Valuing a Medium-Scale Gas Fired Power Plant with Capacity Expansion Options Under a Competitive Environment

M. Takahashi, T. Hattori, N. Yamaguchi,
K. Okada, and H. Asano

EMF Working Paper 20.2

August 2003

Proceedings of the Fourteenth Annual Conference of
Power and Energy Society, IEE of Japan, August 2003.

The authors are with the Central Research Institute for the Electric Power Industry (CRIEPI), Tokyo, Japan.

Valuing a Medium-Scale Gas Fired Power Plant with Capacity Expansion Options Under a Competitive Environment

1. Introduction

Deregulation of electricity markets increases the uncertainty about the market environment and firms face investment risks associated with power generation assets. Valuing flexibility of investment projects and the management of project risks are crucial issues for firms to achieve their corporate objectives, such as stable earnings and growth in volatile electricity markets(1)(2).

If there was no uncertainty in market environments, investing in a large-capacity generating unit would be more profitable than a small-capacity investment because of the economy of scale and higher generating efficiency. However, in an uncertain electricity market, a large-capacity generating unit increases investment risks that would be lowered by choosing a set of small capacities of generating units and so starting with a smaller capacity might have some option value related with capital investment flexibility, which is known as capacity expansion option.

The traditional net present valuation is no longer an adequate method of valuing flexibility of investment project of power generation assets and more sophisticated method such as real options analysis is necessary to value the assets in volatile market environments(3). The real options analysis gives insights into these risks of investing in generating assets.

In this appendix, we show a simple example of real options valuation of the capacity expansion option of CCGT(4). The Japanese electricity market is taken as an example, though the valuation model may have applicability to other markets.

2. Capacity expansion option of CCGT

Suppose that a generation company has two choices of investment project of CCGT within a project period of the next ten years (see below) and can make a choice of the project that might give higher net present value than another.

(a) Large CCGT - The company invests in one CCGT generating unit of 1200MW at the beginning of the project period and has no option to expand its generating capacity in response to changes of market environment later.

(b) Small CCGT - The company invests in one CCGT generation unit of 600MW at the beginning of the project period and holds an option to expand its generating capacity from 600MW to 1200MW anytime within the project period in response to changes of market environment, which is called a capacity expansion option.

3. Binomial option valuation model

We estimate a present value of the generation investment project of CCGT using a binomial option valuation model, in which the evolution of the asset value in an uncertain market is represented by a binomial tree as shown in Figure 1, where the horizontal axis is a time scale within a project period and the vertical axis is a possible future asset value.

A mathematical formulation of a one-step binomial valuation model of the CCGT investment project is shown in Equations (1)-(4) as an example. The present value of the project, V, is given by discounting the expected payoff of the project at time 1 by a risk-free rate, r, where C_u is the payoff of the project at time 1 when the underlying asset value, V_0, goes up, C_d is the payoff at time 1 when the underlying asset value goes down, and p is the risk-neutral probability when the underlying asset value goes up. When the firm holds a capacity expansion option, it can make a decision whether or not it should invest in additional generating unit of CCGT at time 1. The additional investment cost corresponds to an exercise price of the option, X, in (2) and (3).

$$V = \frac{pC_u + (1-p)C_d}{(1+r)} \tag{1}$$

$$C_u = \max(2 \times uV_0 - X, V_0) \tag{2}$$

$$C_d = \max(2 \times dV_0 - X, V_0) \tag{3}$$

$$p = \frac{1+r-d}{u-d} \tag{4}$$

where u and d are increasing and decreasing rates of the underlying asset value. The price volatility of electricity affects the present value of the project via these parameters.

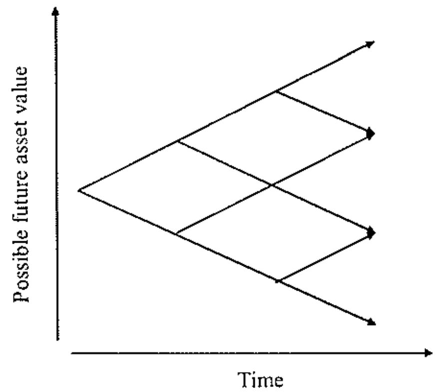

Figure 1 Binomial tree model of option valuation

4. Data setting

4.1 Cost parameters of CCGT power generation

Table 1 shows cost parameters of CCGT power generation in this study. The unit construction cost is assumed to be independent of the size of a generating unit and two kinds of the cost parameter, 130000yen /kW(1080 US$/kW) and 140000yen/kW(1170 US$/kW), are considered in the model valuation to perform a sensitivity analysis of the present value of CCGT. Japanese firms purchase LNG mainly based on the long-term purchase contract and so we suppose that LNG price for CCGT power generation is not volatile within the project period in contrast to electricity price. Since a larger-capacity generating unit of CCGT has a higher generating efficiency, the generating efficiencies of CCGT of 1200MW and 600MW are supposed to have 44% and 43.5% respectively, making the differences of unit generation cost of 0.05yen/kWh -0.06 yen/kWh as shown in the table. Capacity factor of generating assets is assumed to increase from 50% to 70% within first five years and keep a constant factor of 70% later because CCGT is utilized as a middle-base load power plant in Japan. The risk-free rate is set to be 1% and the weighted average of capital of cost (WACC), that is, a risk-adjusted discount rate, is set to be 3.5%, which is a current regulated rate of return of electric utilities in Japan.

4.2 Electricity price model and volatility estimates of underlying asset value of CCGT

Mean reversion processes of electricity price have been observed in a lot of electricity markets and we assume that movements of future electricity price, P_t, follow a first-order autoregressive (AR1) model as shown in Equation (5).

$$P_t = P_{t-1} - b \times (P_{t-1} - \overline{P}) + \varepsilon_t = \alpha + \beta \times P_{t-1} + \varepsilon_t \qquad (5)$$

where $\overline{P}$ is the mean value of future electricity price and β is the auto-correlation coefficient and ε_t is the disturbance term.

The parameters of electricity price model are shown in Table 2. The mean value of electricity price decreases at 1% annually within the project period because of price competition among power generators. The disturbance term has a lognormal distribution with a standard deviation of 10% of the mean value. To perform a sensitivity analysis, two kinds of auto-correlation coefficient are considered: 0% (no mean-reversion process) and -30% (mean-reversion process).

The volatility of the underlying asset value of CCGT under the assumed electricity price movement is calculated by a Monte Carlo simulation approach. The estimated volatility of rate of return of the underlying asset is shown in Table2. When the auto-correlation coefficient is negative, the volatility is lower than that in a case of a zero auto-correlation coefficient, since the mean reversion processes make the population of the future electricity price more concentrated around the mean value.

Table 1 Cost parameters of a generating unit of CCGT

Unit construction cost	(a)130000(yen/kW), (b)140000(yen/kW)
Fuel cost	
LNG price	30000yen/ton(1st year)-33140yen/ton(10th year)
average growth rate	1% per year
generating efficiency(avg.)	44%(1200MW), 43.5%(600MW)
unit generation cost(1200MW)	4.5yen/kWh(1st year)-4.92yen/kWh(10th year)
unit generation cost(600MW)	4.55yen/kWh(1st year)-4.98yen/kWh(10th year)
Maintenance cost	1.52yen/kWh(1st year)-1.66yen/kWh(10th year)
average growth rate	1% per year
Load factor	increases from 50% to 70% during first five years and keeps a constant facor of 70% later in the project period.
Risk-free rate	1.00%
Weighted average capital cost	3.50%

Table 2 Assumptions and PV volatility estimates of an underlying asset of CCGT

Assumptions: AR(1) model of electricity price movement		
mean value	7.9yen/kWh(1st year)-7.22yen/kWh(10th year)	
decrease rate of mean value	1% per year	
distribution of disturbances	Lognormal distribution	
standard deviation	10% of the mean value	
auto-correlation coefficient β	0%	-30%
Estimates: Volatilities of rate of return of underlying asset of CCGT		
1200MW	8.28%	6.17%
600MW	8.86%	6.65%

5. Results: Present value of capacity expansion option of CCGT

Figure 2 shows the estimated total present value of the investment project of CCGT per generating capacity, comparable to the unit construction cost. The black portion is a present value of the underlying asset of CCGT without a capacity expansion option, the white one is the capacity expansion option value, and the horizontal lines indicate the unit construction costs.

It can be seen in the figure that, the higher the volatility of the underlying asset value becomes, the higher the option value of a small CCGT grows. In a case of unit construction cost of 130000yen/kW, only a large CCGT has a positive net present value and has an investment opportunity when the option value is out of consideration. However, a small CCGT also gains an investment opportunity if the option value is taken into consideration. On the other hand, in a case of unit construction cost of 140000yen/kW, although the investment project of large CCGT is rejected because of a negative net present value, small CCGT might represent an investment opportunity when the future electricity price is highly volatile. These numerical results imply that price volatility might cause different investment decisions of firms from traditional net present valuation results.

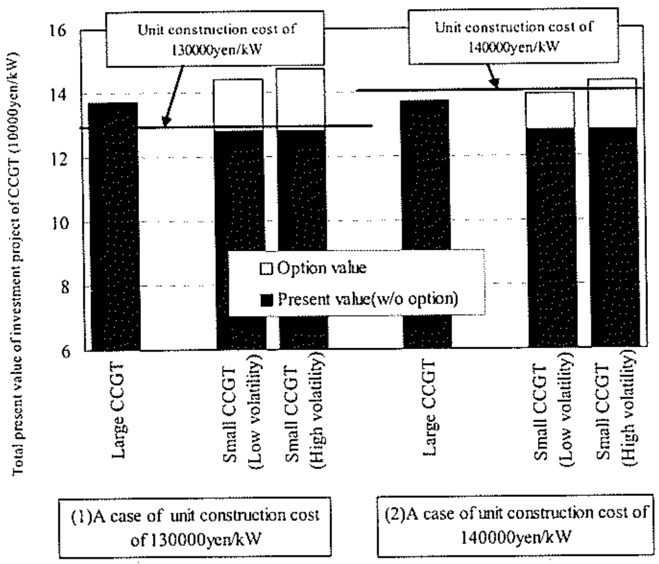

Figure 2 Estimated present value of investment project of CCGT

6. Conclusions and summary

In this study, we estimate the value of a capacity expansion option of CCGT using a binomial tree evaluation model. The results imply that, due to the option value, a small-capacity CCGT power plant might gain a great investment opportunity in a volatile electricity market rather than a large-capacity CCGT power plant.

Although we considered only the electricity price volatility as a risk factor of capital investment in the model valuation, other factors affecting the option value should be taken into consideration to make accurate option valuations. Natural gas price volatility would be another important risk factor affecting the value of generating assets of CCGT in the regions where natural gas prices move significantly, such as North America. In that case, the spark spread option between electricity and natural gas markets might give the value of the generation assets of CCGT(5).

The uncertain market environment affects the firm's decision-making in investment project of power generation assets and might cause different technological choices from traditional net present valuation results.

References

(1)P. Griffes, M.Hsu and E. Kahn, Power Asset Valuation: Real Options, Ancillary Services and Environmental Risks, The New Power Markets Corporate Strategies for Risk and Reward, Risk Books, P103-126, 1999

(2)J. Frayer and N.Z. Uludere, What Is It Worth? Application of Real Options Theory to the Valuation of Generation Assets, Electricity Journal, October 2001, p40-51

(3) T. Copeland and V. Antikarov, Real Options: A Practitioner's Guide, Texere, 2001

(4) T. Hattori et.al., Description and Use of Real Option Valuation in Electricity Utility Industry (in Japanese), Central Institute of Electric Power Industry report Y02013, 2003

(5) S. Deng, B. Johnson and A. Sogomonian, Exotic Electricity Options and the Valuation of Electricity Generation and Transmission Assets, 1998