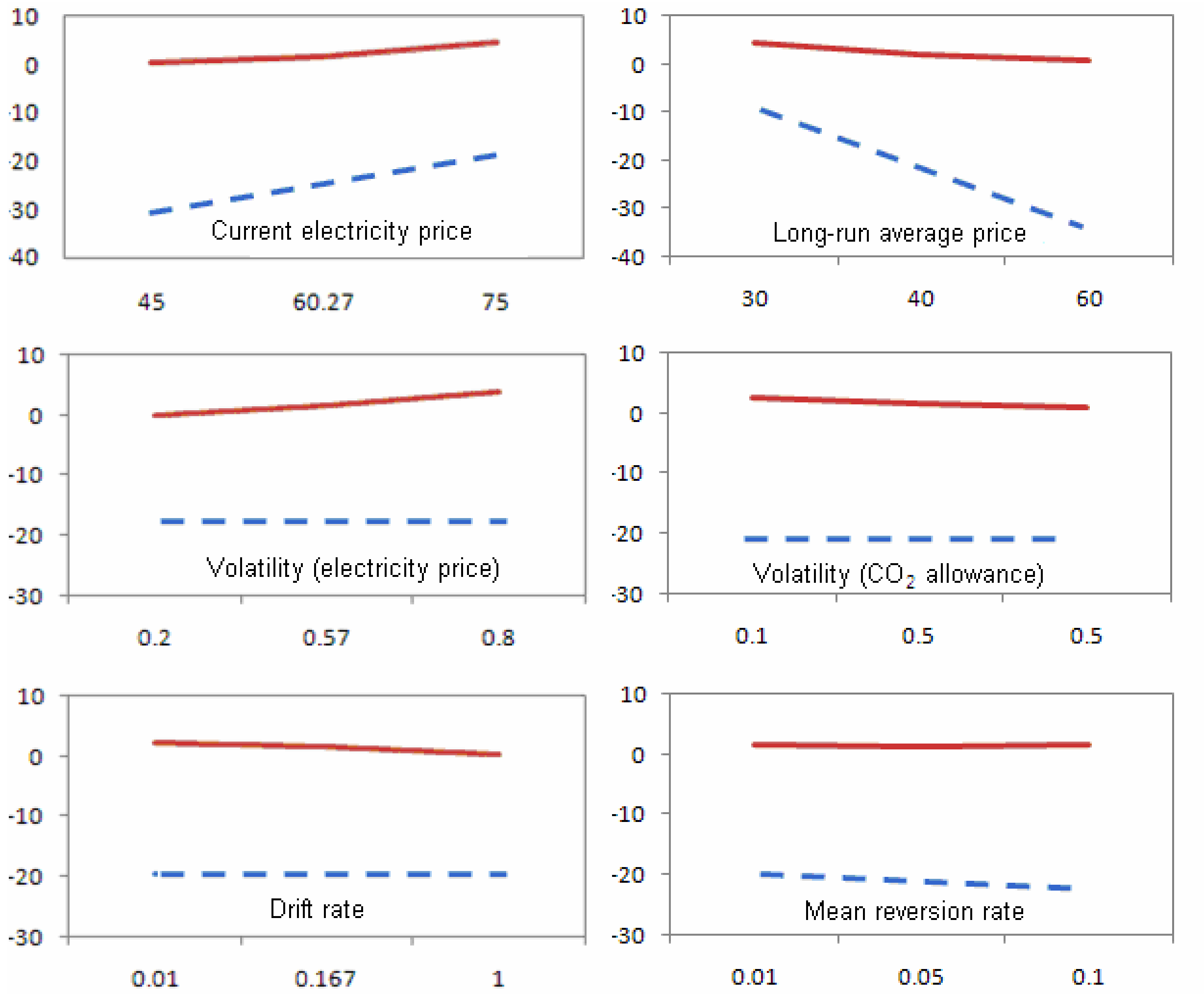

Fig. 8. Sensitivity test

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